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HOUSEHOLD WATER TREATMENT FOR THE PREVENTION OF DIARROEAL DISEASE

A Thesis Submitted in Partial Fulfilment of the
Degree of Doctor of Philosophy

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ABSTRACT

Unsafe drinking water, together with poor hygiene and sanitation, are the main contributors to diarrhoeal disease, a leading cause of mortality and morbidity especially among young children in low-income settings. While the Millennium Development Goals seek to halve the portion of the population without access to safe water by 2015, the high cost of piped-in supplies has led the World Health Organization to call for alternative approaches, including household water treatment. This thesis describes the results of certain research concerning the effectiveness, cost-effectiveness and field implementation of household water treatment for the prevention of diarrhoeal disease.

In a systematic review of interventions to improve water quality for the prevention of endemic diarrhoea, 30 studies covering 38 intervention trials were identified and meta-analyzed. The studies varied considerably in design, setting, type of intervention and point of intervention. The evidence suggests that in settings with sufficient water quantity, interventions to improve the microbiological quality of drinking water are effective in preventing diarrhoea, and that household-based interventions are about twice as effective as conventional improvements at the water source.

The costs of such water quality interventions was compiled and combined with the effectiveness data from the systematic review to determine the cost-effectiveness of interventions to improve water quality. In most settings, household water treatment meets established criteria for "highly cost effective" health interventions.

In a six-month pilot programme in Colombia, household-based water filters were associated with a substantial improvement in microbial water quality and a 60% reduction in the prevalence of diarrhoea (OR = 0.40, 95% CI = 0.25, 0.63, $P < 0.0001$).

In a study to assess the drinking water response to the Indian Ocean tsunami, household water treatment had only a limited role, suggesting the need to consider under what circumstances such interventions can contribute to the delivery of safe drinking water in the immediate aftermath of an emergency.

The thesis concludes with some thoughts on the challenge of implementing household water treatment and the need for further research.

DEDICATION AND ACKNOWLEGEMENT

Theses tend to end with an almost perfunctory nod to author's family—last but not least. I hope readers will indulge my departure from this tradition by starting there. After 20 years in international corporate law, I was ready for a change. And with the encouragement and support of my dear wife of 26 years, Mary Pat, I was able to pursue the formal training and field work that is partly reflected in the following pages. That meant dragging our teenage children, Tomás and Ceci, along with us to London and La Paz, and abandoning our older children, Peter and Chris, at university. I am very grateful to all of you, and dedicate this thesis to you. And kids, my hope is that it will not take you 20 years to find work that is not only intellectually engaging but also profoundly meaningful.

Perhaps no one has contributed more to the body of knowledge concerning drinking water in low-income settings than Sandy Cairncross. He and several other extraordinary people patiently guided me through my re-tooling from law to public health over these past four years. Rob Quick and Steve Luby from the CDC and Mark Sobsey from UNC, are among the pioneers in household water treatment. They warned me about having Sandy as my PhD supervisor, given his reservations about the impact of improvements in water quality compared to other environmental interventions. But they were also right—defending one's work before a sceptic provides perhaps the best training for scientific research. Many thanks, Sandy, and to my unofficial tutors as well.

A few others deserve my deep thanks for their help over the last several years. I had the privilege of learning about systematic reviews from Ian Roberts at LSHTM, and to be supported by the Infectious Diseases Review Group of the Cochrane Collaboration at the Liverpool School of Tropical Medicine (Paul Garner, Carrol Gamble, Rob Reive and others). Anne Mills encouraged me to undertake the cost-effectiveness analysis, and with support from Laurence Haller and others at WHO and Damian Walker (now at JHU), I was able to learn the basics of economic evaluation. Much of my field work was conducted with the cooperation of Oxfam GB, especially Andy Bastable for whom I first investigated the faecal recontamination of drinking water in the home among returning refugees in Sierra Leone. Finally, when I first entered Jacqueline Rosby's lab at MATC, I didn't know how to streak a plate. But she and Peter Donachie at LSHTM patiently taught me enough environmental bacteriology to do my field work on the microbiological performance of ceramic filters.

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Finally, this work was inspired in part by *Drawers of Water* (White 1972), the seminal text on household water management and a classic work in tropical environmental health. The fact that so little progress has been made in improving water and health in East Africa over these last 35 years is sobering. At the same time, it suggests the need to consider new options for bringing the health gains associated with safe drinking water to the hundreds of millions still without household connections. The book's authors expressed their hope that their work would lead others "working on improving water supplies in developing countries to consider the wider implications of [their] actions, and to measure what we have had to guess at." I have tried to do so, and I hope it will not appear arrogant if I close by expressing the same valuable purposes for this work.

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TABLE OF ACRONYMS AND ABBREVIATIONS

AED	Academy for Educational Development
AIDS	Acquired immune deficiency virus
BoD	Burden of disease
CAWST	Center for Affordable Water and Sanitation Technology
CBA	Cost-benefit analysis
CDC	Centers for Disease Control and Prevention
CEA	Cost-effectiveness analysis
CER	Cost-effectiveness ratio
CFU	Colony forming units
CMH	Commission on Macroeconomics and Health
CVM	Contingent valuation method
DALY	Disability-adjusted life year
DHS	Demographic Health Study
DOTS	Directly observed therapy, short course
DPD	diethyl-p-phenylenediamine
EAWAG	Swiss Federal institute of Environmental Science and Technology
GCEA	Generalized cost-effectiveness analysis
HIV	Human immunodeficiency virus
HLL	Hindustan Lever Limited
HLY	Healthy life year
HWTS	Household water treatment and safe storage
IDE	International Development Enterprises
IDP	Internally displaced persons
I$	International Dollars
JMP	Joint Monitoring Programme
LRV	Log Reduction Value
MESH	Medical Subject Headings
MoH	Ministry of Health
ORT	Oral rehydration therapy
PHI	Public health inspectors
P&G	Procter & Gamble Company
PPP	Purchasing Power Parity

PSI	Population Services International
QALY	Quality-adjusted life year
POU	Point-of-use
RCT	Randomised controlled trial
SANDEC	Department of water and Sanitation in Developing Countries
SWS	Safe Water System
TTC	Thermotolerant coliform
US$	United States Dollars
USAID	United States Agency for International Development
WHO	World Health Organization
WTP	Willingness to pay
YLL	Years of life lost

PROLOGUE

Chapter 1: Background and Introduction

1.1 Background

1.1.1 The Burden of Diarrhoeal Disease

Diarrhoeal diseases kill an estimated 1.8 million people each year (WHO 2005). Among infectious diseases, diarrhoea ranks as the third leading cause of both mortality and morbidity (after respiratory infections and HIV/AIDS), placing it above tuberculosis and malaria. Young children are especially vulnerable, bearing 68% of the total burden of diarrhoeal disease (Bartram 2003). Among children under five years, diarrhoea accounts for 17% of all deaths (WHO 2005a). For those infected with the human immunodeficiency virus (HIV) or who have developed acquired immunodeficiency syndrome (AIDS), diarrhoea can be prolonged, severe and life-threatening (Hayes 2003).

Diarrhoea is a symptom complex characterized by stools of decreased consistency and increased number (Black 1995). The clinical symptoms and course of the disease vary greatly with the age, nutritional status and immunocompetence of the patient, and the aetiological agent infecting the intestinal system and interfering with normal absorption. Most cases resolve within a week, though a small percentage continue for two weeks or more and are characterized as "persistent" diarrhoea. Dysentery is a diarrhoeal disease defined by the presence of blood in the liquid stools (Blaser 1995). About 35% of the deaths from diarrhoea in children under 5 are believed to be attributable to acute non-dysenteric diarrhoea, with 45% from persistent diarrhoea and 20% from dysentery (Black 1993). Though epidemic diarrhoea such as cholera and shigellosis (bacillary dysentery) are well known risks, particularly in emergency settings, their global health significance is small compared to endemic diarrhoea (Hunter 1997).

The immediate threat from diarrhoea is dehydration, a loss of fluids and electrolytes. Thus, the widespread promotion of oral rehydration therapy (ORT) has significantly reduced the case fatality rate associated with the disease. Such improvements in case management, however, have not reduced morbidity, which is estimated at 4 billion cases annually (Kosek 2003). And since diarrhoeal diseases inhibit normal ingestion of foods and adsorption of nutrients, continued high morbidity is an important cause of malnutrition, leading to impaired physical growth and cognitive function (Guerrant 1999), reduced resistance to infection (Baqui 1993), and potentially long-term gastrointestinal disorders (Schneider 1978).

But the impact of diarrhoea is not limited to health. With continued high attack rates, diarrhoeal disease is also an enormous economic burden, resulting in lost time at work, school and other productive activities, and millions of dollars in expenditures for prevention and treatment (Sacks 2005). Moreover, unlike many other diseases, the burden of diarrhoea falls mainly on the poor (Blakely 2005). As a result, it aggravates poverty among those who can least afford it. For this reason, efforts to prevent diarrhoeal diseases are not only integrally related to the Millennium Development Goals (MDGs) for safe drinking water and sanitation (Goal 7) and reduced childhood mortality (Goal 4), but also for the reduction of poverty (Goal 1).

1.2.2 Disease Agents and Pathways

The infectious agents associated with diarrhoeal disease are transmitted chiefly through the faecal-oral route (Byers 2001). A wide variety of bacterial, viral, and protozoan pathogens excreted in the faeces of humans and animals are known to cause diarrhoea. Among the most important of these are *Escherichia coli, Salmonella sp., Shigella sp., Campylobacter jejuni, Vibrio cholerae,* Rotavirus, Norovirus, *Giardia lamblia, Cryptosporidium sp., and Entamoeba histolytica* (Leclerc 2002). The importance of individual pathogens varies between settings, seasons and conditions. While bacterial agents as a group are believed to cause a majority of diarrhoeal disease in developing countries, viral and protozoan agents tend to cause more cases in developed countries (Hunter 1997).

Many of these diarrhoeagenic agents are potentially waterborne - transmitted through the ingestion of contaminated water. However, most of the same pathogens are also transmitted by ingestion of contaminated food and other beverages, by person-to-person contact, and by direct or indirect contact with infected faeces. Because of this variety of pathways, interventions for the prevention of diarrhoeal disease not only include enhanced water quality but also steps to improve the proper disposal of human faeces (sanitation), increase the quantity and improve access to water (water supply), and promote hand washing and other hygiene practices within domestic and community settings (hygiene).

While water quality is also adversely impacted by chemical contaminants, the level of disease associated with metals, nitrates, organics and other chemicals is usually small relative to infectious diarrhoea (WHO 2002). Other important diseases associated with drinking water, such as hepatitis A and E, poliomyelitis, gastroenteritis and typhoid fever, may not cause diarrhoea, but are nevertheless associated with potentially waterborne microbes of faecal origin. For this reason, efforts to assess drinking water quality focus primarily on faecal pathogens (WHO 1993).

Because of the difficulty of monitoring water for the presence of all such agents, an indirect approach has been adopted where water is examined for indicator bacteria whose presence implies some degree of contamination. While there is controversy over the preferred indicator (Gleeson 1997), even those that accept the use of the coliform group use different target indicators (total coliforms, thermotolerant coliforms, *Escherichia coli*) and different methods for assaying the level of indicator present (membrane filtration, multiple tube/most probable number) (Clesceri 1998).

1.1.3 Water Treatment Generally

A number of interventions have been developed to improve the microbiological quality of water. While the actual methods and technologies are many, they can be grouped into four main categories. The first involves the physical removal of pathogens, for example, by filtration, adsorption or sedimentation. The second involves chemically treating water to kill or deactivate pathogens, most commonly with chlorine. A third includes disinfection by heat (e.g., boiling or pasteurisation) and ultra-violet (UV) radiation, either using the sun (solar disinfection) or an artificial UV lamp. The fourth involves a combination of these approaches (e.g., filtration or flocculation combined with disinfection). Water quality can also be enhanced by protecting it from recontamination, for example, by residual disinfection, piped distribution and safe storage.

A combination approach is also common in conventional systems since individual approaches are not effective against the full range of microbial pathogens under all water conditions. Mechanical removal of viruses, for example, presents a challenge to most filters due to their sub-micron size. Similarly, certain encysted protozoa are resistant to chemical disinfection. The microbiological performance of these approaches may also be impacted by the temperature, pH, turbidity, chemical content and other characteristics of the water.

In higher income countries, and in many urban settings worldwide, drinking water is treated centrally at the source of supply and is distributed to consumers through a network of pipes and household taps. However, such conventional systems involve significant upfront investment and continued maintenance. In remote and low-income settings, water quality may nevertheless be improved at the source, for example, by providing protected groundwater (springs, wells and bore holes) or harvested rainwater as an alternative to surface sources (rivers and lakes) that are more susceptible to faecal contamination. Microbial water quality may also be improved at the source or other point in the distribution system by chlorination, filtration and other means. Improving water at the source is also frequently accompanied by improvements in quantity or access to water by increasing the volume or frequency of water delivery or reducing the time spent in collecting water. This may result in significant benefits not only in health but also in economic and social welfare (Hutton 2004). For purposes of this document, any form of treatment at the water source or otherwise prior to the point of use will be referred to collectively as "source" water treatment.

1.1.4 Household Water Treatment: Accelerating the Health Benefits of Safe Water

More than 30 years ago, White and colleagues observed that fully a quarter of the world's then 3.7 million population lacked access to safe drinking water supplies (White 1972). Although the proportion of the population that still relies on unimproved sources of drinking water has shrunk over this period, the raw number of people without coverage has actually increased, from 950 thousand in 1970 to an estimated 1.1billion in 2000 (WHO/UNICEF, 2002). Moreover, the current definition of “improved” supplies speaks only to the type of supply (protected well, borehole, etc.), not to the microbial quality of that supply. Thus, millions of those whose supplies meet the definition of “improved” nevertheless rely on water that is unsafe for consumption (WHO/UNICEF 2005). In addition, under applicable definitions, such sources are treated as improved even if they are a full kilometre from the household. Thus, large numbers of those with access to improved water supply must nevertheless collect, transport and store water in the home. It is well known that even water that is safe at the point of delivery often becomes dangerously recontaminated with faecal pathogens at each stage of this process (Clasen 2003; Wright 2004; Trevett 2005).

As part of its MDGs, the United Nations expressed its commitment by 2015 to reduce by one half the 1.1 billion people without "sustainable access to safe drinking water"(United Nations 2000). This target at least addresses the need to ensure the microbial quality of drinking water at the source. The evidence to date, however, suggests that current efforts will fall well short of the target (UNDP 2005). Moreover, even if this goal could be met, it would still leave hundreds of millions without such access.

Filtering and disinfecting water at conventional treatment facilities and distributing it reliably and in sufficient quantities through intact distribution systems to each household is perhaps the ultimate solution to waterborne disease. Household connections have also been shown to reduce other water-related diseases and to provide other health and non-health benefits (Hutton & Haller 2005; Cairncross & Valdmanis 2004). The World Health Organization (WHO) acknowledges, however, that such a solution would entail an investment of tens of billions of dollars each year to connect households at the rate of 280,000 per day (WHO/UNICEF 2000). Accordingly, while careful not to encourage diversion of resources away from connected taps, it has called for other approaches that will provide some of the health benefits of safe drinking water while progress is made in improving infrastructure (Thompson 2003; WHO/UNICEF 2005).

Interventions to treat and maintain the microbial quality of water at the household level may be among the most promising of these alternatives. In many settings, both rural and urban, populations have access to sufficient quantities of water, but that water is microbiologically unsafe. This is increasingly true even for piped-in water, since supplies are rarely provided on a 24 hour / 7day basis, forcing householders to store more water in the home and leading to microbial infiltration of poorly maintained systems (Thompson 2001). Effective treatment at the household level--often using the same basic approaches of filtration, disinfection and assisted sedimentation or a combination thereof as characterize conventional water treatment—can remove or deactivate most microbial pathogens (Quick 1996; Luby 2001; Rangel 2003; Souter 2003; Caslake 2004; Clasen 2004). Moreover, by focusing at the point of use rather than the point of delivery, treating water at the household level minimizes the risk of recontamination that even improved water supplies can present (Mintz 2001). A review commissioned by the WHO has identified a wide variety of options for household-based water treatment and assessed the available evidence on their microbiological effectiveness, health impact, acceptability, affordability, sustainability and scalability (Sobsey 2002). The WHO now advocates household water treatment as a means of accelerating the health benefits of safe water for populations without piped-in water supplies (WHO 2002). The WHO-backed International Network to Promote Household Water Treatment and Safe Storage (http://www.who.int/household_water/en/) has been organized by international organizations, research institutions, NGOs and the private sector to share information and resources in order to advance household water treatment.

1.2 Water Quality and Diarrhoea

1.2.1 The Emergence of the Dominant Paradigm

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 2004a). 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 1986; Lindskog 1987; Cairncross 1989). Since 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). Even more fundamentally, there are also questions about the methods and validity of studies designed to assess the health impact of environmental interventions (Blum & Feachem 1983; Briscoe 1986; Imo State Evaluation Team 1989).

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

1.2.2 Household water treatment and safe storage: an exception to the dominant paradigm?

Under the dominant paradigm, household-based water treatment, like other interventions to improve water quality, should be expected to reduce diarrhoea morbidity by 15% to 17%. In fact, however, the mean reduction in diarrhoea from intervention studies conducted over the last twenty years is almost three times that level. A brief analysis of 21 controlled field trials over the last twenty years dealing specifically with interventions designed to enhance the microbial quality of drinking water at the household level showed a median reduction in endemic diarrhoeal disease of 42% compared to the control groups (Clasen 2004d). The result was fairly consistent regardless of the type of the intervention.

These studies strongly suggest that interventions at the household level may, in fact, represent an exception to the dominant paradigm.

In a recent update to Esrey's reviews, Fewtrell and colleagues (2005) provided more systematic evidence of the possible advantage of household-based water treatment over conventional source-based interventions in preventing diarrhoeal disease. In a meta-analysis, they reported that the pooled relative risk from 3 studies of source-based interventions was 0.89% (95% CI: 0.42 to 1.90), while the same estimate from 12 studies of household-based interventions was 0.65 (95% CI: 0.48 to 0.88). Thus, only the household interventions combined to yield a statistically meaningful reduction in diarrhoea, and that reduction (of 35%) was twice the rate predicted by Esrey. As discussed below, however, this review presents certain methodological problems.

1.2.3 Refining the dominant paradigm: the need for a systematic review

The growing body of evidence pointing to substantial health gains from household-based water treatment suggests the need for a reconsideration and possible refinement of the dominant paradigm. There are several reasons for undertaking such a review. First, none of the studies that Esrey and colleagues examined for their conclusions regarding the impact of water quality reflected interventions at the point of use.[1] While the extent to which even safe water becomes faecally contaminated during collection, transport, storage and drawing in the home is well known (Wright 2003), only recently have low-cost health interventions been promoted to improve and preserve water quality at the household level (Mintz 2001).

Second, the methodology and statistical methods employed by Esrey and colleagues in their 1985 and 1991 reviews, while comprehensive and pioneering at the time, do not fully conform to current standards for disciplined systematic reviews (Egger 2001). Perhaps

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[1] In conducting their reviews, Esrey and colleagues suffered from the disadvantage of having no studies point-of-use interventions with which to compare conventional source-based improvements in water supplies. Nevertheless, they did make an important, though frequently overlooked, observation that should perhaps have led subsequent investigators and programme implementers to focus on water quality at the point of consumption: "In the studies reporting a health benefit, the water supply was piped into or near the home, whereas in those studies reporting no benefit, the improved water supplies were protected wells, tubewells, and standpipes." (Esrey 1991) Cairncross and Valdmanis (2004) have calculated the median reduction in diarrhea from the 12 studies of household connections included in Esrey's review to be 49%, or 63% from the 2 better quality studies.

most important, they based their conclusions chiefly on observational studies. In addition to the confounding and bias inherent in such studies, they and others have pointed out significant and widespread methodological problems (Blum & Feachem 1983; Esrey & Habicht, 1986). In terms of coverage, neither review involved a comprehensive search strategy. Accordingly, the conclusions with respect to water quality are based on a very 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 2001). Moreover, they do not distinguish between the various case definitions (Moy 1991) and measures of diarrhoea morbidity (Morris 1996; Pickering 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. Furthermore, these prior reviews did not explore publication bias or perform sensitivity analyses.

While the review conducted by Fewtrell and colleagues addresses certain of these issues, it also has certain shortcomings. First, they appear to have limited their review to published studies, and found only 15 studies that met their inclusion criteria. As a result, they did not include the results of a substantial number of unpublished studies that met their inclusion criteria. This introduced selection bias into the review and also increased the risk that their results would be subject to publication bias. Second, while they reportedly included only interventional studies in their review, their analysis of water quality included three observational studies (Ghannoum 1981; Iijima 2001; Sathe 1996). Such studies present greater risk of systematic bias than randomized, controlled trials (Egger 2001). Third, while the outcome of interest was purportedly limited to endemic diarrhoea, three studies included in the review had cholera or dysentery as their outcomes (Colwell 2003, Ghannoum 1981, Iijima 2001). Finally, though they observed and reported substantial heterogeneity in their results from water quality interventions, they performed only limited sub-grouping to help explain such heterogeneity. Moreover, they reported pooled estimates of effect without cautioning readers about the risk of drawing conclusions therefrom in the presence of massive heterogeneity.

The encouraging results from studies of improved household water management, and the shortcomings of other reviews, provide a sufficient impetus for re-examining 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 environmental health interventions, their context 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.

1.3 Cost and Cost Effectiveness

While it is important to understand the effectiveness of the various interventions to improve water quality to prevent diarrhoeal disease, and the circumstances under which such effectiveness is optimized, the extent to which such interventions are ultimately deployed to reduce the burden of disease will not be determined on their effectiveness alone. It will also depend on their cost. With limited resources, particularly in developing countries, governments are forced to allocate health expenditures to an array of public health challenges. NGOs must do the same in order to satisfy donors of the responsible use of their funds. Even interventions such as insecticide-treated nets that have shown the potential for commercial or quasi-commercial (e.g., social marketing) distribution often require public expenditures to promote basic health messages, awareness of the intervention, and continued and appropriate use. The use of purely commercial products that also have a health impact, such as soap, is also effectively rationed by the cost that consumers can afford to pay for it (Clasen 2002).

While public sector decisions on health expenditures are often based on political commitments or other expediencies, economic efficiency, by definition, requires that resources be directed to their most productive use. In the health context, such allocative efficiency means "assessing which intervention will produce greatest health gains for a given investment of resources, and focusing on that activity" (Witter 2000). This implies more than cost; the lowest cost intervention is seldom the most effective. Thus, economic evaluation is normally a function of both the cost of the intervention and the return on that cost, measured either in terms of overall economic benefits (a "cost-benefit analysis" or CBA) or in the realization of a social objective, such as the prevention of disease (a "cost-effectiveness analysis" or CEA). In a CBA, all of the outcomes of the investment are valued in economic terms, and the output is expressed as a return on the investment. The output of a CEA is a ratio (the cost-effectiveness ratio) between the cost of the intervention and a operational outcome measured in its own units. For health interventions, a common unit of measurement is healthy life years (HLYs) gained or deaths or disability adjusted life years (DALYs) averted as a result of the intervention.

Traditionally, economic evaluation of water and sanitation interventions has focused on infrastructural improvements--mainly construction of facilities to improve water supplies and excreta disposal. Owing to the high cost of such improvements, such water and sanitation interventions carried costs per death averted of US$3600, well above the US$200 to US$250 for an intervention such as primary health care (Walsh 1979). Briscoe (1984a) argued that the methodology being used was misleading, since it employed gross rather than net costs and underestimated the health impact. Varley and colleagues (1998) also challenged this approach, arguing that the benefits associated with such infrastructural improvements in water and sanitation were beyond health, and thus that the health sector should not be charged with the full cost or responsibility of such "hardware" interventions. Their analysis found that improved "software", including project design, hygiene education and water quality regulation, were cost-effective approaches for controlling childhood diarrhoea. However, when interventions to improve the microbial quality of water—all of which involved hardware expenditures—were added to the analysis, they were in fact cost effective, since their ratio was below the US$150 per DALY averted then prescribed by the World Bank as upper limit of cost effectiveness (World Bank 1993).

In its *2002 World Health Report*, the WHO assessed the cost effectiveness of interventions to increase coverage of water and sanitation services. It concluded that the most cost-effective strategy was the provision of disinfection capacity at the point of use—a combined hardware and software intervention not evaluated by Varley and colleagues (WHO 2002). A CBA analysis of water and sanitation improvements came to the same conclusion: while all of the interventions were found to be cost-beneficial, the combination of high health improvements and low incremental cost suggests that household water treatment and safe storage may offer the highest return on investment among interventions to improve water or sanitation (Hutton 2004). This was true even though household-based water treatment did not provide the benefit of time savings associated with improved water supply. The principal benefits from household water treatment are health related—reducing patient and health system costs by preventing water-borne disease.

However, the foregoing analyses had certain shortcomings, which their authors themselves acknowledged. First, the reliability of any tool of economic evaluation depends largely on the accuracy of its inputs, namely effectiveness in preventing disease and cost of implementation. Varley and colleagues (1998) based their analysis on a limited number of disparate health outcome studies, and the WHO CEA based its estimate of effectiveness on household-based chlorination (Quick 1999, Quick 2002). The Cochrane review described in this thesis provides perhaps the best available evidence on the effectiveness of such interventions and will form a more reliable basis on which to estimate the effectiveness of interventions in a CEA. Second, Varley excludes the hardware component from its cost analysis, arguing that it is not properly borne by the health sector. The cost estimates for the WHO assessments, on the other hand, were based principally on the hardware component of the home water chlorination method, and did not assess the full programmatic cost of implementing the intervention (Haller, personal communication).[2] A comprehensive analysis would include all costs associated with an intervention, including hardware and software. Third, Varley does not address household-based interventions whatsoever, and the WHO analyses include only home-based chlorination. As the Cochrane review shows, we now have a number of studies providing effectiveness data from at least three other means of household water treatment that Sobsey (2002) deemed promising: filtration, solar disinfection and combined flocculation/disinfection. Finally, like all CBAs, the Hutton and Haller (2004) assessment requires certain assumptions about the valuation and magnitude of the time saving from improved water supplies that the authors acknowledge are not always evidence-based.

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[2] While Esrey and colleagues (1985) were charged with estimating the cost-effectiveness of water and sanitation interventions as part of their analysis, they ultimately declined to do so, partly because of the inability to value the multiple benefits derived from such interventions but also because of the lack of reliable data on the costs of software support (e.g., promotion of community participation, hygiene education) and of apportioned institutions overheads. Like other assessments, their cost data included only hardware costs.

The cost effectiveness analysis presented below attempts to build on these previous analyses and provide a more accurate assessment of the cost-effectiveness of interventions to improve water quality for the prevention of diarrhoeal disease. First, effectiveness will be based on the results of the systematic review. Second, cost estimates are based on a more comprehensive assessment of costs using a methodology now followed by the WHO for assessing the cost-effectiveness of health interventions generally. Third, the analysis will include each of the four leading approaches to household-based water treatment. However, since policy makers are not simply choosing among this group but between these and conventional source-based improvements in water supply, the analysis also includes three of the leading approaches to such source-based interventions as well (tap stands, bore holes and dug wells). Finally, by following the cost-effectiveness approach and reporting the results in terms of DALYs averted for each dollar invested, this analysis does not need to speculate on the economic valuation of other possible benefits of the interventions as with a CBA. At the same time, by reporting more detailed cost information for each category of intervention, it provides the basis for a more comprehensive, if not more accurate, CBA. The economic and policy implications of this analysis are raised in Sections 10.2.3 and 10.2.4.

1.4 Household-based Ceramic Filters

The increasing body of evidence supporting the substantial health gains from improvements in water quality at the household level led the WHO to undertake a comprehensive review of the available technologies (Sobsey, 2002). The review sought to identify the most promising candidates based on selected technical characteristics and performance criteria, including effectiveness in improving and maintaining microbial water quality, health impact, technical difficulty or simplicity, accessibility, cost, acceptability, sustainability and potential for dissemination. After evaluating at least 37 different technologies for improving water quality at the point of use, Sobsey concluded that 5 were the most promising: filtration with ceramic filters, chlorination with storage in an improved vessel, solar disinfection in clear bottles, thermal disinfection (pasteurization) in solar cookers or reflectors, and combination systems employing chemical flocculation and chlorination.

Ceramic filters are manufactured in a variety of pore sizes. Good quality filters have micron or submicron ratings and are impregnated or coated with silver for additional bacteriostatis. The filters are typically formed into hollow cylindrical "candles" which are mounted into the top of a two-compartment vessel. Pathogens are removed as contaminated water passes through the candles in the top compartment to the lower holding compartment. Because the filtered water can only be accessed from this lower compartment by a tap or spigot, it is protected from another significant risk--recontamination prior to consumption (Clasen 2003).

Household filters potentially present certain advantages over these other technologies. They operate under a variety of conditions (temperature, pH, turbidity), introduce no chemicals into the water that may affect use due to objections about taste and odour, are easy to use, do not require consumers to have access to and to purchase consumables, and improve water aesthetics thus potentially encouraging routine use without extensive intervention to promote behavioural change. Higher quality ceramic filters treated with bacteriostatic silver have been shown effective in the lab at reducing waterborne protozoa and bacteria (Ongerth 1989; Schlosser 2001). To date, however, they have not met targets for reducing waterborne viruses. While the hollow core of ceramic "candles" can be filled with granular activated carbon (GAC) to adsorb viruses and even chemical contaminants, the adsorption sites can become filled quickly, thus reducing the overall life of the filter element. Special coatings which enhance the sorption capacity of porous media may present one option for improving the capacity of ceramic filters to reduce waterborne viruses (Scott 2002; Brown 2005).

Although ceramic filters have been used for decades, and in some cases have been tested for microbiological efficacy in the laboratory, they have not traditionally been used as a public health intervention. Accordingly, they have not been evaluated carefully in field trials for microbiological effectiveness or health impact. Demonstrating the performance of a household-based intervention in improving the microbial quality of drinking water and reducing the risk of diarrhoeal disease are necessary but not sufficient conditions for the overall impact of such interventions on human health; that also depends on their acceptability, affordability, scalability and sustainability. However, they are essential first steps in exploring the potential role of this approach to reduce the heavy burden of disease associated with waterborne microbes and form the basis for further research in connection with this intervention.

1.5 Research Questions

The objective of this research is to shed light on the potential role of household-based water treatment for preventing endemic diarrhoeal disease. It consists of three parts.

Part I (Chapters 2-4) presents a systematic review of interventions to improve water quality for the prevention of diarrhoea. The review follows the strict methodology prescribed by the Cochrane Collaboration and the procedures established by its protocol. Perhaps its chief contribution is to identify and describe a considerable body of randomized and quasi-randomized controlled trials that fall within its inclusion criteria. While the review is mainly descriptive, however, it is also analytical. It employs meta-analysis and sub-grouping in an attempt to assess the effects of interventions to improve the microbiological quality of drinking water on the morbidity and mortality of endemic diarrhoea among children and adults, to identify any significant differences in such effects among various types of interventions (e.g., source versus household and different types of household-based interventions), and to explore other possible explanations for the differences in the effectiveness of water quality interventions.

Part II (Chapters 5-6) presents the cost and cost-effectiveness of interventions to improve water quality for the prevention of diarrhoea. Chapter 5 introduces the approach to cost-effectiveness analysis employed, which is based on the WHO CHOICE model. It outlines the general methodology with particular emphasis on the means by which cost information was solicited. Chapter 6 summarizes and discusses the results of the analysis. It begins by reporting the cost information obtained on household-based water treatment interventions and summarizes how this information was used to develop cost estimates and ranges for each type of intervention. Cost-effectiveness ratios are then reported and compared, not only among the four types of household-based interventions but also with conventional source-based water interventions and with other health interventions generally based on WHO data. The discussion suggests possible interpretations of these findings, but also notes the limitations on the conclusions that can be drawn therefrom.

Part III presents the results of certain field studies involving household water treatment. Chapters 7 and 8 consist of a case study of one type of household-based water treatment intervention: ceramic filters. The study addresses two questions about ceramic filters that any point-of-use water treatment technology must address in order to demonstrate is potential suitability among a vulnerable population. First, does the intervention consistently deliver microbiologically safe water when used by the target population under field conditions? Second, does the intervention actually prevent diarrhoea among such a population under these conditions? The implications and limitations of this field work are discussed. Chapter 9 examines the role of household water treatment in emergencies and is based on a rapid field investigation of the drinking water response to the 2004 Indian Ocean tsunami.

The thesis closes with a discussion about the challenge of implementing household water treatment, especially in the areas of uptake and scaling up, and the need for further research (Chapter 10).

PART I

INTERVENTIONS TO IMPROVE WATER QUALITY TO PREVENT DIARRHOEA: A SYSTEMATIC REVIEW

Chapter 2: Background and Development of Protocol

2.1 Background and rationale

The purpose of research in health interventions is to inform policy and practice. Robust, well-designed and well-conducted studies provide the best available evidence. However, the proliferation of studies can make it difficult to locate, synthesize and understand the significance of such research, much less translate it into effective policies and practices. Even in a relatively discrete segment of environmental health such as the impact of water quality on diarrhoeal disease, for example, at least 285 studies have been published in the English language between 1980 and 2003. This number does not include important research that may be older, unpublished or presented in other languages. Even among these 285 studies, however, the size, settings, methodologies, specific interventions, measures of effect, analyses and overall quality can be so heterogeneous as to make it nearly impossible to distil any common conclusions or useful guidance.

The systematic review methodology was designed to address such a challenge. Like narrative reviews, systematic reviews attempt to identify, synthesize and explain a variety of studies relating to a particular health intervention. The distinctive characteristic of the systematic review, however, is that it is performed using a carefully planned, documented and repeatable approach—much like the methods and materials section of any scientific paper—in order to minimize bias and random errors (Chalmers 1995). This approach is outlined in a protocol that governs all important aspects of the review procedure. Key elements of the systematic review include (i) a well-formulated research question, (ii) clear criteria for including and excluding studies based on the scope of the review and an objective assessment of quality, (iii) transparent and exhaustive methods for searching for studies that potentially meet the inclusion criteria, (iv) joint application of inclusion criteria and extraction of data from studies to minimize bias, and (v) a clear statement of findings. A systematic review may or may not include meta-analysis, a statistical method to summarize and combine the results of independent studies and thus produce a pooled measure of effect (Egger 2001).

An important goal of the systematic review is to establish whether scientific findings are consistent and can be generalised across populations, settings and variations of the intervention. For some interventions, such as a particular vaccine of a given dose, the results of various studies may exhibit considerable homogeneity and result in a pooled measure of effect inside a tight confidence interval. But for interventions such as improvements in microbiological water quality, where the methods may be quite disparate and combined with other environmental interventions in a wide variety of settings and ambient risks, the results may be exceptionally heterogeneous. Fortunately, the methodology of systematic reviews, including subgroup and statistical analyses, provide valuable means for assessing and potentially explaining such heterogeneity (Thompson 1999).

2.2 The Cochrane Collaboration

While systematic reviews tend to follow certain basic steps, their methodology and procedures are still evolving. Various approaches have been advocated to enhance the rigour of such reviews (CMR 2004) and at least five organizations now promote and disseminate systematic reviews (Reeves 2002). Among the most advanced of these is the Cochrane Collaboration (Jadad 1998).

Founded in 1993, the Cochrane Collaboration is an international organization of researchers, practising physicians and other healthcare professionals whose mission is to prepare, maintain and promote the accessibility of systematic reviews of the effects of healthcare interventions. The main work of the Collaboration is performed by 50 collaborative review groups who have been designated by the organization to prepare and maintain Cochrane Reviews in a particular subject matter. Each collaborative review group has an editorial base that may include search coordinators and statistical advisors in addition to the editorial staff. Each collaborative review group is responsible for preparing a module of reviews that form part of a the Cochrane Database of Systematic Reviews (CDSR), a growing collection of regularly updated systematic reviews that cover the entire gamut of healthcare interventions. Waterborne diseases are covered by the Infectious

Diseases Review Group (IDRG) which is currently headed by Dr. Paul Garner of the Liverpool School of Tropical Medicine. To be eligible for inclusion in the CDSR, reviews must be prepared in accordance with a comprehensive set of guidelines published by the Collaboration (Clarke 2003) as well as any special procedures prescribed by the relevant collaborative review group.

The decision to conduct the present review under the auspices of the Cochrane Collaboration was based on several factors. First, the Collaboration offers a set of precise, explicit and comprehensive methods that have been shown to limit bias (systematic errors) and chance effects, thus providing more reliable results (Oxman 1993). Second, while not exclusively so, the Cochrane Collaboration and its methodology focus particularly on systematic reviews of randomized controlled trials (RCTs) because they are likely to provide more reliable evidence on the differential effects of interventions (Kunz 2003). By limiting itself to RCTs and quasi-RCTs,[3] the present review was able to focus on a smaller number of studies likely to yield the most reliable information while at the same time making the undertaking more manageable. Third, the review would benefit from the editorial, research and statistical expertise and experience of the IDRG in the formulation of the study question, the development and implementation of the study protocol, the design and execution of the search strategy for relevant studies, and the analysis and presentation of the final results. Fourth, as discussed more fully below, the process used by the Collaboration in carefully developing the protocol for the review, including peer review of the protocol prior to publication, helps ensure that the issues have been carefully considered and that the project will proceed along a prescribed path, thus minimizing uncertainty, bias and delay. Publication of the protocol in the Cochrane Database of Systematic Reviews (CDSR) also provides additional opportunity for comment and criticism from the research community. Finally, because reviews registered with the Collaboration are published in the CDSR rather than a traditional scientific journal, they are designed at the outset to be regularly updated to reflect additional studies, thus providing the most up-to-date evidence of the effectiveness of an intervention (Jadad 1998)

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[3] A quasi-randomized controlled trial is one in which the intervention is allocated in a way that is not strictly random (perhaps due to economic, political, or other community priorities, though not through self-selection), but where the investigators nevertheless conduct the study as an experiment, allocating participants to groups (Last 2001). Historically, most improvements in water quality involved interventions at the point of distribution and were allocated on the basis of political or other priorities, physical barriers or economic limitations. More recently, improvements have been at the point of use, which can be allocated randomly at the household level for trial purposes.

As can be seen, a systematic review prepared in accordance with the Cochrane guidelines is a collaborative effort. In addition to the cooperation between the reviewer and Cochrane review group, the review itself is a group effort. Under its guidelines, various aspects of the review, such as the application of the inclusion criteria, extraction of data and assessment of methodological quality, must be performed independently by separate reviewers, with arbitration by a third reviewer in the case of disagreement. Reviews also require both substantive and methodological expertise in addition to the considerable time preparing the protocol, conducting the search, extracting data and performing the analysis. For these reasons, a group was formed to carry out the present review. Prof. S. Cairncross conceived of the review and provided substantive expertise. Prof. I. Roberts provided experience and expertise in methodological and epidemiological issues. Tamer Rabie and Wolf-Peter Schmidt provided independent assessment and statistical support to the project. All serve as co-authors of the review. Except as otherwise expressly noted, T. Clasen conducted the review, including drafting the protocol and clearing it through the Collaboration, conducting the search, extracting the data, performing the meta-analysis, and drafting the review itself. T. Clasen is the review's chief author.

2.3 The Protocol

The protocol for a systematic review to be registered with the Cochrane Collaboration follows a prescribed format set forth in the Cochrane Reviewers' Handbook (Clarke 2004). The main sections of a protocol are as follows:

- Background
- Objectives
- Criteria for selecting studies for the review
- Search strategy for identification of studies
- Methods of the review
- Description of Studies
- Methodological Quality

Like the review itself, the protocol is prepared, submitted, reviewed and revised using the Collaboration's proprietary software known as RevMan (Review Manager 4.2). RevMan also has prescribed fields for entering information on the main author and other contributors to the project, acknowledgements, conflicts of interest and references (included studies, excluded studies, studies awaiting assessment and other references). All this other information is published in the CDSR with the protocol and, when completed, the review itself.

In the present case, the protocol contemplates a review to be known under the title *Interventions for improving water quality for preventing diarrhoea* (Clasen 2004b). A copy of the protocol appears in Appendix 2.1 to this thesis. It is also available online through the CDSR at http://www.update-software.com/Cochrane/default.HTM. Table 2.1 summarizes the major steps and schedule in the preparation of the protocol, including the editorial and peer review process.

Table 2.3: Summary of steps and schedule for development of protocol

Item	**Schedule**
Background reading and consultation with LSHTM and outside experts regarding substantive issues	June-August, 2003
Formulation of question	August, 2003
Recruiting co-members of the review group	August-September, 2003
Initial draft of protocol by T. Clasen and review by co-members of group	September, 2003
Initial review of protocol by Cochrane IDRG editors	October, 2003
Revision of protocol by T. Clasen and resubmission for peer review	November, 2003
Receipt of comments on protocol by 3 peer reviewers plus 1 statistical referee	December, 2003
Revision of protocol by T. Clasen and resubmission after consultation with co-members of review group	December, 2003
Receipt of final comments on protocol by Cochrane IDRG editors	January, 2004
Revision of protocol by T. Clasen and resubmission	February, 2004
Notification of acceptance of protocol	March 1, 2004
Cochrane IDRG submission of protocol to publisher	March, 2004
Publication of protocol in CDSR	April 19, 2004

2.4 Criteria for considering studies for the review

A threshold issue in designing the review is the delineation of the criteria to be used to determine whether particular studies are to be included or excluded in the review. Among the elements to be considered are (i) types of studies, (ii) types of participants, (iii) types of interventions, and (iv) types of outcomes.

During the summer of 2003, while conducting background research to help formulate the objective and approach of the review and pilot search strategies, T. Clasen identified 285 papers published in English since 1980 that reported on field studies involving water quality and endemic diarrhoeal disease. Only 21(7.4%) were interventional studies (RCTs or quasi-RCTs). Previous reviews by Esrey and colleagues relied principally on observational studies (Esrey 1985; Esrey 1991). Such studies, however, present a greater risk of confounding and bias than RCTs, the gold standard in epidemiological evidence. At the same time, the elimination of quasi-RCTs would exclude a number of interventional studies. Water quality interventions, particular those involving improvements at the source, are often allocated on the basis of political, economic or practical reasons, and thus are not strictly randomized. At the same time, such allocation is not under the control of the investigators and does not necessarily undermin the probity of the results. Apart from the potential for selection bias, these studies meet much of the rigour and discipline of RCTs. Since the Cochrane guidelines favour RCTs and quasi-RCTs over observational studies, it was agreed that the inclusion criteria would be limited to those types of studies. However, studies in which the exposure groups were self-selected (e.g., by opting whether or not to purchase a device) were excluded.

With regard to the types of participants, the protocol contemplated that the review would include studies of children and adults, as well as the various clusters (e.g., families, households, communities) from areas where diarrhoeal disease is endemic. This endemicity criterion was necessary to exclude studies of outbreaks and other epidemics of waterborne disease. Such outbreaks, though frequently the subject of published papers, represent a small fraction of the total burden of disease associated with poor water quality and are normally characterized by a breakdown in treatment or distribution systems rather than the introduction of a intervention among a vulnerable population (Gleeson 1997). Accordingly, these studies are excluded from the review.

The review is intended to include all types of interventions while taking note of important characteristics of the intervention for possible subgroup analysis. Studies of any intervention aimed at improving the microbial quality of drinking water are included. This includes steps to improve water quality by removing or deactivating microbial pathogens (e.g., by filtration, sedimentation, chemical treatment, heat or UV radiation). Also included are interventions to protect the microbial integrity of water prior to consumption (e.g., residual disinfection, protected distribution or improved storage). An intervention, such as chlorination, is to be included if it has been shown elsewhere to reduce the quantity of waterborne microbes, even if such improvement was assumed or otherwise not measured in the particular study. Studies which combine improvements in water quality with other interventions (e.g., improvements in water quantity or access, sanitation or hygiene) are also included but separately analyzed. Studies of environmental interventions which do not improve the quality of drinking water, or studies of interventions to reduce chemical or other non-biological contaminants, are expressly excluded.

Finally, the primary outcome of studies that meet the inclusion criteria is diarrhoea episodes, whether or not confirmed by microbiological examination. An episode was defined using the case definition set forth in each study. It customarily is characterized by increased frequency and decreased consistency, and many studies simply use the mother's definition. A more precise definition--three or more loose stools in a twenty-four hour period—has been proposed (Baqui 1991; Moy 1991) and is now widely used by WHO and investigators. Studies with outcomes consisting solely of clinically confirmed pathogens (infection) but not diarrhoea morbidity (disease) were excluded because of the inability to compare such results with the incidence or prevalence of associated disease. The following secondary outcomes were also extracted from included studies: (i) mortality attributed to diarrhoea, (ii) level of pre- and post- intervention faecal contamination of water; (iii) utilization of intervention; and (v) adverse events. Age ranges will be addressed by subgroup analysis.

2.5 Search for and identification of studies included in the review

One of the most important components of the protocol is the development of the search strategy for identification of studies that meet the inclusion criteria. A review that fails to identify all such studies not only misses an opportunity to achieve higher power and more precise measure of effect, but can also be biased and misleading. A comprehensive search of the relevant studies is what best distinguishes a systematic review from a traditional review. As recommended by the Cochrane Collaboration, the search is intended to identify all studies which meet the inclusion criteria, regardless of whether they were published or unpublished, whether in English or other languages, and without any limitations on the year in which the study was undertaken or reported.

In the present case, the search strategy starts with a search of the key electronic databases recommended by the Cochrane Collaboration: MEDLINE, EMBASE, LILACS and the Cochrane Central Register of Controlled Trials (CENTRAL). The search follows a prescribed strategy for identifying controlled trials (Clarke 2003) and a comprehensive list of MeSH® (medical subject headings) and free search terms developed with the assistance of information specialists with the Cochrane Collaboration (Figure 2.5). However, since studies have shown that only 30%-80% of RCTs are identifiable through such electronic searches (Dickersin 1994), the protocol contemplates additional steps as part of the overall search strategy. These include hand searching of references from included studies and relevant journals as well as the proceedings of relevant conferences. Finally, to help identify unpublished and ongoing trials, individual researchers and institutions that conduct, fund or otherwise support relevant research were contacted.

Figure 2. 5 Search strategy for identifying studies from electronic databases

#1 water purification [MESH] OR water microbiology [MESH]
#2 water quality/water treatment/water purification/water chlorination/water
#3 decontamination/water filtration/water supply/water storage/water
#4 consumption/drinking water
#5 diarrhoea/epidemiology [MESH] OR diarrhoea/microbiology [MESH] OR diarrhoea/prevention and control [MESH]
#6 waterborne infection
#7 intestinal diseases [MESH]
#8 cholera/vibrio
#9 cholera/shigell*/dysenter*/cryptosporidi*/giardia*/escherichia
#10 coli/clostridium/enterobacteriaceae [MESH]

MESH = Medical Subject Headings, the US National Library of Medicine's controlled vocabulary thesaurus.

In the present case, the execution of the electronic search strategy resulted in the identification of 939 studies. In accordance with the protocol, two reviewers (T. Clasen and T. Rabie) then independently reviewed titles and abstracts of these 939 studies and selected 46 studies which either of them believed could potentially fall within the inclusion criteria. T. Clasen made full copies of these 46 studies, and T. Clasen and T. Rabie then independently reviewed them to make determinations as to inclusion using an Eligibility Form developed for that purpose.

In addition to the electronic search, the protocol prescribed certain additional steps to identify other studies that met the review's inclusion criteria. T. Clasen searched the conference proceedings of the International Water Association (IWA) and Water, Engineering and Development Centre, Loughborough University, UK (WEDC) for relevant abstracts. He also contacted individual researchers working in the field from the Water, Sanitation and Health Programme of the World Health Organization; World Bank Water and Sanitation Programme; UNICEF Water, Environment and Sanitation (WES); Environmental Health Project (EHP); IRC International Water and Sanitation Centre; Foodborne and Diarrhoeal Diseases Branch, Division of Bacterial and Mycotic Diseases, Centers for Disease Control and Prevention (CDC); US Agency for International Development (USAID); and the Department for International Development (DFID), UK for unpublished and ongoing trials. Finally, he checked the reference lists of all studies identified by the above. These additional steps proved very productive, yielding an additional 37 studies that potentially met the review's inclusion criteria.

2.6 Selection of studies

T. Clasen and T. Rabie independently reviewed the titles and abstracts resulting from the searches and selected all studies that potentially fell within the inclusion criteria for the review. After obtaining full copies of all such studies, they independently determined if the trial met such inclusion criteria. Where they agreed, they either included or excluded the trial. Where they were unable to agree, they consulted S. Cairncross and arrived at a consensus. Any studies that initially appeared to meet the inclusion criteria but which were ultimately determined not to be included are identified together with the reason for exclusion in the 'Characteristics of excluded studies' table of the review (Table 3.1 in Chapter 3).

2.7 Assessment of methodological quality

T. Clasen and T. Rabie independently assessed the methodological quality of the trials on the basis of their generation of allocation sequence, allocation concealment, blinding, and loss to follow up. These quality criteria were developed by the Cochrane Collaboration and have been used widely in reviews (Juni 2001). Under these criteria, the generation of allocation sequence—the process used to generate the randomisation list—is "adequate" if the method used is described and the resulting sequences are unpredictable (e.g., computer-generated random numbers, table of random numbers, coin toss, drawing lots); "unclear" if stated that the trial is randomised, but the method is not described; or "inadequate" if sequences could be related to outcomes (e.g., according to case record number, date of birth, alternation). Allocation concealment—the process used to prevent foreknowledge of group assignment—is "adequate" if the participants and the investigators enrolling participants cannot foresee assignment; "unclear" if method is not described; or "inadequate" if participants or investigators enrolling the participants can foresee their upcoming assignment. Blinding—whether the participant or outcome assessor is blind to the intervention group—is classified as "double blind" if the trial uses a placebo or double dummy technique such that neither the participants nor the assessor knows whether or not the participants receive the intervention; "single blind" if the participant or the assessor knows whether or not the participant receives the intervention; or open if both participant and assessor know whether or not the participant receives the intervention. Finally, loss to follow up—the portion of participants in the trial who are not included in the analysis—is classified as "adequate" if more than 90% of all participants randomised to the trial were included in the analysis; "unclear" if it is not clear what portion of participants randomised to the trial were included in the analysis; or "inadequate" if less than 90% of all participants randomised to the trial were included in the analysis.

Additionally, we assessed the quality of quasi-randomised controlled trials. The applicable criteria, which were also recommended for Cochrane reviews, consist of two components. Comparability of characteristics was assessed between intervention and control groups with respect to relevant baseline characteristics such as water quality, diarrhoeal morbidity, age, socioeconomic status, access to water, hygiene practices, and sanitation facilities. This was classified as "adequate" if no substantial differences are present; "unclear" if not reported or not known whether substantial differences exist; or "inadequate" if one or more substantial difference exists. The second criterion assesses the contemporaneousness of data collection for intervention and control groups—i.e., did they occur at the same time. This was classified as "adequate" if data were collected at similar points in time; "unclear" if the relative timing was not reported or not clear from the trial; or "inadequate" if data were not collected at similar points in time.

2.8 Data extraction

Data were extracted using a pre-piloted form. Where necessary, attempts were made to contact authors to supply missing data. The extracted data were then entered into Review Manager 4.2.

T Clasen, T Rabie and W-P Schmidt extracted, and where necessary calculated, the measure of effect of the intervention on diarrhoea. They extracted and reported the measure of effect as reported by the authors of each study, whether it be odds ratio, risk ratio, prevalence ratio or ratio of means. In doing so, it is important to note the potential error in treating all such measures of effect as equivalent for common outcomes such as diarrhoea (Zhang 1998; McNutt 2003). While it would be possible to calculate a single measure of effect for most studies based on the raw study data, the author elected not to do so for the following reasons. Although all studies included in the review assess outcomes on an individual level, the unit of randomisation is not the individual but a household, group of households, neighbourhood or village. As described in the Description of Studies below, most studies included in this review correct for this potential error by adjusting for the inter-cluster variance. Studies of diarrhoeal disease also frequently adjust for other common covariates, including age and repeated episodes within the same subject. Because these adjustments are generally deemed appropriate, a re-calculation of a measure of effect based on raw data would ignore these important adjustments. Comparisons presented in this review (and the estimated pooled effects) are thus based on the various measures of effect reported in the studies and not on a single or re-calculated measure of effect. As recommended by Deeks (2001), however, sub-group analysis was performed to explore any differences in outcome based on the principal measures of effect reported in the studies (Figure 4.1.11 in Chapter 4).

2.9 Data analysis

The data were compiled and analysed using RevMan 4.2. Estimates of effect were entered using the generic inverse variance method on the log scale (Egger 2001; Woodward 2001). Thus, the measure of effect (e.g., a risk ratio of 0.83) is entered as the Log_e of such relative risk (-0.1863). The standard error was then calculated by first computing the natural log of the upper limit of the confidence interval [e.g., Log_e (0.91), or -0.0305], and dividing the difference between such result and the log transformed ratio by 1.96, all in accordance with Formula 2.9. In the example, the resulting standard error is 0.0795.

Formula 2.9: Computation of generic inverse variance on log scale.

[Log_e (upper limit of confidence interval)-Log_e(risk ratio)]/1.96.

Tests for heterogeneity were performed by visually examining the forest plots and by using the Chi-squared test for heterogeneity with a 10% level of statistical significance[4] and the I-squared test for consistency[5] (Thompson 1999). In accordance with the study protocol, where there was evidence of heterogeneity subgroup analyses were then undertaken based on the following criteria: age of study population (all ages versus children < 5 years); intervention point (source versus household); intervention type (source improvement, chlorination, filtration, solar disinfection, combined flocculant/disinfectant, or improved storage); water quality only versus compound interventions (i.e., with hygiene message, vessel, improved sanitation, improved supply); ambient water quality (i.e.,, water testing results at pre-intervention or of control group, based on log scale levels of thermotolerant coliform per 100ml); compliance with intervention (<50% versus >50%), and effectiveness under various water supply, sanitation and water access conditions. In subgrouping based on water supply and sanitation facilities, the terms "improved" or "unimproved" were used as

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[4] The test examines the null hypothesis that all of the studies are evaluating the same effect. A test statistic (sometime designated "*Q*") is computed by summing the squared variance of each study's estimate from the estimate derived from the meta-analysis. P values are then obtained by comparing the statistic with a X^2 distribution with k-1 degrees of freedom (with k being the number of studies included). Thus, a low p-value (eg <0.10) suggests an actual underlying difference in effect between studies that is unlikely to be attributable to chance.

[5] Unlike tests for heterogeneity, the I-squared tests for consistency. It is less affected by the number of studies in the analysis. I^2, which ranges from 0% to 100%, is the percentage of total variation across studies that is due to heterogeneity rather than chance. Thus, low values indicate little heterogeneity while larger values indicate increasing heterogeneity. I^2 is calculated from the information provided in the test for heterogeneity as follows: I^2=100% x (Q-df)/Q. (Higgins 2003)

defined by the WHO/UNICEF Global Assessment (WHO/UNICEF 2000); studies were categorized as "unclear" with respect to water supply if they contained insufficient information. In subgroupings based on access to water source, the terms "sufficient" and "insufficient" were used as defined by The Sphere Project (Sphere Project 2004). Once again, studies were categorized as "unclear" with respect to access if they contained insufficient information. Subgrouping was also used to compare effectiveness based on methodological quality of the studies. Finally, subgrouping was used to explore the extent to which effectiveness may have varied based on the reported measure of effect (risk ratio, rate ratio, longitudinal prevalence ratio and odds ratio). Table 2.9 summarizes the categories and subgroups used in the subgroup analysis.

Table 2.9: Categories and subgroups for subgroup analysis

Category	Subgroups
Age of study population	• All ages • < 5 years
Intervention point	• Source • Household
Intervention type	• Source • Chlorination • Filtration • Solar Disinfection • Flocculation/Disinfection • Improved Storage
Water quality only versus compound intervention	• Water quality only • Water quality plus hygiene message • Water quality plus vessel • Water quality plus sanitation • Water quality plus improved supply
Ambient water quality	• 0 TTC/100ml • 1-10 TTC/100ml • 11-100 TTC/100ml • 101-1000 TTC/100ml • >1000 TTC/100ml
Compliance with intervention	• <50% compliance • >50% compliance
Ambient water supply	• Improved • Unimproved
Ambient sanitation	• Improved • Unimproved
Ambient water access	• Sufficient • Insufficient
Ambient water quantity	• Sufficient

Category	Subgroups
	• Insufficient
RCT Study Quality—generation of allocation sequence	• Adequate • Unclear • Inadequate
RCT study quality—concealment of allocation sequence	• Adequate • Unclear • Inadequate
RCT study quality—follow up	• Adequate • Unclear • Inadequate
RCT study quality—blinding	• Double blinded • Open
Quasi-RCT study quality—comparability of characteristics	• Adequate • Unclear • Inadequate
Quasi-RCT study quality—contemporaneousness of data collection	• Adequate • Unclear • Inadequate

Meta-analysis was used to derive pooled estimates of effect. The weight ascribed to each study in the meta-analysis was based on the precision of its results in accordance with the inverse variance method, where weight is a function of the reciprocal of the squared standard error of the point estimate of effect. Because of important differences in study methodology, settings, intervention types, as well as substantial heterogeneity in study results, the random effects (rather than fixed effects) model was employed.[6] These same differences should also lead readers to exercise caution in attaching too much weight to the pooled results. Moreover, because this review is mainly descriptive with only limited meta-analysis, no sensitivity analyses was undertaken except for reporting, in appropriate cases, the effect of excluding one study that was considered an outlier.

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[6] A fixed-effects model assumes that the true effect of the intervention is the same (or fixed) in each study, and that the differences between study results are due solely to chance. Under such a model, if the studies were infinitely large, they would give identical results. In a random effects model, the effect of the intervention is assumed to vary, following a normal distribution, around an overall average effect. This acknowledges a different underlying effect for each study, and takes this "between study" variance, along with "within study" variance, into account in pooling the results The random effects model is appropriate, in cases such as this, where there is evidence of heterogeneity. It should not, however, be regarded as an alternative to investigating and attempting to explain such heterogeneity. (Egger 2001)

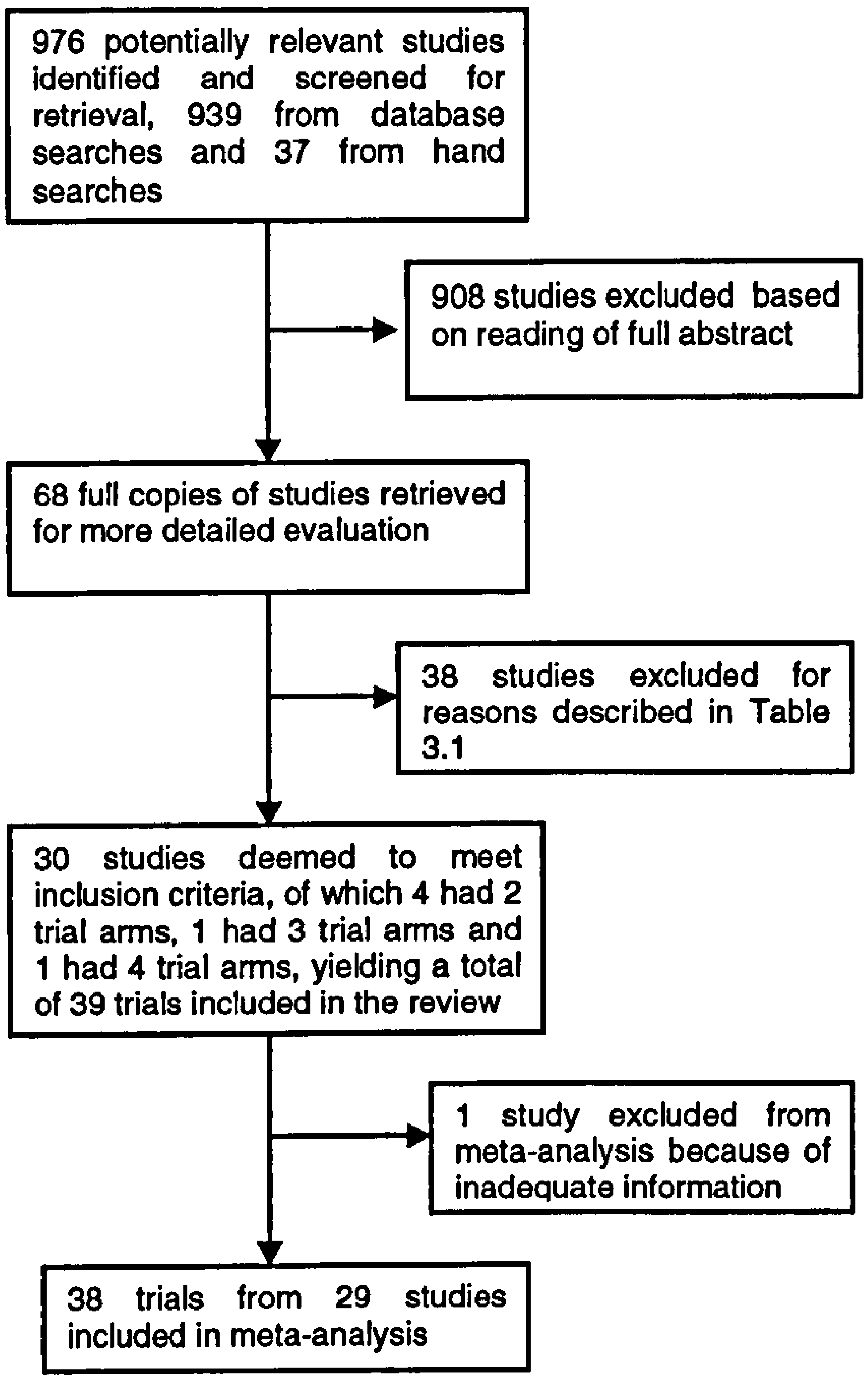
Finally, we produced a funnel plot to explore publication bias. We chose not to present results from statistical analysis of publication bias since they are not yet fully accepted (Egger 2001).

Chapter 3: Description of Studies

3.1 Studies Found, Included and Excluded

Execution of the search strategy elicited 976 titles and abstracts, 939 from the databases and 37 from the other sources. These titles and abstracts were screened and the full text of 68 studies was obtained for further assessment. Of these 68 studies, 30 met the inclusion criteria of this review. One of these studies (Torun 1982) met the review's inclusion criteria but contained inadequate information on disease morbidity to include in the analysis of results. The authors of that study could not be reached. Accordingly, while information from Torun 1982 is included in this description of the studies, data from the study are not included in the results below. As noted more fully below, several studies had more than one intervention arm, thus yielding a total of 38 sets of results from the 30 included studies. Figure 3.1 sets forth a flow diagram of studies found, included and excluded.

Figure 3.1 Flow diagram of studies found, included and excluded



Of the 30 included studies, 18 were published in journals (Alam 1989; Aziz 1990; Clasen 2004; Colford 2002; Conroy 1996; Conroy 1999; Gasana 2002; Jensen 2003; Kirchhoff 1985; Luby 2004a; Mahfouz 1995; Messou 1997; Quick 1999; Quick 2002; Reller 2003; Roberts 2001; Semenza 1998; Xiao 1997), 1 was published in a book (Torun 1982), 2 were included in PhD dissertations (Austin 1993; Handzel 1998), and 9 have were not published as of the 31December 2004 (Chiller 2004; Clasen 2004a; Crump 2004; Doocy 2004; du Preez 2004; Garrett 2004; Luby 2004b; Lule 2004; URL 1995).

A total of 38 studies identified from the search were excluded from this review. The reasons for excluding those studies were (1) that the study design was not an RCT or quasi-RCT, (2) that the intervention did not include an improvement in water quality, (3) that the outcome was not diarrhoea, or (4) that the results of the study were duplicative of those of another study that is included in the review. The specific reasons for exclusion are set forth in Table 3.1.

Table 3.1: Excluded studies and reasons for exclusion

Study Reference	**Type of Study** (Not RCT or Quasi-RCT)	**Type of Intervention** (Not improvement in water quality)	**Type of Outcome** (Not Diarrhoea)	**Duplicate Data**: (Reference to included study)
Asaolu 2002	X		X	
Azurin 1974			X	
Bahl 1976	X			
Bersh 1985	X			
Chongsuvivatwong 1994	X			
Colwell 2003			X	
Conroy 2001			X	
Deb 1986			X	
Esrey 1991	X			
Fewtrell 1994	X		X	
Fewtrell 1997	X		X	
Ghannonum 1981	X		X	
Hasan 1989				Aziz 1990
Hellard 2001			X	
Henry 1990				Aziz 1990
Hoque 1996	X			
Iijima 2001	X			
Jensen 2002			X	
Khan 1984			X	
Macy 1998	X	X	X	
Maeusezahl 2003	X			
McCabe 1957		X		
Mertens 1990	X	X	X	
Nanan 2003	X			
Payment 1991	X		X	
Payment 1991a			X	
Pinfold 1990			X	
Rubenstein 1969	X			
Sathe 1996	X			
Shiffman 1978	X			
Shum 1971	X	X	X	
Sobsey 2002				Handzel 1998 and Quick 1999
Sorvillo 1994			X	
Tonglet-R 1992	X			
Trivedi 1971	X			

Study Reference	**Type of Study** (Not RCT or Quasi-RCT)	**Type of Intervention** (Not improvement in water quality)	**Type of Outcome** (Not Diarrhoea)	**Duplicate Data**: (Reference to included study)
Van Derslice 1995	X	X		
Varghese 2002	X			
Venczel 1997				Quick 1999

Two studies failed to meet the inclusion criteria for the review only because their outcome of interest consisted of gastrointestinal disease that included, but was not limited to, diarrhoea.[7] Payment (1991a) was a 15-month randomized, controlled but non-blinded trial of domestic reverse-osmosis water filters among 606 households in a suburb of Montreal. Despite finding that the treated municipal water supplied to all participating households was free of indicator bacteria and human enteric viruses, members of intervention households reported 35% less incidence of highly credible gastrointestinal infection (HCGI) than members of control households ($p<0.01$). Investigators noted that reporting bias could not be ruled out as a possible explanation for the difference, but the study raised concerns about waterborne pathogens in treated water that were not associated with widely accepted microbial indicators. On the other hand, in a double-blinded, randomized, controlled trial over 68 weeks among 600 families residing in Melbourne, Hellard (2001) found no difference in the incidence of HCGI between intervention and control groups. Intervention households were supplied with a domestic water treatment unit combining microfiltration and ultra-violet radiation; control households received an identical sham unit. All participating households were supplied with water from the city's protected catchments where it is stored for a minimum of 12 months and chlorinated prior to distribution. While these studies are excluded from the present review, their results are of potential interest, particularly since they followed a rigorous design. The lack of a protective effect in Hellard's blinded study compared to the other studies is particularly noteworthy given the difference in results between blinded and open studies included in the present review.

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[7] Gastrointestinal disease was also the primary outcome of the study reported by Colford (2001). However, because Colford and colleagues also separately reported rates of diarrhoea among intervention and control groups, the study could be included in the review.

3.2 Study design and length

Of the 30 included studies, 19 were RCTs (Austin 1993; Chiller 2004; Clasen 2004; Clasen 2004a; Colford 2002; Conroy 1996; Conroy 1999; Crump 2004; Doocy 2004; du Preez 2004; Handzel 1998; Kirchhoff 1985; Luby 2004b; Lule 2004; Quick 1999; Reller 2003; Roberts 2001; Semenza 1998; Reller 2003), and 11 were quasi-RCTs (Alam 1989; Aziz 1990; Garrett 2004; Gasana 2002; Jensen 2003; Luby 2004a; Mahfouz 1995; Messou 1997; Quick 2002; Torun 1982; Xiao 1997). Among RCTs, 3 were placebo-controlled and double-blinded (Austin 1993; Colford 2002; Kirchhoff 1985) and the remainder followed an open design (i.e., both participant and assessor knew whether or not the participant received the intervention). Among studies using the RCT design, the unit of randomisation was the household (Clasen 2004; Clasen 2004a; Colford 2002; Conroy 1996; Conroy 1999; Crump 2004; du Preez 2004; Garrett 2004; Handzel 1998; Kirchhoff 1985; Quick 1999; Reller 2003; Roberts 2001; Semenza 1998; Reller 2003), a neighbourhood or other cluster of households (Chiller 2004; Doocy 2004; Luby 2004b) or a village or other community (Austin 1993).

Included studies tended to be undertaken quite recently: 10 were completed or published in 2004 alone, and 16 since 2000; only 3 were done in the 1980s and none before 1982. Study design varied with the type of intervention: while the RCT design was used for 19 of 23 studies of household interventions, the quasi-RCT design was used in all 7 studies investigating interventions to improve water quality at the water source or other point prior to distribution.

The length of the intervention period of included studies ranged from 9.5 weeks to 3 years. The duration of the RCTs (median 5 months, range 9.5 weeks to 12 months) tended to be shorter than that of the quasi-RCTs (median 12 months, range 3 to 60 months). Insofar as point-of-distribution interventions tended to follow the quasi-RCT design, this type of intervention was also the subject of longer-term investigations (median 36 months, range 12 months to 60 months) compared to studies of point-of-use interventions (median 5 months, range 9.5 weeks to 12 months). For additional details regarding study design and length, see Table 3.2.

Table 3.2 Certain characteristics of included studies

Study	Methods	Participants	Intervention	Outcomes
Alam 1989	3-year quasi-RCT among 5 political sub-units of a village in rural Bangladesh	623 children 6-23 months of age; 3 sub-units received the intervention, 2 sub-units of the same village served as controls	Improved water supply + hygiene education	Incidence of diarrhoea among children 6-23 months by water source, hygiene practices, household socio-economic characteristics
Austin 1992	20-week RCT among 22 rural villages in The Gambia; unit of randomization is the village (11 intervention and 11 control)	144 children between 6 and 24 months (group A), and 287 children between 25 and 60 months (group B), from villages primarily using open, shallow wells for drinking water	Sodium hypochlorite solution used at household level	Incidence of diarrhoea; change in nutritional status using weight-for-height Z-score
Aziz 1990	3-year quasi-RCT among 2 villages in rural Bangladesh	Approximately 9600 persons of all ages from 1570 households	Improved water supply, + sanitation + hygiene education	Incidence of diarrhoea (portion of among children <5; portion of episodes classified as persistent; percentage of days with diarrhoea; odds ratios of frequent diarrhoea related to environmental factors
Chiller 2004	13-week RCT in 42 neighbourhood clusters in 12 rural villages in Guatemala	3401 persons of all ages from 514 households with at least one child under 1year	Flocculant-disinfectant sachets used at household level + hygiene education	Longitudinal prevalence of diarrhoea (portion of total days of diarrhoea out of total days of observation) among all ages; also measured incidence of persistent diarrhoea
Clasen 2004	6-month RCT in rural Bolivian community	280 persons of all ages from 50 households, half using intervention and half serving as controls	Household ceramic filters	Period prevalence of diarrhoea among all ages; microbial water quality
Clasen 2004a	5-month RCT in rural Bolivian community	324 persons of all ages from 60 households, 40 of which received the intervention and the balance serving as controls	Household ceramic filters	Period prevalence of diarrhoea among all ages; microbial water quality
Colford 2002	4-month "triple-blinded" RCT in urban community in California, USA	236 children 12 years or older from 77 households	Household reverse osmosis filters	Incidence of watery diarrhoea; also measured gastrointestinal illness and various other symptoms, water consumption, effectiveness of blinding
Conroy 1996	12-week RCT among Maasai in rural Kenya	206 children 5-16 years in three adjoining areas of single province	Solar disinfection in plastic bottles at household level	Period prevalence of diarrhoea
Conroy 1999	1-year RCT among Maasai in rural Kenya	349 children <6 years in 140 households	Solar disinfection in plastic bottles at household level	Period prevalence of diarrhoea
Crump 2004	20-week RCT among 49 rural villages in western Kenya	6650 persons of all ages in 604 family compounds; participation limited to family compounds with at least one child <2 years and	Arm 1: flocculant-disinfectant sachets used at household level + hygiene Arm 2: sodium hypochlorite used	Longitudinal prevalence (weeks with diarrhoea/ weeks of observation) among all ages; breastfeeding and consumption of food and

Study	Methods	Participants	Intervention	Outcomes
		likely to be using highly turbid source water	at household level + hygiene education	water for children <2 years; deaths; use of intervention; mothers' knowledge and acceptance of intervention (weeks 5 and 15); microbial water quality and turbidity; mothers' knowledge and attitudes of intervention;
Doocy 2004	12-week RCT in two Liberian camps for displaced persons	2191 persons of all ages (1138 intervention, 1053 controls), of which 735 are children <5 (395 intervention, 340 controls) from households in settlement area not using treated water for drinking	Flocculant-disinfectant sachets used at household level, plus water storage vessel; controls also received vessel	Longitudinal prevalence (weeks with diarrhoea/total weeks of observation)
du Preez 2004	6-month RCT in rural South Africa and Zimbabwe	115 children <5 years (60 in intervention group, 55 in control)	Household ceramic filter	Incidence of diarrhoea; incidence of bloody diarrhoea and non-bloody diarrhoea; microbiological water quality
Garrett 2004	Quasi-RCT of unknown duration in rural Kenya	960 children <5 years (618 in intervention group, 342 in control)	Household chlorination using sodium hypochlorite solution + Improved water supply + sanitation + hygiene education + improved storage	Incidence of diarrhoea
Gasana 2002	1-year quasi-RCT in rural Rwanda	150 children <5 years (95 in intervention group, 55 controls)	Improved water supply (pipes, sedimentation tank, ceramic filter, storage tank and communal tap)	Incidence of diarrhoea
Handzel 1998	8-month RCT in informal settlement in urban Bangladesh	447 children 3-60 months from 276 households (140 intervention, 136 control) using municipal water (household taps) as primary source of drinking water which had tested positive at baseline for *E coli*	Household chlorination using sodium hypochlorite solution and special storage vessel	Incidence of diarrhoea; microbial water quality
Jensen 2003	6-month quasi-RCT among 2 villages in Pakistan; controlling for sanitation and water storage status of households, and for seasonality	226 children <5 years (82 in intervention village, 144 in control village);	Village level chlorination of water supply using calcium hypochlorite	Incidence of diarrhoea; microbial water quality
Kirchhoff 1985	18 week blinded cross-over RCT in rural Brazil	112 persons from 20 families with at least 2 children living at home and using water from pond exclusively	Household level chlorination with sodium hypochlorite	Longitudinal prevalence of diarrhoea; microbial water quality; acceptability of intervention to study population

Study	Methods	Participants	Intervention	Outcomes
Luby 2004	6-month quasi-RCT among 3 neighbourhoods in squatter settlements in Karachi, Pakistan	2365 persons <15 years from 285 households (640 persons in bleach + regular vessel group, 697 in bleach + insulated vessel group, 1027 in control group)	Two water quality intervention arms: Arm 1: bleach + regular vessel Arm 2: bleach + insulated vessel	Incidence of diarrhoea; use of intervention by certain household characteristics
Luby 2004a	8-month RCT among 47 squatter settlements of Karachi, Pakistan	5520 persons of all ages (1869 in flocculant-disinfection group, 1776 in bleach group, 1875 controls)	Two water quality intervention arms: Arm 1: flocculant-disinfectant + vessel Arm 2: dilute bleach + vessel	Incidence and longitudinal prevalence of diarrhoea
Lule 2004	5-month RCT among households in rural Uganda; succeeded by 18 month RCT that included cotrimoxazole prophylaxis	2201 persons of all ages (1097 in intervention group, 1104 controls) among 458 households with at least one person HIV+ without access to chlorinated municipal water;	Household level chlorination using sodium hypochlorite + special vessel	Incidence of diarrhoea, days with diarrhoea (longitudinal prevalence), days lost from work or school, aetiology of diarrhoea; frequency of clinic visits and hospitalization; mortality
Mahfouz 1995	6-month quasi-RCT among 9 villages in rural Saudi Arabia	311 children <5 years (159 among intervention households, 152 among controls) among 171 families	Household level chlorination using calcium hypochlorite	Reported cases of diarrhoea in intervention year compared with previous year
Messou 1997	5-year quasi-RCT among 4 villages in rural Ivory Coast, 2 of which underwent the interventions, and the other 2 of which served as controls	Approximately 985 to 1260 (depending on study year) children <5 years	Improved water supply +sanitation + hygiene education	Incidence of diarrhoea; reduction in deaths attributable to diarrhoea; utilization of oral rehydration solution
Quick 1999	5-month RCT among 2 peri-urban communities in Bolivia	791 persons of all ages (400 intervention, 391 control) from 127 households (64 intervention, 63 control)	Household level chlorination + vessel + hygiene education	Incidence of diarrhoea; microbiological water quality
Quick 2002	3-month quasi-RCT in 2 peri-urban communities in Zambia	1584 persons of all ages from 260 households (166 intervention, 94 control)	Household level chlorination + vessel + hygiene education	Incidence of diarrhoea; microbiological water quality
Reller 2003	12-month RCT among 12 villages in rural Guatemala	492 households (102, 97, 97, 100 to intervention arms 1-4, respectively, and 96 to control) each with a child <12 months or mother in last trimester of pregnancy	Four intervention arms: Arm 1: Flocculant-disinfectant + education Arm 2: Flocculant-disinfectant + vessel + education Arm 3: bleach + education Arm 4: bleach + vessel + education	Incidence of diarrhoea; intervention knowledge and acceptability; microbiological water quality; intervention utilization

Study	Methods	Participants	Intervention	Outcomes
Roberts 2001	4-month RCT in a Malawi refugee camp	1160 persons of all ages (310 intervention, 850 control) from 400 households (100 intervention, 300 control); of these, 208 were children <5 (51 among intervention households, 157 among controls)	Improved storage (bucket with spout and narrow opening to limit hand entry)	Incidence of diarrhoea; microbiological water quality; incidence of diarrhoea by selected environmental factors
Semenza 1998	9.5 week RCT in urban Uzbekistan among 240 households, half with and half without access to piped water	1583 persons of all ages from 240 households, half with access to piped water (first control group) and half without (of which 62 received intervention, and 58 served as a second control group); these included 344 children <5 (176 from piped water households, 88 intervention and 80 no-chlorination)	Household level chlorination + vessel + hygiene education	Incidence of diarrhoea; incidence of diarrhoea by selected household and water management practices
Torun 1982	12-month quasi-RCT in 2 small villages in Guatemala	2103 persons of all ages from two villages, 1006 in intervention villages and 1097 in control villages	Source protection (spring), chlorination facilities, "adequate storage", and water mains with faucets to yards of intervention villages	Incidence of diarrhoea
URL 1995	12 month study from three demographic regions of Guatemala	1120 children <5 (265, 289 and 297 were allocated to the intervention arms, and 269 to the control arm) from 680 families from three demographic regions	Three intervention arms: Arm 1: Hygiene education Arm 2: Household ceramic filters Arm 3: Household ceramic filters + hygiene education	Incidence of diarrhoea; nutritional status (weight/age)
Xiao 1997	3-year quasi-RCT among 2 villages in rural China	4649 persons of all ages (2363 from intervention village, 2286 from control)	Improved water supply + sanitation + hygiene education	Incidence of diarrhoea

3.3 Settings and participants

The 30 studies included in this review covered at least 53,476 participants[8]. Nineteen RCTs with at least 29,920 participants had a median size of 607 participants (range 112 to 6650); 11 quasi RCTs with a total of 23,556 participants had a median size of

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[8] This figure excludes the number of persons from Garrett 2004, an unpublished study that did not report the number of persons included in the study. The author could not be reached to complete this and other information from the study.

972 participants (range 150 to 9600). Seven studies of point-of-distribution interventions had at total of 18,336 participants and a median size of 804 (range 150 to 9600); 23 studies of point-of-use interventions had a total of 35,140 participants and a median size of 875 (range 112 to 6650). Details on the number of participants for each study appear in Table 3.2.

Fifteen studies enrolled and presented results for all ages of participants (Aziz 1990; Chiller 2004; Clasen 2004; Clasen 2004a; Crump 2004; Doocy 2004; Kirchhoff 1985; Luby 2004b; Lule 2004; Quick 1999; Quick 2002; Reller 2003; Roberts 2001; Semenza 1998; Xiao 1997), while 9 studies included only children under 5 years or a subgroup thereof (Alam 1989; Austin 1993; du Preez 2004; Garrett 2004; Gasana 2002; Handzel 1998; Jensen 2003; Mahfouz 1995; Reller 2003). The other studies used alternative age criteria for participants. Where studies included data on children under 5 years (or a subgroup thereof), these data were extracted and included in the analysis of results presented below for the under 5 year age group.

Except for one study which took place in the United States (Colford 2002), all the included studies were undertaken in developing countries. These included Bangladesh (Alam 1989; Aziz 1990; Handzel 1998), Bolivia (Clasen 2004; Clasen 2004a; Quick 1999), Brazil (Kirchhoff 1985), China (Xiao 1997), Guatemala (Chiller 2004; Reller 2003; Torun 1982; Reller 2003), Gambia (Austin 1993), Ivory Coast (Messou 1997), Liberia (Doocy 2004), Kenya (Conroy 1996; Conroy 1999; Crump 2004; Garrett 2004), Malawi (Roberts 2001), Pakistan (Jensen 2003; Luby 2004a; Luby 2004b) , Rwanda (Gasana 2002), Saudi Arabia (Mahfouz 1995), South Africa/Zimbabwe (du Preez 2004), Uganda (Lule 2004), Uzbekistan (Semenza 1998), and Zambia (Quick 2002). Two studies took place in urban settings (Colford 2002; Semenza 1998), 2 in peri-urban settings (Quick 1999; Quick 2002), 3 in urban informal/squatter settlements (Handzel 1998; Luby 2004a; Luby 2004b), 2 in camps for refugees or displaced persons (Doocy 2004; Roberts 2001), 1 in multiple settings (Reller 2003) and the balance in villages or other rural settings.

Where possible, data were extracted from studies in order to ascertain certain other characteristics of the study setting that may be used for sub-group analysis. This information is summarized in Table 3.2 and Table 3.3 (Details of control/pre-intervention water, sanitation and hygiene practices). The primary drinking water supply was "unimproved" (i.e., unprotected well or spring, vendor- or tanker-provided water or bottled water) in 18 studies, "improved" (i.e., household connection, public standpipe, borehole, protected dug well or spring, or rainwater collection) in 8 studies, and “unclear” or not reported in 3 studies. Sanitation facilities in trial settings were "improved" (connection to a public sewer or septic system, pour-flush latrine, simple pit latrine, ventilated improved pit latrine) in 8 studies, unimproved (i.e., service or bucket latrines, public latrines, open latrines) in 9 studies, and unclear or unreported in 13 studies. Access to a water source was deemed "sufficient" (i.e., a consistently available source located within 500m, with queuing no more than 15 min and filling time for a 20L container no more than 3 minutes) in 8 studies and unclear or unreported in the remainder; no studies reported a setting that provided "insufficient" access to a water source. The quantity of water available to study participants was considered sufficient (consisting of a minimum of 15L per person per day) in 7 studies, insufficient in 3 studies and unclear in 20 studies.

Table 3.3: Details of control/pre-intervention water, sanitation and hygiene practices

Study	Description of Control or Pre-Intervention Water Supply	Primary type of water source[9]	Access to water source[10]	Quantity of water[11]	Microbiological water quality tested?	Details of microbiological assessment of water at source	Primary sanitation facilities among study population
Alam 1989	Shallow, hand-dug wells; some hand pumps	Unimproved	Unclear	Unclear	No	NA	Unclear
Austin 1992	Open wells	Unimproved	Sufficient	Unclear	Yes	Mean 1871FC/100ml in wells; among stored water samples, mean 3358FC/100ml in rainy season, 1014FC/100ml in dry season	Unclear
Aziz 1990	Fewer hand pumps and latrines; no hygiene instruction	Unimproved	Unclear	Unclear	No	NA	Unimproved
Chiller 2004	Rivers, springs, taps and wells	Unclear	Unclear	Sufficient	Yes	98% of source samples contained *E. coli*; precise level not reported	Mostly unimproved
Clasen 2004	Irrigation canals and other surface sources	Unimproved	Sufficient	Sufficient	Yes	Baseline mean thermotolerant coliform count	Unimproved

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[9] "improved" (includes household connection, public standpipe, borehole, protected dug well, protected spring, rainwater collection); "unimproved" (includes unprotected well, unprotected spring, vendor-provided water, bottled water); or "unclear" (unclear or not reported). Definition based on WHO (2000). Global Water Supply and Sanitation Assessment 2000 Report. Geneva: World Health Organization.

[10] "sufficient" (located within 500m; queuing no more than 15 min; no more than 3 min. to fill 20L container; maintained so available consistently); "insufficient" (does not meet any of above); or "unclear" (unclear or not reported). Definition based minimum standards established by The Sphere Project (2004). Humanitarian Charter and Minimum Standards in Disaster Response. Geneva: The Sphere Project

[11] "Sufficient" (minimum of 15L/day/person); "insufficient" (less than 15L/day/person); or "unclear (unclear or not reported). Definition based minimum standards established by The Sphere Project (2004). Humanitarian Charter and Minimum Standards in Disaster Response. Geneva: The Sphere Project

Study	Description of Control or Pre-Intervention Water Supply	Primary type of water source[9]	Access to water source[10]	Quantity of water[11]	Microbiological water quality tested?	Details of microbiological assessment of water at source	Primary sanitation facilities among study population
						of 793/100ml	
Clasen 2004a	80% yard taps supplied from untreated surface source, directly from 20% surface sources	80% improved, 20% unimproved	Sufficient	Sufficient	Yes	Baseline mean thermotolerant coliform count of 145/100ml at taps and 52/100ml at surface sources	Unimproved
Colford 2002	Household taps supplied by municipal water treatment works	Improved	Sufficient	Sufficient	Used data from water treatment plant	Met US federal and California drinking water standards	Improved
Conroy 1996	Open water holes, tank fed by untreated, piped, water supply ; control households provided identical bottles, but were instructed to keep them indoors	Unimproved	Unclear	Unclear	Yes	All water sources positive for faecal coliform; "counts of more than 10^3 CFU per ml" (no further details)	Unclear
Conroy 1999	Open water holes, tank fed by untreated, piped water supply; control household provided identical bottles, but were instructed to keep them indoors	Unimproved	Unclear	Unclear	No	NA	Unclear
Crump 2004	50% ponds, 49% rivers	Unimproved	Unclear	Insufficient	Yes	Baseline mean *E. coli* level was 98/100ml	Unclear; 33% defecate on ground
Doocy 2004	Surface sources and some tap stands	Unimproved	Unclear	Insufficient	Yes	Qualitative measure only	Improved
du Preez 2004	Protected wells	Improved	Sufficient	Unclear	Yes	Samples with *E. coli* per 100ml: 31 <10, 9 >10<100, 1 >100<1000, 3 >1000	Improved
Garrett 2004	No details reported	Unclear	Unclear	Sufficient	No	N/A	Unimproved
Gasana 2002	Spring	Unimproved	Unclear	Unclear	Yes	Baseline sample range from 4-1100 total coliforms per 100ml	Unimproved

Study	Description of Control or Pre-Intervention Water Supply	Primary type of water source[9]	Access to water source[10]	Quantity of water[11]	Microbiological water quality tested?	Details of microbiological assessment of water at source	Primary sanitation facilities among study population
Handzel 1998	48% tap, 52% tubewell; 61% paid for drinking water	Improved	Sufficient	Sufficient	Yes	Baseline geometric mean faecal coliform counts/100ml: tap water—138 at source, 280 stored in home; tubewell water—6.7 at source, 138 stored in home	Unimproved
Jensen 2003	Some slow sand filters in poor condition; some household taps; majority used ground water	Improved	Unclear	Unclear	Yes	Baseline (pre-intervention) geometric mean in intervention village of 13.3 *E. coli* CFU /100ml; geometric mean *E. coli* count of 137/100ml in control village	Unclear
Kirchhoff 1985	Pond water stored in clay pots after filtering with cloth	Unimproved	Unclear	Insufficient	Yes	Mean of 9700 faecal coliforms/100ml from pond sources; 16000 faecal coliforms/100ml in control stored water	Unimproved
Luby 2004a	Tanker trucks, shared municipal taps	Unimproved	Unclear	Unclear	Yes	At baseline, 79% of participating household samples from stored water were free of *E. coli*	Improved
Luby 2004b	Unclear	75% improved	Sufficient	Unclear	No	NA	Improved
Lule 2004	16% surface or shallow wells, 50% protected springs, 49% boreholes or taps	Unimproved	Sufficient	Sufficient	Yes	Baseline mean *E. coli* counts: 11 at source, 163 stored water; 54% of source water had some contamination, compared to 89% of stored water	Improved
Mahfouz 1995	Shallow wells	Unimproved	Unclear	Unclear	Yes	92.3% positive with *E. coli*; amount not recorded	Improved
Messou 1997	Not reported	Unimproved	Unclear	Unclear	No	NA	Unclear
Quick 1999	Shallow uncovered wells; 38% treated water	Unimproved	Unclear	Unclear	Yes	Baseline median colony count of E. coli: 57050/100ml	Unimproved (but 47% used

Study	Description of Control or Pre-Intervention Water Supply	Primary type of water source^9	Access to water source^{10}	Quantity of water^{11}	Microbiological water quality tested?	Details of microbiological assessment of water at source	Primary sanitation facilities among study population
						for source water and 46950/100ml for stored water	latrine)
Quick 2002	Shallow wells; some boiling	Unimproved	Unclear	Unclear	Yes	Baseline median colony count of E. coli: 34/100ml for source water and 44/100ml for stored water	Unclear
Reller 2003	Surface water from shallow wells, rivers and springs	Unimproved	Unclear	Unclear	Yes	Baseline median colony count of E. coli: 63/100ml	Unclear
Roberts 2001	Traditional pots or standard ration buckets filled at refugee camp water point	Improved	Unclear	Unclear	Yes	At well, 71% of samples were 1FC/100ml or less; 100% <100 FC/100ml	Unclear
Semenza 1998	Households without piped water (procured from street tap, neighbour tap, well, vendor or river)	Unimproved	Unclear	Unclear	Yes	Baseline mean 49 faecal coliform/100ml	Unclear
Torun 1982	Shallow, unprotected, hand-dug wells	Unimproved	Unclear	Unclear	Yes	3% of 698 samples from control villages had coliform bacteria	Unimproved
URL 1995	Household tap (27%), public tap (21%), well (23%)	Improved	Unclear	Unclear	Yes	Range 5-260 FC/100ml depending on site	Improved
Xiao 1997	Not reported	Unimproved	Unclear	Unclear	No	NA	Unclear

Of the 30 studies included in this review, 23 measured the microbial contamination of the drinking water at baseline prior to introduction of the intervention as an indication of the ambient risk and the microbiological quality of the water consumed by the control group. Eighteen measured colony forming units (CFU) of thermotolerant coliforms, faecal coliforms or Escherichia coli. Other studies measured the frequency of samples containing such bacteria, or CFU of total coliforms or other indicators of microbial contamination.

3.4 Interventions

Six of the studies had more than one intervention arm that met the review's definition for interventions to improve water quality: Austin 1993; Crump 2004; Luby 2004a; Reller 2003 each had 2 intervention arms; Luby 2004b had 3 intervention arms; and Reller 2003 had 4 intervention arms. Thus in some cases below, studies are described in more than one sub-group. As a result of these multiple-intervention group studies, the 30 studies produced a total of 38 discrete trials for analysis (30 total, less Torun 1982 with inadequate information, plus 9 additional sets of results from multi-arm interventions).

In accordance with the review's inclusion criteria, each of the studies investigated an intervention to improve the microbial quality of drinking water. Beyond this, however, interventions can only be described in certain broad categories. Seven studies involved interventions to improve water quality at the source (Alam 1989; Aziz 1990; Gasana 2002; Jensen 2003; Messou 1997; Torun 1982; Xiao 1997), while the others all involved interventions at the household level. Among point-of-use studies, interventions can be grouped around improved storage (Roberts 2001) or one of four basic technologies for treating water in the home: chlorination (Austin 1993; Crump 2004; Garrett 2004; Handzel 1998; Kirchhoff 1985; Luby 2004a; Luby 2004b; Lule 2004; Mahfouz 1995; Quick 1999; Quick 2002; Reller 2003; Semenza 1998), solar disinfection (Conroy 1996; Conroy 1999), filtration (Clasen 2004; Clasen 2004a ; Colford 2002; du Preez 2004; Reller 2003), and combination flocculation-disinfection using the Proctor & Gamble PUR® product (Chiller 2004; Crump 2004(arm 2); Luby 2004b; Reller 2003). It must be noted, however, that apart from singular interventions such as solar disinfection and PUR, these groups are not homologous. For example, filtration interventions varied by filter medium and pore size, and chlorination varied by chlorine source, dose and contact time.

As noted in Background above, the interventions used in these studies have varying degrees of microbiological performance, particularly under different water conditions. Nevertheless, due to the obvious logistical difficulties, none of the studies continually measured the microbiological performance of their interventions against the full range of microbial pathogens (bacterial, viral and protozoan) that are known to cause diarrhoea.

Many of the studies involved interventions in addition to improvements in microbial water quality. Most common was some type of supplemental hygiene education or instruction beyond the use of the intervention itself (Alam 1989; Chiller 2004; Crump 2004; Luby 2004b(arm 2)), in some cases combined with an improvement in sanitation facilities (Aziz 1990; Messou 1997; Xiao 1997). Among household interventions, household-based water treatment was often combined with some form of improved storage (Doocy 2004; Luby 2004a; Luby 2004b; Lule 2004), hygiene support for the intervention (Chiller 2004; Reller 2003) or both (Handzel 1998; Quick 1999; Quick 2002; Semenza 1998), in one case together with improved supply and sanitation (Garrett 2004). In only one multiple-intervention arm study did investigators establish different intervention groups with and without hygiene or other non-water improvement steps in order to isolate the water quality impact from that of additional steps (Reller 2003). In the end, only 14 of the included trials could be said to involve only an improvement in microbial water quality without some other material intervention that could impact the outcome (Austin 1993; Austin 1993(arm 2); Clasen 2004; Clasen 2004a; Colford 2002; Conroy 1996; Conroy 1999; du Preez 2004; Jensen 2003; Kirchhoff 1985; Mahfouz 1995; Reller 2003; Reller 2003(arm 2); Reller 2003), though even among these, the ceramic filter trials (Clasen 2004; Clasen 2004a; du Preez 2004) and solar disinfection trials (Conroy 1996; Conroy 1999) provided water treatment in an integrated system that may have also improved storage.

Seven studies did not report actually having measured microbial water quality among control and intervention groups (Alam 1989; Aziz 1990; Conroy 1999; Garrett 2004; Luby 2004b; Messou 1997; Xiao 1997). Thus, it cannot be concluded definitively that the interventions investigated in such studies actually resulted in an improvement in drinking water quality. Nevertheless, in accordance with the decision expressed in the protocol for this review—that interventions such as protection of wells or springs which have generally been shown to improve water quality will be included even without measuring the same—

they are included in this review. Among the 7 studies investigating interventions to improve water quality at the point of distribution, only 3 tested microbial water quality (Gasana 2002; Jensen 2003; Torun 1982). Because these tests were at the source or point of distribution and not the point of use, their results do not reflect possible post-collection contamination.

Compliance with the intervention (i.e., consumption of the improved quality water) is an important factor in assessing potential impact of the intervention on the outcome. Nevertheless, none of the studies assessed compliance directly. Studies of source water interventions tended to assume compliance based on the fact that the primary water supply had been improved. Some studies of household water treatment undertook indirect assessments of compliance by measuring residual chlorine levels in stored household water (Austin 1993; Chiller 2004; Crump 2004; Doocy 2004; Garrett 2004; Handzel 1998; Mahfouz 1995; Quick 1999; Quick 2002; Reller 2003; Semenza 1998), by comparing microbial water quality of intervention and control households (Chiller 2004; Clasen 2004; Clasen 2004a; Crump 2004; Kirchhoff 1985), by conducting periodic or post-study surveys (Chiller 2004; Reller 2003) or by counting the number of intervention products used (Reller 2003). In most other studies, compliance was measured only by occasional observation. Seven of the 30 studies included in the review did not report on compliance (Alam 1989; Conroy 1999; Gasana 2002; Luby 2004a; Lule 2004; Torun 1982; Xiao 1997). The studies of chorine residuals reported compliance ranging from a high of 95% (Doocy 2004) to a low of 27% (Reller 2003). Even among these studies, however, investigators acknowledged that it was not possible to know to what extent intervention group participants actually consumed treated water or avoided consuming untreated water. None of the studies reported on differences in outcome based on level of compliance within that study's population itself.

Most interventions at the point of distribution also involved improvements in supply that probably also increased water quantity and/or access, though none of the studies on such interventions reported any measurements thereof. As noted in the Background section above, such improvements in water quantity and/or access may be a separate and possibly more significant contributor to health than water quality.

Additional details regarding interventions appear in Table 3.4 (Details of intervention).

Table 3.4: Details of Intervention

Study	Water quality intervention	Water improved at source or through point-of-use (household)	Was compliance with intervention measured?	Other material components of intervention
Alam 1989	Improved water supply	Source	Not reported	Hygiene education
Austin 1992	Household chlorination	Household	60% compliance measured by residual chlorine	None
Aziz 1990	Improved water supply	Source	Periodic cross-sectional assessments; rate not reported	Improved sanitation, hygiene education
Chiller 2004	Flocculant-disinfectant sachets used at household level	Household	85% compliance measured by residual chlorine	Hygiene education
Clasen 2004	Household ceramic filters	Household	Not reported	Filter included improved storage
Clasen 2004a	Household ceramic filters	Household	Not reported	Filter included improved storage
Colford 2002	Household reverse osmosis filters	Household	Plumbed-in unit	None
Conroy 1996	Solar disinfection in plastic bottles at household level	Household	Random checks by project workers; rate not reported	None
Conroy 1999	Solar disinfection in plastic bottles at household level	Household	Not reported	None
Crump 2004	Arm 1: flocculant-disinfectant sachets used at household level Arm 2: sodium hypochlorite used at household level	Household	86% and 85% compliance (measured by residual chlorine) for arms 1 and 2, respectively at scheduled visits; 44% and 61% during unannounced weekly visits	Hygiene education (both arms)
Doocy 2004	Flocculant-disinfectant sachets used at household level in refugee camp	Household	95% compliance based on residual chlorine sampling	Both controls and intervention group received water storage vessel
du Preez 2004	Household ceramic filter	Household	100% based on observation	Filter included improved storage
Garrett 2004	Household chlorination using sodium hypochlorite	Household	43% based on residual chlorine	Sanitation, hygiene education, storage, supply
Gasana 2002	Source improvements (water pipes, sedimentation tank, ceramic filter, storage tank, communal tap	Source	Not reported	None

Study	Water quality intervention	Water improved at source or through point-of-use (household)	Was compliance with intervention measured?	Other material components of intervention
Handzel 1998	Household chlorination using sodium hypochlorite solution and special storage vessel	Household	90% compliance based on residual chlorine measurements	None
Jensen 2003	Village level chlorination of water supply using calcium hypochlorite	Source	Unclear, though chlorinated water was supplied through distribution system to all intervention households	None
Kirchhoff 1985	Household level chlorination with sodium hypochlorite	Household	None reported	None
Luby 2004	Arm 1: bleach + regular vessel Arm 2: bleach + insulated vessel	Household	None reported	Vessel provided improved storage; hygiene instruction
Luby 2004a	Arm 1: flocculant-disinfectant + vessel Arm 2: dilute bleach + vessel	Household	Yes, though not yet available	Vessel provided improved storage
Lule 2004	Household level chlorination using sodium hypochlorite + special vessel	Household	Not reported	Vessel provided improved storage; hygiene education was provided to both intervention and comparison groups
Mahfouz 1995	Household level chlorination using calcium hypochlorite	Household	Some residual chlorine in all intervention samples	None
Messou 1997	Improved water supply	Source	Measured increase in water supplied and change in sanitation and hygiene practices	Sanitation, hygiene education, oral rehydration
Quick 1999	Household level chlorination + vessel	Household	70% to 95% compliance based on residual chlorine (increased during course of study)	Improved storage, hygiene education
Quick 2002	Household level chlorination + vessel	Household	70% compliance based on residual chlorine	Improved storage, hygiene education
Reller 2003	Four intervention arms: Arm 1: Flocculant-disinfectant Arm 2: Flocculant-disinfectant + vessel Arm 3: bleach Arm 4: bleach + vessel	Household	Residual chlorine >0.1mg/L in unannounced visits: Arm 1: 27% Arm 2: 34% Arm 3: 36% Arm 4: 44%	All intervention arms included hygiene education component
Roberts 2001	Improved storage (bucket with spout and narrow opening to limit hand entry)	Household	While intervention householders received vessel, actual use was not reported	None
Semenza 1998	Household level chlorination	Household	73% based on residual chlorine levels at time of	Improved storage, hygiene education

Study	Water quality intervention	Water improved at source or through point-of-use (household)	Was compliance with intervention measured?	Other material components of intervention
			visit	
Torun 1982	Improved water treatment and distribution	Source	No	Hygiene education
URL 1995	Two water intervention arms: Arm 1: Household ceramic filters Arm 2: Household ceramic filters + hygiene education	Household	87%-93% use of filter by children	Second intervention arm included hygiene education
Xiao 1997	Improved water supply	Source	Community intervention; use not otherwise reported	Sanitation, hygiene education

3.5 Outcome Measures

The principal outcome of studies included in this review was diarrhoeal disease. However, just as variety characterizes other aspects of the studies included in this review, investigators did not follow a uniform methodology in defining, assessing and reporting on this outcome or the effect of the intervention thereon.

Eighteen of the 30 studies included in the review used the WHO definition of diarrhoea (i.e., 3 or more loose or fluid stools within a period of 24 hours) (Alam 1989; Aziz 1990; Clasen 2004; Clasen 2004a; Doocy 2004; du Preez 2004; Garrett 2004; Handzel 1998; Jensen 2003; Luby 2004a; Luby 2004b; Lule 2004; Mahfouz 1995; Quick 1999; Quick 2002; Roberts 2001; Semenza 1998; Reller 2003). Other studies used the mother's or other respondent's definition (Austin 1993; Chiller 2004; Crump 2004; Gasana 2002; Messou 1997; Reller 2003), watery diarrhoea as a component of gastroenteritis (Colford 2002), the local term (Conroy 1996; Conroy 1999), a "significant change in bowel habits towards decreased consistency or increased frequency" (Kirchhoff 1985). Two studies did not report the case definition used for diarrhoea (Torun 1982; Xiao 1997).

The method of diarrhoea surveillance and assessment also varied among studies. In most cases, participants were visited on a periodic basis, either weekly (Alam 1989; Aziz 1990; Chiller 2004; Crump 2004; Doocy 2004; Handzel 1998; Jensen 2003; Luby 2004a;

Luby 2004b; Lule 2004; Quick 1999; Quick 2002; Reller 2003), biweekly (Conroy 1996; Conroy 1999; Messou 1997; Torun 1982; Reller 2003) or more infrequently (Clasen 2004; Clasen 2004a; Gasana 2002; Kirchhoff 1985). They were then asked to recall and report on cases of diarrhoea during a previous period, usually 7 days (Alam 1989; Aziz 1990; Chiller 2004; Clasen 2004; Clasen 2004a; Crump 2004; Doocy 2004; Garrett 2004; Handzel 1998; Jensen 2003; Luby 2004a; Luby 2004b; Lule 2004; Quick 1999; Quick 2002; Reller 2003) to 14 days (Conroy 1996; Conroy 1999; Gasana 2002; Messou 1997; Torun 1982; Reller 2003). In other studies, logs or records were kept by each participant or by a designated householder indicating days with or without diarrhoea (Austin 1993; Colford 2002; du Preez 2004). In one study, diarrhoea data were procured from family records and disease registries (Mahfouz 1995), and in another it was assessed by paediatricians during regular medical checkups (Gasana 2002). In one study, the method was not reported (Xiao 1997).

Using these data, investigators reported diarrhoeal disease using one or more of the following epidemiological measures of disease frequency: incidence (Alam 1989; Aziz 1990; Colford 2002; du Preez 2004; Garrett 2004; Gasana 2002; Handzel 1998; Jensen 2003; Luby 2004a; Luby 2004b; Lule 2004; Mahfouz 1995; Quick 1999; Quick 2002; Reller 2003; Roberts 2001; Semenza 1998; Reller 2003; Xiao 1997), period prevalence (Clasen 2004; Clasen 2004a; Conroy 1996; Conroy 1999; Crump 2004; Messou 1997) and longitudinal prevalence (i.e., days of diarrhoea/days under observation) (Austin 1993, Chiller 2004, Crump 2004; Doocy 2004; Kirchhoff 1985; Luby 2004b). Studies also reported other measures of disease, including incidence of persistent diarrhoea (Chiller 2004), gastrointestinal illness, including specific symptoms thereof (Colford 2002), incidence or prevalence of bloody diarrhoea (Doocy 2004; du Preez 2004) and days of work or school lost due to diarrhoea (Lule 2004).

The different means of assessing and reporting diarrhoea led to different measures of effect for the interventions. These included risk ratios (Alam 1989; Aziz 1990; Gasana 2002;Garrett 2004; Jensen 2003; Mahfouz 1995; Roberts 2001; Semenza 1998; Reller 2003; Xiao 1997), rate ratios (Handzel 1998; Luby 2004a; Lule 2004; Colford 2002; du Preez 2004), longitudinal prevalence ratios (Austin 1993; Chiller 2004; Crump 2004; Doocy 2004; Kirchhoff 1985; Luby 2004b; Messou 1997), odds ratios (Clasen 2004; Clasen 2004a; Conroy 1996; Conroy 1999, Quick 2002; Reller 2003), and a ratio of means (Quick 1999).

As noted above, 1 study (Torun 1982) did not include sufficient information on diarrhoea to estimate the measure of effect of the intervention.

Of the studies with adequate information to analyse, 10 presented results both for children under 5 years of age (or a subgroup thereof) and for all ages or older age groups (Chiller 2004; Clasen 2004; Clasen 2004a; Crump 2004; Doocy 2004; Kirchhoff 1985; Quick 1999; Reller 2003; Roberts 2001; Semenza 1998). Nine studies presented results only for all ages or older age groups (Aziz 1990; Colford 2002; Conroy 1996; Conroy 1999; Luby 2004a; Luby 2004b; Lule 2004; Quick 2002; Xiao 1997), and 10 presented results only for children under 5 years of age (or a subgroup thereof) (Alam 1989; Austin 1993; du Preez 2004; Garrett 2004; Gasana 2002; Handzel 1998; Jensen 2003; Mahfouz 1995; Messou 1997; Reller 2003).

In presenting results, most studies adjusted raw data to account for possible covariates, including age (Clasen 2004; Clasen 2004a; Conroy 1996; Conroy 1999; Handzel 1998; Luby 2004a; Lule 2004; Reller 2003), seasonality (Aziz 1990; Jensen 2003; Messou 1997; Reller 2003), sex (Conroy 1996; Conroy 1999; Reller 2003), sanitation or hygiene practices (Alam 1989; Jensen 2003; Lule 2004), area of residence (Conroy 1996; Conroy 1999) household income or proxies thereof (Handzel 1998; Reller 2003), education (Alam 1989), age and occupation of the head of household (Alam 1989; Handzel 1998), maternal literacy (Reller 2003), number of subjects in the household (Semenza 1998) or absent therefrom (Aziz 1990), or other variables associated with the household environment and subject behaviour (Roberts 2001). Most trials of interventions at the household level also used statistical methods to adjust their results for clustering within the household (Chiller 2004; Clasen 2004; Clasen 2004a; Colford 2002; Conroy 1996; Conroy 1999; Crump 2004; du Preez 2004; Garrett 2004; Handzel 1998; Luby 2004a; Luby 2004b; Lule 2004; Quick 1999; Quick 2002; Reller 2003; Roberts 2001; Semenza 1998) or for repeated episodes of diarrhoea by the same subject (Clasen 2004; Clasen 2004a; Lule 2004; Quick 1999; Quick 2002).

Two studies reported on mortality associated with diarrhoea (Crump 2004; Messou 1997). In accordance with the protocol for this review, these results are reported in the results section below, but only morbidity results are included in the comparisons. None of the other studies reported adverse outcomes associated with the intervention.

Table 3.5a: measure of effect, all age

Study	Outcome measure	Adjusted for clustering	Adjusted for covariates	Measure of effect
Alam 1989	rate ratio	no	no	0.83 (0.71 to 0.97
Austin 1992 (25-60 mos) (arm 1)	longitudinal prevalence ratio	no	no	0.95 (0.23 to 3.93)
Austin 1992 (6-24 mos.) (arm 2)	longitudinal prevalence ratio	no	no	1.01 (0.19 to 5.39)
Aziz 1990	rate ratio	no	no	0.75 (0.70 to 0.80)
Chiller 2004	longitudinal prevalence ratio	no	no	0.62 (0.40 to 0.82)
Clasen 2004	Odds ratio	yes	no	0.30 (0.20 to 0.47)
Clasen 2004a	Odds ratio	yes	yes	0.47 (0.24 to 0.92)
Colford 2002	rate ratio	yes	no	0.54 (0.28 to 1.06)
Conroy 1996	Odds ratio	no	no	0.66 (0.50 to 0.87)
Conroy 1999	Odds ratio	no	no	0.69 (0.63 to 0.75)
Crump 2004 (bleach) (arm 1)	longitudinal prevalence ratio	no	no	0.77 (0.62 to .95)
Crump 2004 (floc/disinfect) (arm 2)	longitudinal prevalence ratio	no	no	0.83 (0.67 to 1.03)
Doocy 2004	longitudinal prevalence ratio	no	no	0.12 (0.11 to 0.13)
du Preez 2004	rate ratio	yes	no	0.21 (0.07 to 0.61)
Garrett 2004	risk ratio	no	no	0.44 (0.28 to 0.69)
Gasana 2002	rate ratio	no	no	1.00 (0.90 to 1.12)
Handzel 1998	rate ratio	no	no	0.67 (0.53 to 0.83)
Jensen 2003	rate ratio	no	no	0.94 (0.73 to 1.21)
Kirchhoff 1985	longitudinal prevalence ratio	no	no	1.07 (0.88 to 1.30)
Luby 2004a (insul. vessel) (arm 1)	rate ratio	yes	yes	0.60 (0.37 to 0.84)
Luby 2004a (reg. vessel) (arm 2)	rate ratio	yes	yes	0.30 (0.16 to 0.52)
Luby 2004b (bleach + vessel) (arm 1)	longitudinal prevalence ratio	no	no	0.45 (0.20 to 0.83)
Luby 2004b (floc/disinfect + soap) (arm 2)	longitudinal prevalence ratio	no	no	0.45 (0.20 to 0.82)
Luby 2004b (floc/disinfect + vessel) (arm 3)	longitudinal prevalence ratio	no	no	0.36 (0.10 to 0.71)
Lule 2004	rate ratio	no	no	0.80 (0.64 to 1.00)
Mahfouz 1995	risk ratio	no	no	0.55 (0.30 to 1.00)
Messou 1997	Period prevalence ratio	no	no	0.56 (0.29 to 0.84)
Quick 1999	Ratio of means	yes	no	0.57 (0.39 to 0.84)
Quick 2002	Odds ratio	yes	no	0.52 (0.30 to 0.90)
Reller 2003 (floc/disinfect) (arm 1)	Odds ratio	yes	yes	0.79 (0.62 to 0.99)
Reller 2004 (bleach + vessel) (arm 3)	Odds ratio	yes	yes	0.97 (0.76 to 1.26)
Reller 2004 (bleach) (arm 2)	Odds ratio	yes	yes	0.74 (0.59 to 0.92)
Reller 2004 (floc/disinfect + vessel) (arm 4)	Odds ratio	yes	yes	0.74 (0.58 to 0.94)
Roberts 2001	risk ratio	no	no	0.79 (0.62 to 1.03)
Semenza 1998	rate ratio	yes	no	0.15 (0.07 to 0.31)
URL 1995 (filter +	risk ratio	no	no	0.35 (0.13 to 0.92)

Study	Outcome measure	Adjusted for clustering	Adjusted for covariates	Measure of effect
education) (arm 2)				
URL 1995 (filter) (arm 1)	risk ratio	no	no	0.47 (0.20 to 1.13)
Xiao 1997	risk ratio	no	no	0.45 (0.43 to 0.47)

Table 3.5b: Measure of effect, under 5s

Study	Outcome measure	Adj. for clustering	Adj. for covariates	RR
Alam 1989	rate ratio	no	No	0.83 (0.71 to 0.97)
Gasana 2002	rate ratio	no	No	1.00 (0.90 to 1.12)
Jensen 2003	rate ratio	no	No	0.94 (0.73 to 1.21)
Messou 1997	Period prevalence ratio	no	No	0.63 (0.50 to 0.81)
Austin 1992 (25-60 mos) (arm 1)	longitudinal prevalence ratio	no	No	0.95 (0.23 to 3.93)
Austin 1992 (6-24 mos.) (arm 2)	longitudinal prevalence ratio	no	No	1.01 (0.19 to 5.39)
Garrett 2004	risk ratio	no	No	0.44 (0.28 to 0.69)
Handzel 1998	rate ratio	no	No	0.78 (0.73 to 0.83)
Kirchhoff 1985	longitudinal prevalence ratio	no	No	0.97 (0.78 to 1.12)
Mahfouz 1995	risk ratio	no	No	0.55 (0.30 to 1.00)
Quick 1999	longitudinal prevalence ratio	no	No	0.75 (0.66 to 0.86)
Reller 2004 (bleach + vessel) (arm 3	Odds ratio	yes	Yes	0.92 (0.66 to 1.30)
Reller 2004 (bleach) (arm 2)	Odds ratio	yes	Yes	0.77 (0.56 to 2.08)
Semenza 1998	rate ratio	yes	No	0.33 (0.19 to 0.57)
Clasen 2004	prevalence odds ratio	yes	No	0.17 (0.06 to 0.49)
Clasen 2004a	prevalence odds ratio	yes	Yes	0.50 (0.27 to 0.94)
du Preez 2004	rate ratio	yes	No	0.21 (0.07 to 0.61)
URL 1995 (filter + education)	risk ratio	no	No	0.35 (0.13 to 0.92)
URL 1995 (filter)	risk ratio	no	No	0.47 (0.20 to 1.13)
Doocy 2004	longitudinal prevalence ratio	no	No	0.08 (0.07 to 0.09)
Reller 2003 (floc/disinfect) (arm 1)	Odds ratio	yes	Yes	1.05 (0.78 to 1.41)
Reller 2004 (floc/disinfect + vessel) (arm 4)	Odds ratio	yes	Yes	0.69 (0.50 to 0.95)
Roberts 2001	risk ratio	no	No	0.69 (0.45 to 1.01)
Luby 2004b (floc/disinfect + soap) (arm 3)	longitudinal prevalence ratio	no	No	0.62 (0.45 to 0.85)
Luby 2004b (floc/disinfect + vessel) (arm 2)	longitudinal prevalence ratio	no	No	0.60 (0.40 to 0.85)
Luby 2004a (bleach + vessel) (arm 1)	longitudinal prevalence ratio	no	No	0.80 (0.52 to 1.14)
Crump 2004 (bleach) (arm 1)	longitudinal prevalence ratio	no	No	0.83 (0.63 to 1.04)
Crump 2004 (floc/disinfect) (arm 2)	longitudinal prevalence ratio	no	No	0.75 (0.60 to 0.95)
Chiller 2004	longitudinal prevalence ratio	no	No	0.63 (0.44 to 0.82)

3.6 Methodological Quality of Studies

3.6.1 Note Regarding Comparisons of RCTs and Quasi-RCTs

The methods of this review established separate and customary criteria for assessing the methodological quality of the included studies. This is not intended to imply, however, that these criteria were equally rigorous. Thus, while these criteria may be used for purposes of comparing the methodological quality of the studies of the same design (RCT or quasi-RCT), we urge caution with respect to inter-design comparisons. An RCT that fails to meet certain quality criteria may nevertheless be of greater methodological rigour than a quasi-RCT that meets its applicable criteria.

3.6.2 Randomised Controlled Studies

Table 3.6.2 summarizes the methodological quality of the 19 RCTs included in this review based on the four criteria more fully described in Section 2.7 above. These include generation of allocation sequence, allocation concealment, blinding and loss to follow up. Twelve RCTs followed an "adequate" method for generation of allocation sequence, while 4 were "inadequate" and 3 were "unclear". Fifteen studies followed an "adequate" method of concealment, while 4 remained "inadequate" on this criterion.

Table 3.6.2: Assessment of methodological quality of randomized controlled trials[12]

Study	**Generation of allocation sequence**	**Allocation concealment**	**Blinding**	**Loss to follow up**
Austin 1992	Adequate	Adequate	Double blind	Inadequate (89.4%)
Chiller 2004	Adequate	Adequate	Open	Adequate
Clasen 2004	Adequate	Adequate	Open	Adequate
Clasen 2004a	Adequate	Adequate	Open	Adequate
Colford 2002	Adequate	Adequate	Double blind	Adequate
Conroy 1996	Inadequate	Inadequate	Single blind	Adequate
Conroy 1999	Inadequate	Inadequate	Single blind	Inadequate (<79%)
Crump 2004	Unclear	Adequate	Open	Inadequate (82%)
Doocy 2004	Adequate	Adequate	Open	Adequate
du Preez 2004	Adequate	Adequate	Open	Adequate

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[12] Based on Juni P, Altman DG, Egger M (2001). Systematic reviews in health care: assessing the quality of controlled trials. *BMJ* 323(7303): 42-6

Study	**Generation of allocation sequence**	**Allocation concealment**	**Blinding**	**Loss to follow up**
Handzel 1998	Unclear	Adequate	Open	Adequate
Kirchhoff 1985[13]	Inadequate	Inadequate	Double blind	Inadequate (approx. 80%)
Luby 2004a	Adequate	Adequate	Open	Adequate
Lule 2004	Unclear	Adequate	Open	Adequate
Quick 1999	Adequate	Adequate	Open	Adequate
Reller 2003	Adequate	Adequate	Open	Inadequate (approx. 88%)
Roberts 2001	Inadequate	Inadequate	Open	Inadequate (88.8%)
Semenza 1998	Adequate	Adequate	Open	Unclear
URL 1995	Adequate	Adequate	Open	Unclear

Only 3 of the 19 RCTs were blinded (Austin 1992; Colford 2002; Kirchhoff 1985); the balance followed an open design (i.e., both participant and assessor knew whether or not the participant received the intervention), though the two studies by Conroy (1996, 1999) might arguably be considered single blinded. Assessing the effectiveness of its blinding methodology was in fact one of the principal objectives of Colford, and that paper provides the most comprehensive analysis of the issues associated therewith. Colford used a sham water filter which even the installer could not know was not effective. Austin and Kirchhoff, who were assessing the effectiveness of home-based chlorination, provided placebos to control households. While one study suggests ethical and other reasons for its decision not to blind the trial (Clasen 2004), it is not clear why so few of the household-based interventions failed to placebo-control their studies.

In summary, 12 studies were "adequate" for both generation of allocation sequence and allocation concealment, and 8 of these were also "adequate" for loss to follow up; only Colford 2002 met all criteria for methodological quality for RCTs including blinding, though Austin over 25m failed only by falling 0.6% short of the “adequate” follow-up criterion over a period of 25 months.

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[13] Cross-over study.

3.6.3 Quasi-Randomised Controlled Studies

Table 3.6.3 summarizes the methodological quality of the 11 quasi-RCTs included in this review. These were assessed on the basis of comparability of characteristics between intervention and control groups and contemporaneousness of data collection. Eight of 11 quasi-RCTs were "adequate" for comparability of study groups, 2 were "inadequate", and 1 was "unclear". Except for Gasana 2002, which was "unclear", all quasi-RCTs met the contemporaneousness of data collection criterion.

In summary, 8 of 11 studies met both criteria for methodological quality of quasi-RCTs.

Table 3.6.3: Assessment of methodological quality of quasi-randomized controlled trials[14]

Study	Comparability of characteristics	Contemporaneousness of data collection
Alam 1989	Adequate	Adequate
Aziz 1992	Adequate	Adequate
Garrett 2004	Inadequate	Adequate
Gasana 2002	Unclear	Unclear
Jensen 2003	Inadequate	Adequate
Luby 2004	Adequate	Adequate
Mahfouz 1995	Adequate	Adequate
Messou 1997	Adequate	Adequate
Quick 2002	Adequate	Adequate
Torun 1982	Adequate	Adequate
Xiao 1997	Adequate	Adequate

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[14] Based on Juni P, Altman DG, Egger M (2001). Systematic reviews in health care: assessing the quality of controlled trials. *BMJ* 323(7303): 42-6

Chapter 4: Results and Discussion

4.1 Results

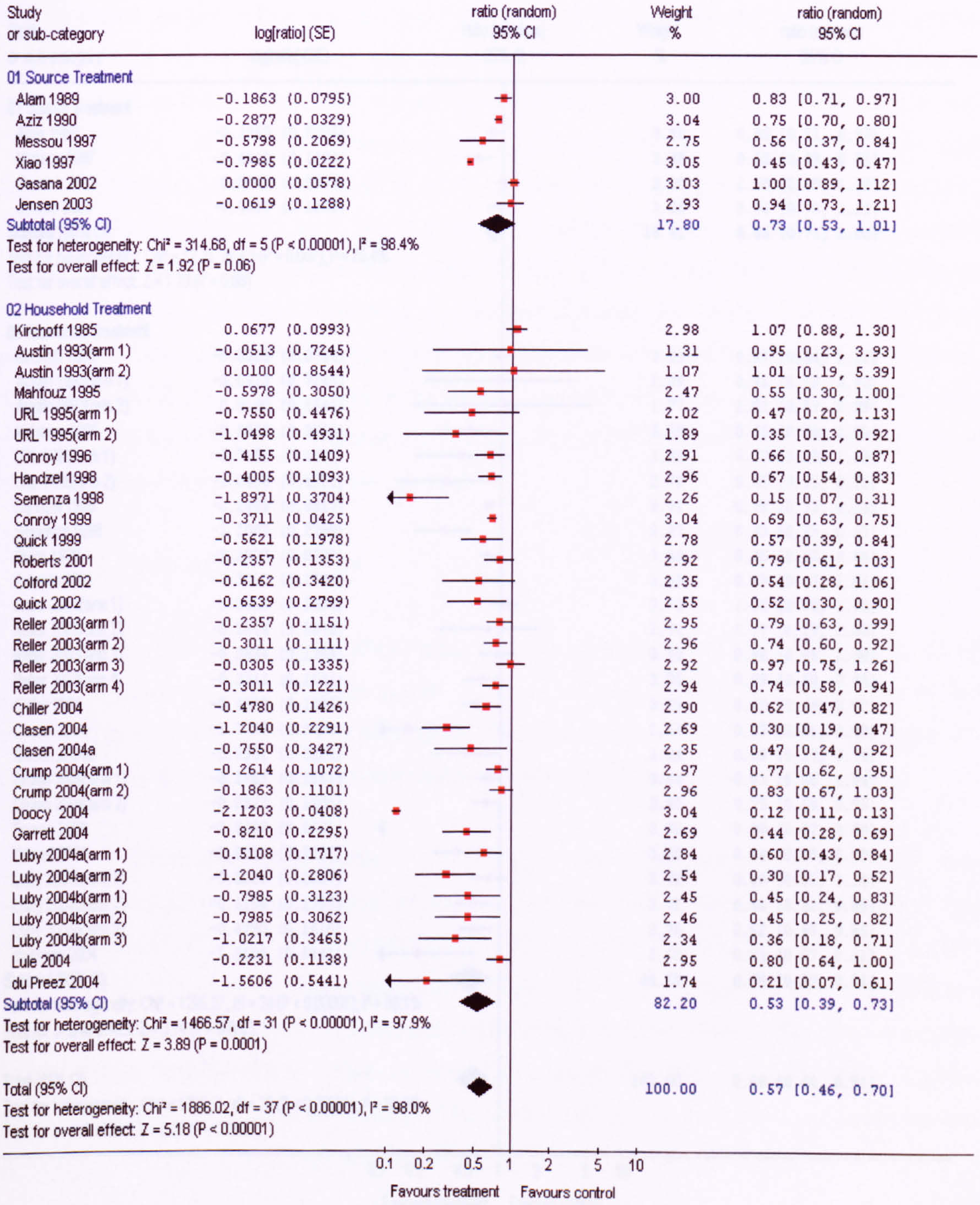
4.1.1 Overall Effectiveness

Figures 4.1.1a and 4.1.1b illustrates the effect of water quality interventions on diarrhoea morbidity for all included studies which provided sufficient information from which to extract or calculate a measure of effect. Figure 4.1.1a presents data for all ages if reported; otherwise, it uses the most inclusive age group reported. Of the 38 trials included in this comparison, none found the water quality intervention to be associated with a statistically significant increase in diarrhoea. The pooled measure of effect was 0.58 (95%CI: 0.46 to 0.72), though this was characterized by considerable heterogeneity (X^2 = 1939.14, p<0.00001, I^2 = 98.0%). Twelve trials found no statistically significant reduction in diarrhoea (Austin 1993; Austin 1993(arm 2); Colford 2002; Crump 2004(arm 2); Gasana 2002; Jensen 2003; Kirchhoff 1985; Lule 2004; Mahfouz 1995; Reller 2003(arm 3); Roberts 2001; Reller 2003), though four of these fell only fractionally short at the 95% confidence interval. While not included in this comparison because of inadequate data, the investigators in Torun 1982 also reported finding no statistical difference in diarrhoea morbidity between intervention and control villages. While the remaining 26 trials found a statistically significant protective effect from the intervention, even these were characterized by a wide range of effect (with risk ratios ranging from 0.12 to 0.83).

The overall effectiveness of water quality interventions on children under 5 years of age is shown in Figure 4.1.1b. While a pooled measure of effect from these studies (0.60, 95%CI: 0.44 to 0.81) was similar to that of the all age trials, it was also characterized by significant heterogeneity (X^2 = 1406.46, p<0.00001, I^2 = 98.0%). It is noteworthy, however, that as the Comparison illustrates, 13 of the 29 trials that presented results for such children found no statistically significant protective effect from the intervention.

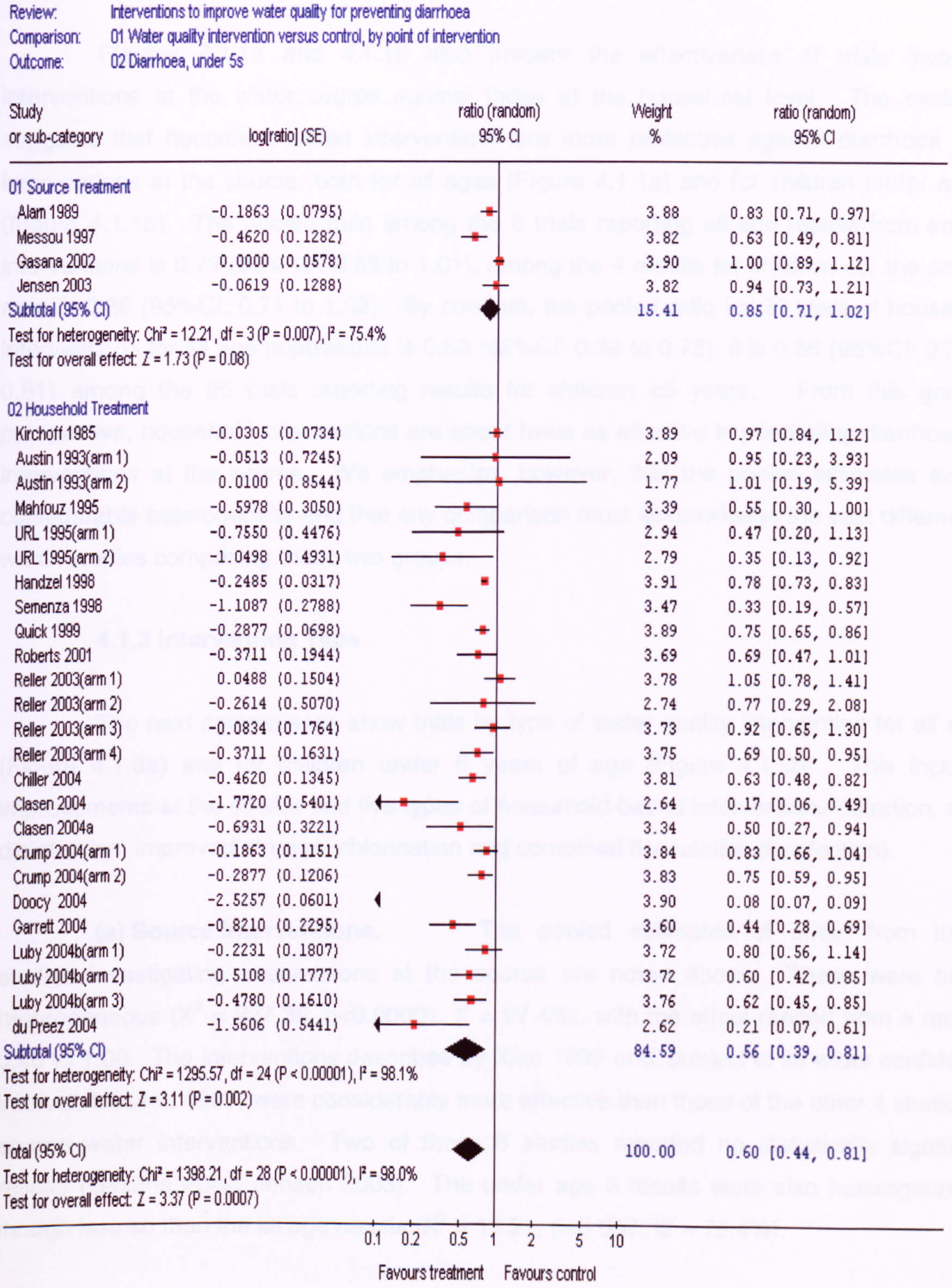
Figure 4.1.1a: Water quality intervention versus control, by point of intervention, all ages

Review: Interventions to improve water quality for preventing diarrhoea
Comparison: 01 Water quality intervention versus control, by point of intervention
Outcome: 01 Diarrhoea, all ages



Study or sub-category	log[ratio] (SE)	Weight %	ratio (random) 95% CI
01 Source Treatment			
Alam 1989	-0.1863 (0.0795)	3.00	0.83 [0.71, 0.97]
Aziz 1990	-0.2877 (0.0329)	3.04	0.75 [0.70, 0.80]
Messou 1997	-0.5798 (0.2069)	2.75	0.56 [0.37, 0.84]
Xiao 1997	-0.7985 (0.0222)	3.05	0.45 [0.43, 0.47]
Gasana 2002	0.0000 (0.0578)	3.03	1.00 [0.89, 1.12]
Jensen 2003	-0.0619 (0.1288)	2.93	0.94 [0.73, 1.21]
Subtotal (95% CI)		17.80	0.73 [0.53, 1.01]
Test for heterogeneity: Chi² = 314.68, df = 5 (P < 0.00001), I² = 98.4%			
Test for overall effect: Z = 1.92 (P = 0.06)			
02 Household Treatment			
Kirchoff 1985	0.0677 (0.0993)	2.98	1.07 [0.88, 1.30]
Austin 1993(arm 1)	-0.0513 (0.7245)	1.31	0.95 [0.23, 3.93]
Austin 1993(arm 2)	0.0100 (0.8544)	1.07	1.01 [0.19, 5.39]
Mahfouz 1995	-0.5978 (0.3050)	2.47	0.55 [0.30, 1.00]
URL 1995(arm 1)	-0.7550 (0.4476)	2.02	0.47 [0.20, 1.13]
URL 1995(arm 2)	-1.0498 (0.4931)	1.89	0.35 [0.13, 0.92]
Conroy 1996	-0.4155 (0.1409)	2.91	0.66 [0.50, 0.87]
Handzel 1998	-0.4005 (0.1093)	2.96	0.67 [0.54, 0.83]
Semenza 1998	-1.8971 (0.3704)	2.26	0.15 [0.07, 0.31]
Conroy 1999	-0.3711 (0.0425)	3.04	0.69 [0.63, 0.75]
Quick 1999	-0.5621 (0.1978)	2.78	0.57 [0.39, 0.84]
Roberts 2001	-0.2357 (0.1353)	2.92	0.79 [0.61, 1.03]
Colford 2002	-0.6162 (0.3420)	2.35	0.54 [0.28, 1.06]
Quick 2002	-0.6539 (0.2799)	2.55	0.52 [0.30, 0.90]
Reller 2003(arm 1)	-0.2357 (0.1151)	2.95	0.79 [0.63, 0.99]
Reller 2003(arm 2)	-0.3011 (0.1111)	2.96	0.74 [0.60, 0.92]
Reller 2003(arm 3)	-0.0305 (0.1335)	2.92	0.97 [0.75, 1.26]
Reller 2003(arm 4)	-0.3011 (0.1221)	2.94	0.74 [0.58, 0.94]
Chiller 2004	-0.4780 (0.1426)	2.90	0.62 [0.47, 0.82]
Clasen 2004	-1.2040 (0.2291)	2.69	0.30 [0.19, 0.47]
Clasen 2004a	-0.7550 (0.3427)	2.35	0.47 [0.24, 0.92]
Crump 2004(arm 1)	-0.2614 (0.1072)	2.97	0.77 [0.62, 0.95]
Crump 2004(arm 2)	-0.1863 (0.1101)	2.96	0.83 [0.67, 1.03]
Doocy 2004	-2.1203 (0.0408)	3.04	0.12 [0.11, 0.13]
Garrett 2004	-0.8210 (0.2295)	2.69	0.44 [0.28, 0.69]
Luby 2004a(arm 1)	-0.5108 (0.1717)	2.84	0.60 [0.43, 0.84]
Luby 2004a(arm 2)	-1.2040 (0.2806)	2.54	0.30 [0.17, 0.52]
Luby 2004b(arm 1)	-0.7985 (0.3123)	2.45	0.45 [0.24, 0.83]
Luby 2004b(arm 2)	-0.7985 (0.3062)	2.46	0.45 [0.25, 0.82]
Luby 2004b(arm 3)	-1.0217 (0.3465)	2.34	0.36 [0.18, 0.71]
Lule 2004	-0.2231 (0.1138)	2.95	0.80 [0.64, 1.00]
du Preez 2004	-1.5606 (0.5441)	1.74	0.21 [0.07, 0.61]
Subtotal (95% CI)		82.20	0.53 [0.39, 0.73]
Test for heterogeneity: Chi² = 1466.57, df = 31 (P < 0.00001), I² = 97.9%			
Test for overall effect: Z = 3.89 (P = 0.0001)			
Total (95% CI)		100.00	0.57 [0.46, 0.70]
Test for heterogeneity: Chi² = 1886.02, df = 37 (P < 0.00001), I² = 98.0%			
Test for overall effect: Z = 5.18 (P < 0.00001)			

Figure 4.1.1b: Water quality intervention versus control, by point of intervention, under 5s



Review: Interventions to improve water quality for preventing diarrhoea
Comparison: 01 Water quality intervention versus control, by point of intervention
Outcome: 02 Diarrhoea, under 5s

Study or sub-category	log[ratio] (SE)	ratio (random) 95% CI	Weight %	ratio (random) 95% CI
01 Source Treatment				
Alam 1989	-0.1863 (0.0795)		3.88	0.83 [0.71, 0.97]
Messou 1997	-0.4620 (0.1282)		3.82	0.63 [0.49, 0.81]
Gasana 2002	0.0000 (0.0578)		3.90	1.00 [0.89, 1.12]
Jensen 2003	-0.0619 (0.1288)		3.82	0.94 [0.73, 1.21]
Subtotal (95% CI)			15.41	0.85 [0.71, 1.02]
Test for heterogeneity: Chi² = 12.21, df = 3 (P = 0.007), I² = 75.4%				
Test for overall effect: Z = 1.73 (P = 0.08)				
02 Household Treatment				
Kirchoff 1985	-0.0305 (0.0734)		3.89	0.97 [0.84, 1.12]
Austin 1993(arm 1)	-0.0513 (0.7245)		2.09	0.95 [0.23, 3.93]
Austin 1993(arm 2)	0.0100 (0.8544)		1.77	1.01 [0.19, 5.39]
Mahfouz 1995	-0.5978 (0.3050)		3.39	0.55 [0.30, 1.00]
URL 1995(arm 1)	-0.7550 (0.4476)		2.94	0.47 [0.20, 1.13]
URL 1995(arm 2)	-1.0498 (0.4931)		2.79	0.35 [0.13, 0.92]
Handzel 1998	-0.2485 (0.0317)		3.91	0.78 [0.73, 0.83]
Semenza 1998	-1.1087 (0.2788)		3.47	0.33 [0.19, 0.57]
Quick 1999	-0.2877 (0.0698)		3.89	0.75 [0.65, 0.86]
Roberts 2001	-0.3711 (0.1944)		3.69	0.69 [0.47, 1.01]
Reller 2003(arm 1)	0.0488 (0.1504)		3.78	1.05 [0.78, 1.41]
Reller 2003(arm 2)	-0.2614 (0.5070)		2.74	0.77 [0.29, 2.08]
Reller 2003(arm 3)	-0.0834 (0.1764)		3.73	0.92 [0.65, 1.30]
Reller 2003(arm 4)	-0.3711 (0.1631)		3.75	0.69 [0.50, 0.95]
Chiller 2004	-0.4620 (0.1345)		3.81	0.63 [0.48, 0.82]
Clasen 2004	-1.7720 (0.5401)		2.64	0.17 [0.06, 0.49]
Clasen 2004a	-0.6931 (0.3221)		3.34	0.50 [0.27, 0.94]
Crump 2004(arm 1)	-0.1863 (0.1151)		3.84	0.83 [0.66, 1.04]
Crump 2004(arm 2)	-0.2877 (0.1206)		3.83	0.75 [0.59, 0.95]
Doocy 2004	-2.5257 (0.0601)		3.90	0.08 [0.07, 0.09]
Garrett 2004	-0.8210 (0.2295)		3.60	0.44 [0.28, 0.69]
Luby 2004b(arm 1)	-0.2231 (0.1807)		3.72	0.80 [0.56, 1.14]
Luby 2004b(arm 2)	-0.5108 (0.1777)		3.72	0.60 [0.42, 0.85]
Luby 2004b(arm 3)	-0.4780 (0.1610)		3.76	0.62 [0.45, 0.85]
du Preez 2004	-1.5606 (0.5441)		2.62	0.21 [0.07, 0.61]
Subtotal (95% CI)			84.59	0.56 [0.39, 0.81]
Test for heterogeneity: Chi² = 1295.57, df = 24 (P < 0.00001), I² = 98.1%				
Test for overall effect: Z = 3.11 (P = 0.002)				
Total (95% CI)			100.00	0.60 [0.44, 0.81]
Test for heterogeneity: Chi² = 1398.21, df = 28 (P < 0.00001), I² = 98.0%				
Test for overall effect: Z = 3.37 (P = 0.0007)				

4.1.2 Intervention Point

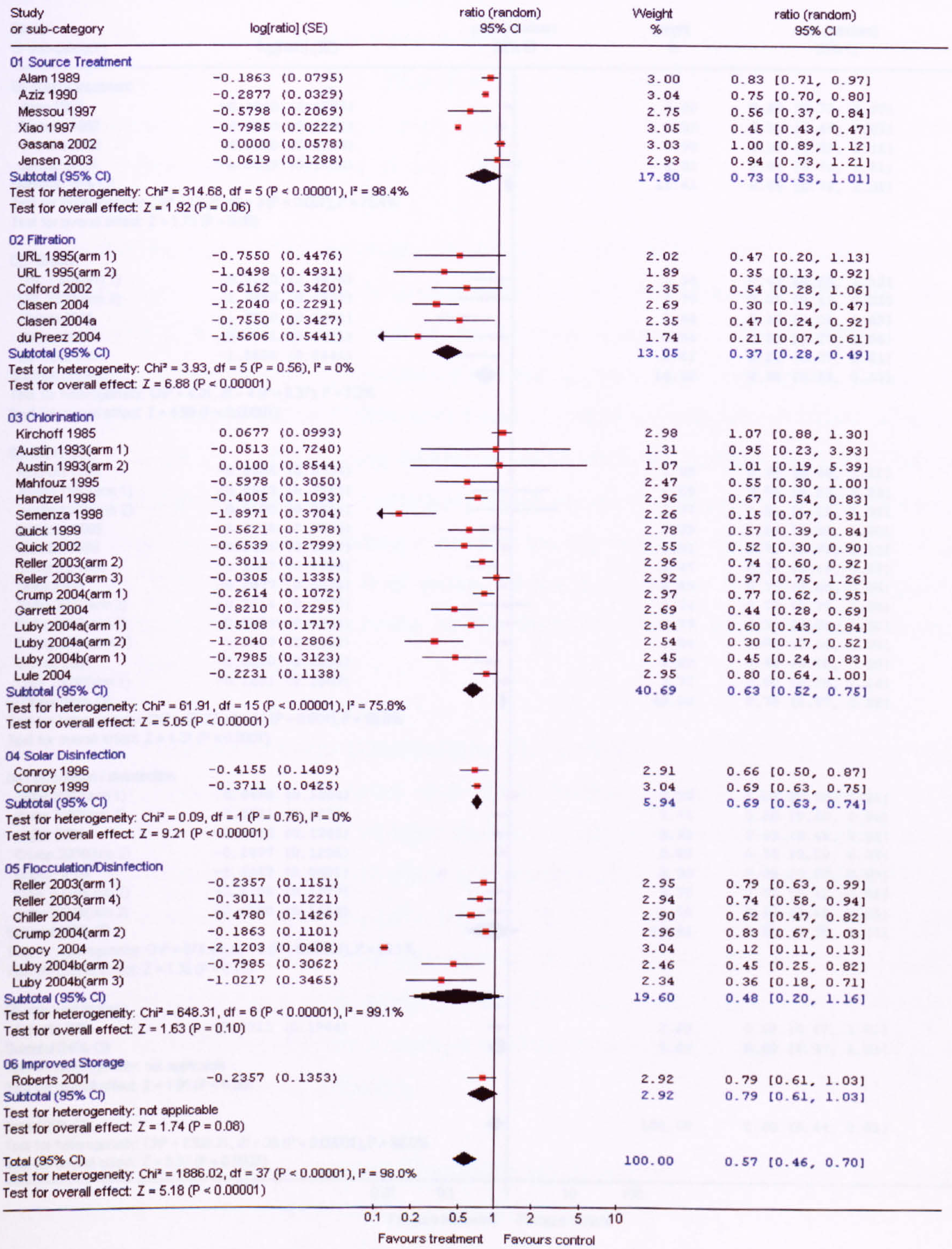
Figures 4.1.1a and 4.1.1b also present the effectiveness of trials involving interventions at the water source against those at the household level. The evidence suggests that household-based interventions are more protective against diarrhoea than interventions at the source, both for all ages (Figure 4.1.1a) and for children under age 5 (Figure 4.1.1b). The pooled ratio among the 6 trials reporting all age results from source interventions is 0.73 (95% CI: 0.53 to 1.01); among the 4 results for children <5, the pooled ratio is 0.85 (95%CI: 0.71 to 1.02). By contrast, the pooled ratio for 32 trials of household interventions for all age populations is 0.53 (95%CI: 0.39 to 0.73); it is 0.56 (95%CI: 0.39 to 0.81) among the 25 trials reporting results for children <5 years. From this general perspective, household interventions are about twice as effective in preventing diarrhoea as interventions at the source. We emphasize, however, that the pooled estimates exhibit considerable heterogeneity and that any comparison must acknowledge the vast differences within studies comprising these two groups.

4.1.3 Intervention Type

The next comparisons show trials by type of water quality intervention for all ages (Figure 4.1.3a) and for children under 5 years of age (Figure 4.1.3b). This includes improvements at the source and five types of household-based interventions (filtration, solar disinfection, improved storage, chlorination and combined flocculation/disinfection).

(a) Source Interventions. The pooled estimates of effect from the 6 studies investigating interventions at the source are noted above. These were highly heterogeneous ($X^2 = 227.39$, $p<0.00001$, $I^2 = 97.4\%$), with the effect ranged from a ratio of 0.45 to 1.00. The interventions described by Xiao 1997 and, subject to its wider confidence interval, Messou 1997, were considerably more effective than those of the other 4 studies of source water interventions. Two of these 6 studies reported no statistically significant results (Gasana 2002; Jensen 2003). The under age 5 results were also heterogeneous, though less so than the all age results ($X^2 = 12.21$, p=0.007, I2 = 75.4%).

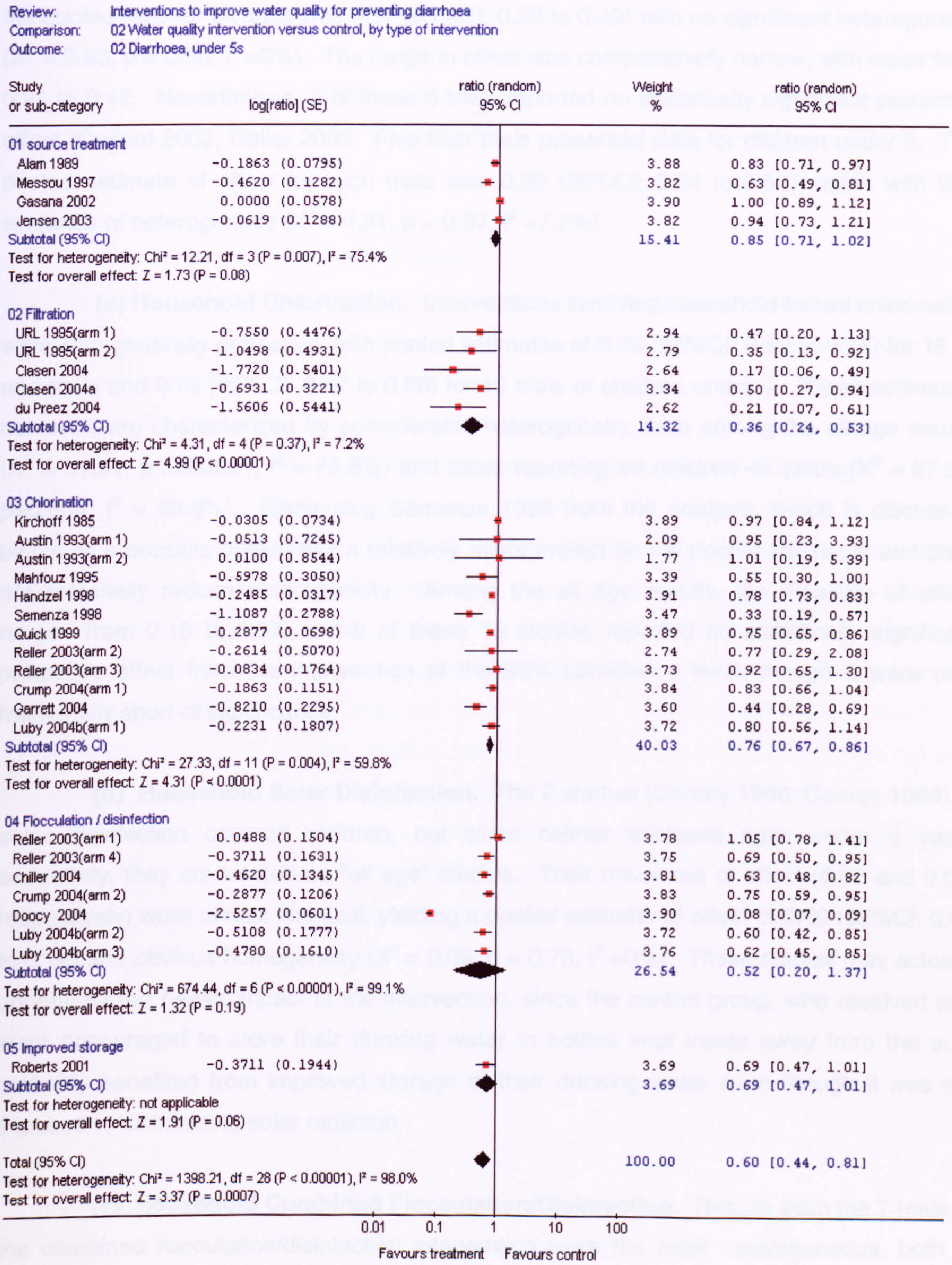
Figure 4.3.1a: Water quality intervention versus control, by type of intervention, all ages



Review: Interventions to improve water quality for preventing diarrhoea
Comparison: 02 Water quality intervention versus control, by type of intervention
Outcome: 01 Diarrhoea, all ages

Study or sub-category	log[ratio] (SE)	ratio (random) 95% CI	Weight %	ratio (random) 95% CI
01 Source Treatment				
Alam 1989	-0.1863 (0.0795)		3.00	0.83 [0.71, 0.97]
Aziz 1990	-0.2877 (0.0329)		3.04	0.75 [0.70, 0.80]
Messou 1997	-0.5798 (0.2069)		2.75	0.56 [0.37, 0.84]
Xiao 1997	-0.7985 (0.0222)		3.05	0.45 [0.43, 0.47]
Gasana 2002	0.0000 (0.0578)		3.03	1.00 [0.89, 1.12]
Jensen 2003	-0.0619 (0.1288)		2.93	0.94 [0.73, 1.21]
Subtotal (95% CI)			17.80	0.73 [0.53, 1.01]
Test for heterogeneity: Chi^2 = 314.68, df = 5 (P < 0.00001), I^2 = 98.4%				
Test for overall effect: Z = 1.92 (P = 0.06)				
02 Filtration				
URL 1995(arm 1)	-0.7550 (0.4476)		2.02	0.47 [0.20, 1.13]
URL 1995(arm 2)	-1.0498 (0.4931)		1.89	0.35 [0.13, 0.92]
Colford 2002	-0.6162 (0.3420)		2.35	0.54 [0.28, 1.06]
Clasen 2004	-1.2040 (0.2291)		2.69	0.30 [0.19, 0.47]
Clasen 2004a	-0.7550 (0.3427)		2.35	0.47 [0.24, 0.92]
du Preez 2004	-1.5606 (0.5441)		1.74	0.21 [0.07, 0.61]
Subtotal (95% CI)			13.05	0.37 [0.28, 0.49]
Test for heterogeneity: Chi^2 = 3.93, df = 5 (P = 0.56), I^2 = 0%				
Test for overall effect: Z = 6.88 (P < 0.00001)				
03 Chlorination				
Kirchoff 1985	0.0677 (0.0993)		2.98	1.07 [0.88, 1.30]
Austin 1993(arm 1)	-0.0513 (0.7240)		1.31	0.95 [0.23, 3.93]
Austin 1993(arm 2)	0.0100 (0.8544)		1.07	1.01 [0.19, 5.39]
Mahfouz 1995	-0.5978 (0.3050)		2.47	0.55 [0.30, 1.00]
Handzel 1998	-0.4005 (0.1093)		2.96	0.67 [0.54, 0.83]
Semenza 1998	-1.8971 (0.3704)		2.26	0.15 [0.07, 0.31]
Quick 1999	-0.5621 (0.1978)		2.78	0.57 [0.39, 0.84]
Quick 2002	-0.6539 (0.2799)		2.55	0.52 [0.30, 0.90]
Reller 2003(arm 2)	-0.3011 (0.1111)		2.96	0.74 [0.60, 0.92]
Reller 2003(arm 3)	-0.0305 (0.1335)		2.92	0.97 [0.75, 1.26]
Crump 2004(arm 1)	-0.2614 (0.1072)		2.97	0.77 [0.62, 0.95]
Garrett 2004	-0.8210 (0.2295)		2.69	0.44 [0.28, 0.69]
Luby 2004a(arm 1)	-0.5108 (0.1717)		2.84	0.60 [0.43, 0.84]
Luby 2004a(arm 2)	-1.2040 (0.2806)		2.54	0.30 [0.17, 0.52]
Luby 2004b(arm 1)	-0.7985 (0.3123)		2.45	0.45 [0.24, 0.83]
Lule 2004	-0.2231 (0.1138)		2.95	0.80 [0.64, 1.00]
Subtotal (95% CI)			40.69	0.63 [0.52, 0.75]
Test for heterogeneity: Chi^2 = 61.91, df = 15 (P < 0.00001), I^2 = 75.8%				
Test for overall effect: Z = 5.05 (P < 0.00001)				
04 Solar Disinfection				
Conroy 1996	-0.4155 (0.1409)		2.91	0.66 [0.50, 0.87]
Conroy 1999	-0.3711 (0.0425)		3.04	0.69 [0.63, 0.75]
Subtotal (95% CI)			5.94	0.69 [0.63, 0.74]
Test for heterogeneity: Chi^2 = 0.09, df = 1 (P = 0.76), I^2 = 0%				
Test for overall effect: Z = 9.21 (P < 0.00001)				
05 Flocculation/Disinfection				
Reller 2003(arm 1)	-0.2357 (0.1151)		2.95	0.79 [0.63, 0.99]
Reller 2003(arm 4)	-0.3011 (0.1221)		2.94	0.74 [0.58, 0.94]
Chiller 2004	-0.4780 (0.1426)		2.90	0.62 [0.47, 0.82]
Crump 2004(arm 2)	-0.1863 (0.1101)		2.96	0.83 [0.67, 1.03]
Doocy 2004	-2.1203 (0.0408)		3.04	0.12 [0.11, 0.13]
Luby 2004b(arm 2)	-0.7985 (0.3062)		2.46	0.45 [0.25, 0.82]
Luby 2004b(arm 3)	-1.0217 (0.3465)		2.34	0.36 [0.18, 0.71]
Subtotal (95% CI)			19.60	0.48 [0.20, 1.16]
Test for heterogeneity: Chi^2 = 648.31, df = 6 (P < 0.00001), I^2 = 99.1%				
Test for overall effect: Z = 1.63 (P = 0.10)				
06 Improved Storage				
Roberts 2001	-0.2357 (0.1353)		2.92	0.79 [0.61, 1.03]
Subtotal (95% CI)			2.92	0.79 [0.61, 1.03]
Test for heterogeneity: not applicable				
Test for overall effect: Z = 1.74 (P = 0.08)				
Total (95% CI)			100.00	0.57 [0.46, 0.70]
Test for heterogeneity: Chi^2 = 1886.02, df = 37 (P < 0.00001), I^2 = 98.0%				
Test for overall effect: Z = 5.18 (P < 0.00001)				

Figure 4.1.3b: Water quality intervention versus control, by type of intervention, under 5s



Review: Interventions to improve water quality for preventing diarrhoea
Comparison: 02 Water quality intervention versus control, by type of intervention
Outcome: 02 Diarrhoea, under 5s

Study or sub-category	log[ratio] (SE)	Weight %	ratio (random) 95% CI
01 source treatment			
Alam 1989	-0.1863 (0.0795)	3.88	0.83 [0.71, 0.97]
Messou 1997	-0.4620 (0.1282)	3.82	0.63 [0.49, 0.81]
Gasana 2002	0.0000 (0.0578)	3.90	1.00 [0.89, 1.12]
Jensen 2003	-0.0619 (0.1288)	3.82	0.94 [0.73, 1.21]
Subtotal (95% CI)		15.41	0.85 [0.71, 1.02]
Test for heterogeneity: Chi² = 12.21, df = 3 (P = 0.007), I² = 75.4%			
Test for overall effect: Z = 1.73 (P = 0.08)			
02 Filtration			
URL 1995(arm 1)	-0.7550 (0.4476)	2.94	0.47 [0.20, 1.13]
URL 1995(arm 2)	-1.0498 (0.4931)	2.79	0.35 [0.13, 0.92]
Clasen 2004	-1.7720 (0.5401)	2.64	0.17 [0.06, 0.49]
Clasen 2004a	-0.6931 (0.3221)	3.34	0.50 [0.27, 0.94]
du Preez 2004	-1.5606 (0.5441)	2.62	0.21 [0.07, 0.61]
Subtotal (95% CI)		14.32	0.36 [0.24, 0.53]
Test for heterogeneity: Chi² = 4.31, df = 4 (P = 0.37), I² = 7.2%			
Test for overall effect: Z = 4.99 (P < 0.00001)			
03 Chlorination			
Kirchoff 1985	-0.0305 (0.0734)	3.89	0.97 [0.84, 1.12]
Austin 1993(arm 1)	-0.0513 (0.7245)	2.09	0.95 [0.23, 3.93]
Austin 1993(arm 2)	0.0100 (0.8544)	1.77	1.01 [0.19, 5.39]
Mahfouz 1995	-0.5978 (0.3050)	3.39	0.55 [0.30, 1.00]
Handzel 1998	-0.2485 (0.0317)	3.91	0.78 [0.73, 0.83]
Semenza 1998	-1.1087 (0.2788)	3.47	0.33 [0.19, 0.57]
Quick 1999	-0.2877 (0.0698)	3.89	0.75 [0.65, 0.86]
Reller 2003(arm 2)	-0.2614 (0.5070)	2.74	0.77 [0.29, 2.08]
Reller 2003(arm 3)	-0.0834 (0.1764)	3.73	0.92 [0.65, 1.30]
Crump 2004(arm 1)	-0.1863 (0.1151)	3.84	0.83 [0.66, 1.04]
Garrett 2004	-0.8210 (0.2295)	3.60	0.44 [0.28, 0.69]
Luby 2004b(arm 1)	-0.2231 (0.1807)	3.72	0.80 [0.56, 1.14]
Subtotal (95% CI)		40.03	0.76 [0.67, 0.86]
Test for heterogeneity: Chi² = 27.33, df = 11 (P = 0.004), I² = 59.8%			
Test for overall effect: Z = 4.31 (P < 0.0001)			
04 Flocculation / disinfection			
Reller 2003(arm 1)	0.0488 (0.1504)	3.78	1.05 [0.78, 1.41]
Reller 2003(arm 4)	-0.3711 (0.1631)	3.75	0.69 [0.50, 0.95]
Chiller 2004	-0.4620 (0.1345)	3.81	0.63 [0.48, 0.82]
Crump 2004(arm 2)	-0.2877 (0.1206)	3.83	0.75 [0.59, 0.95]
Doocy 2004	-2.5257 (0.0601)	3.90	0.08 [0.07, 0.09]
Luby 2004b(arm 2)	-0.5108 (0.1777)	3.72	0.60 [0.42, 0.85]
Luby 2004b(arm 3)	-0.4780 (0.1610)	3.76	0.62 [0.45, 0.85]
Subtotal (95% CI)		26.54	0.52 [0.20, 1.37]
Test for heterogeneity: Chi² = 674.44, df = 6 (P < 0.00001), I² = 99.1%			
Test for overall effect: Z = 1.32 (P = 0.19)			
05 Improved storage			
Roberts 2001	-0.3711 (0.1944)	3.69	0.69 [0.47, 1.01]
Subtotal (95% CI)		3.69	0.69 [0.47, 1.01]
Test for heterogeneity: not applicable			
Test for overall effect: Z = 1.91 (P = 0.06)			
Total (95% CI)		100.00	0.60 [0.44, 0.81]
Test for heterogeneity: Chi² = 1398.21, df = 28 (P < 0.00001), I² = 98.0%			
Test for overall effect: Z = 3.37 (P = 0.0007)			

(b) Household Filtration. Among the 6 filtration trials presenting data for all ages, the pooled ratio for all ages was 0.37 (95%CI: 0.28 to 0.49) with no significant heterogeneity ($X^2 = 3.93$, $p = 0.56$, $I^2 = 0\%$). The range in effect was comparatively narrow, with ratios from 0.21 to 0.47. Nevertheless, 2 of these 6 trials reported no statistically significant protective effect (Colford 2002; Reller 2003. Five filter trials presented data for children under 5. The pooled estimate of effect for such trials was 0.36 (95%CI: 0.24 to 0.53), again with little evidence of heterogeneity ($X^2 = 4.31$, $p = 0.37$, $I^2 = 7.2\%$)

(c) Household Chlorination. Interventions involving household-based chlorination were also generally protective, with pooled estimates of 0.63 (95%CI: 0.52 to 0.75) for 16 all age trials and 0.76 (95%CI: 0.67 to 0.86) for 12 trials of children under 5. These estimates, however, are characterized by considerable heterogeneity, both among the all age results ($X^2 = 61.91$, $p<0.00001$, $I^2 = 75.8\%$) and those reporting on children <5 years ($X^2 = 27.33$, $p=0.004$, $I^2 = 59.8\%$). Eliminating Semenza 1998 from the analysis, which is discussed below as a possible outlier, has a relatively minor impact on the pooled estimates and does not materially reduce heterogeneity. Among the all age results, the measure of effect ranged from 0.15 to 1.07, and 6 of these 16 studies reported no statistically significant protective effect from the intervention at the 95% confidence level, though 2 were only fractionally short of significance.

(d) Household Solar Disinfection. The 2 studies (Conroy 1996; Conroy 1999) of solar disinfection covered children, but since neither analysed ages under 5 years separately, they are treated as "all age" studies. Their measures of effect (0.66 and 0.69, respectively) were almost identical, yielding a pooled estimate of effect of 0.69 (95%CI: 0.63 to 0.74) and obvious homogeneity ($X^2 = 0.09$, $p = 0.76$, $I^2 = 0\%$). These studies may actually understate the health impact of the intervention, since the control group, who received and were encouraged to store their drinking water in bottles kept inside away from the sun, probably benefited from improved storage of their drinking water even though it was not exposed to disinfecting solar radiation.

(e) Household Combined Flocculation/Disinfection. Results from the 7 trials of the combined flocculation/disinfection intervention were the most heterogeneous, both in their results for all ages ($X^2 = 700.10$, $p<0.00001$, $I^2 = 99.1\%$) and for children <5 ($X^2 =$

674.44, $p<0.00001$, $I^2 = 99.1\%$). In both cases, however, much of this heterogeneity appears to be attributable to the results reported by Doocy 2004, discussed below as a potential outlier. Excluding those results, the pooled ratio for all age populations is 0.69 (95%CI: 0.58 to 0.82) ($X^2 = 9.81$, $p=0.08$, $I^2 = 49.0\%$). Among children <5, the results are fairly homogenous if the Doocy study is excluded ($X^2 = 9.37$, $p=0.10$, $I^2 = 46.6\%$), and the pooled measure of effect shows the protection to be statistically significant (0.71, 95%CI: 0.61 to 0.84).

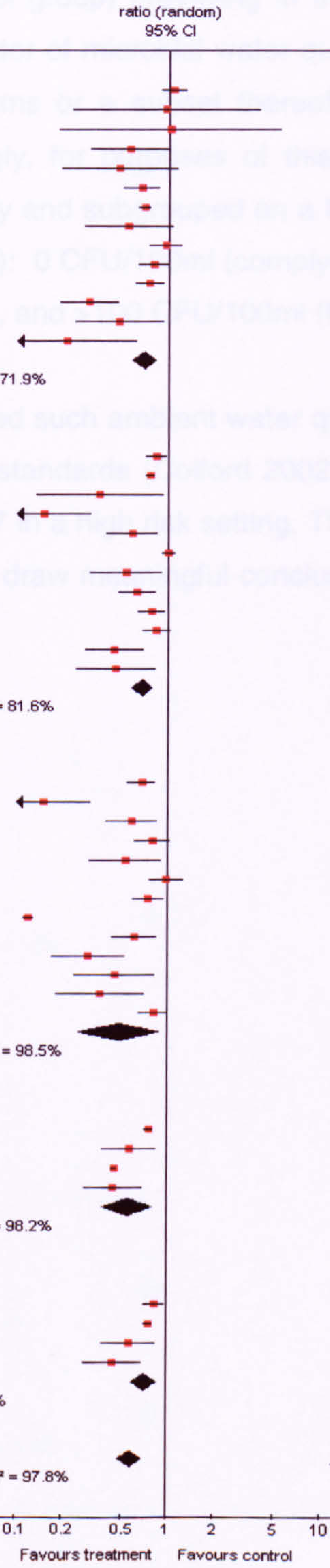
(f) Household Improved Storage. Only one study involved improved storage as the main intervention (Roberts 2001). It reported an apparently protective but not statistically significant effect for both all ages (RR 0.79, 95%CI: 0.62 to 1.03) and for children under 5 years (RR 0.69, 95%CI: 0.45 to 1.01).

4.1.4 Water Quality Only versus Compound Environmental Interventions

Figure 4.1.4 compares trials of interventions that involved improvements in water quality alone with those which combined water quality with one of the following interventions: hygiene promotion, separate vessel for water treatment and/or storage, improvements in sanitation (excreta disposal) or improvements in water supply (quantity or access). Pooled estimates of effect for each of these subgroups all exhibit significant heterogeneity ($p<0.0001$). While there is some suggestion that combining the water quality intervention with a vessel or sanitation may lead to greater effectiveness, the evidence is not compelling and much of the added benefit of vessels is attributable to Doocy (2004), a possible outlier. In general, there is no clear evidence that water quality interventions are more effective in preventing diarrhoea when combined with any of these additional interventions.

Figure 4.1.4: Water quality intervention versus control, simple and compound interventions, all ages

Review: Interventions to improve water quality for preventing diarrhoea
Comparison: 03 Water quality intervention versus control, simple and compound environmental interventions
Outcome: 01 Diarrhoea



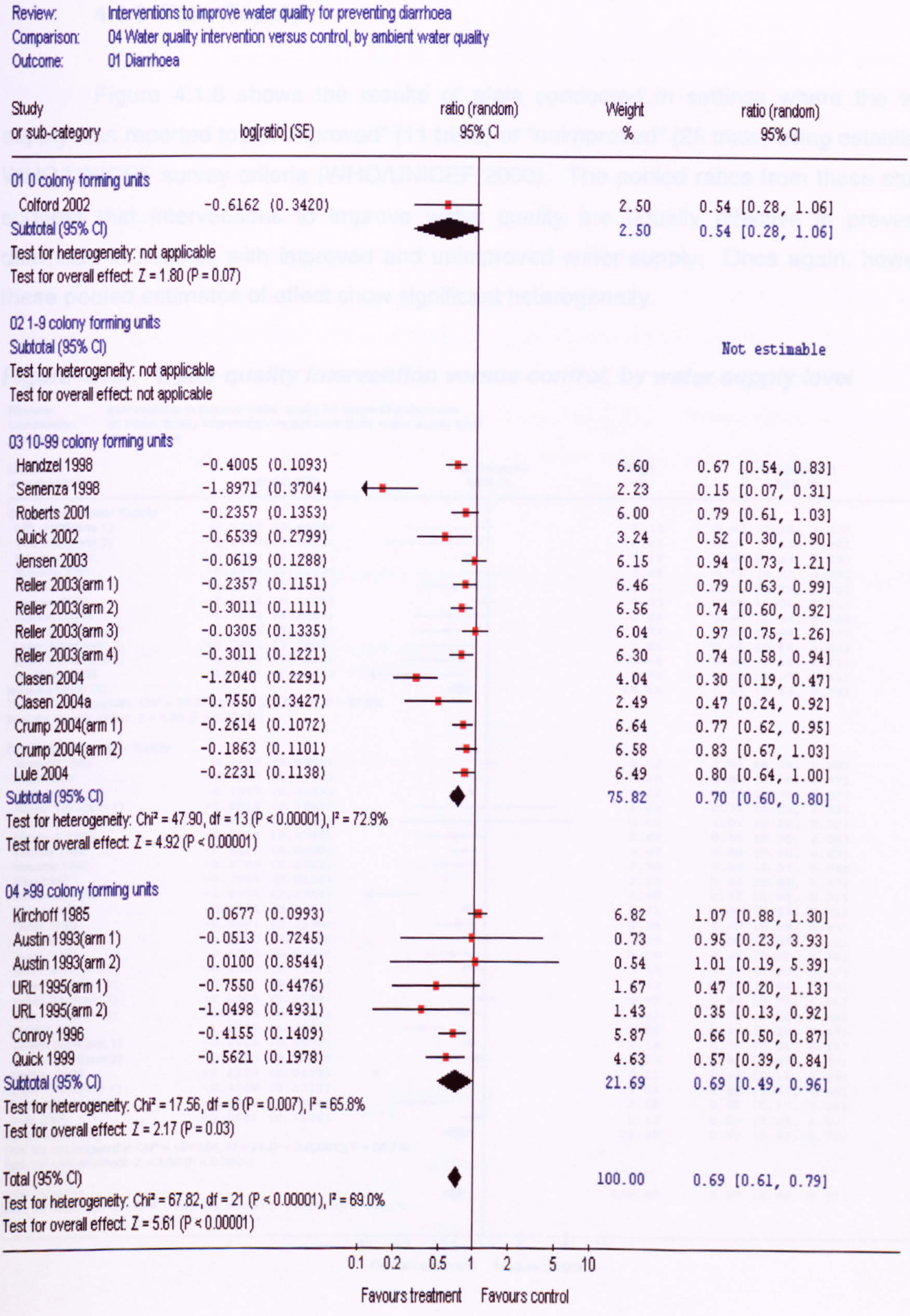
Study or sub-category	log[ratio] (SE)	Weight %	ratio (random) 95% CI
01 Water Quality Only			
Kirchoff 1985	0.0677 (0.0993)	2.44	1.07 [0.88, 1.30]
Austin 1993(arm 1)	-0.0513 (0.7245)	0.92	0.95 [0.23, 3.93]
Austin 1993(arm 2)	0.0100 (0.8544)	0.74	1.01 [0.19, 5.39]
Mahfouz 1995	-0.5978 (0.3050)	1.93	0.55 [0.30, 1.00]
URL 1995(arm 1)	-0.7550 (0.4476)	1.52	0.47 [0.20, 1.13]
Conroy 1996	-0.4155 (0.1409)	2.37	0.66 [0.50, 0.87]
Conroy 1999	-0.3711 (0.0425)	2.51	0.69 [0.63, 0.75]
Colford 2002	-0.6162 (0.3420)	1.82	0.54 [0.28, 1.06]
Jensen 2003	-0.0619 (0.1288)	2.39	0.94 [0.73, 1.21]
Reller 2003(arm 1)	-0.2357 (0.1151)	2.41	0.79 [0.63, 0.99]
Reller 2003(arm 2)	-0.3011 (0.1111)	2.42	0.74 [0.60, 0.92]
Clasen 2004	-1.2040 (0.2291)	2.15	0.30 [0.19, 0.47]
Clasen 2004a	-0.7550 (0.3427)	1.81	0.47 [0.24, 0.92]
du Preez 2004	-1.5606 (0.5441)	1.27	0.21 [0.07, 0.61]
Subtotal (95% CI)		26.69	0.67 [0.57, 0.80]
Test for heterogeneity: Chi² = 46.24, df = 13 (P < 0.0001), I² = 71.9%			
Test for overall effect: Z = 4.53 (P < 0.00001)			
02 Water Quality + Hygiene Promotion			
Alam 1989	-0.1863 (0.0795)	2.47	0.83 [0.71, 0.97]
Aziz 1990	-0.2877 (0.0329)	2.51	0.75 [0.70, 0.80]
URL 1995(arm 2)	-1.0498 (0.4931)	1.40	0.35 [0.13, 0.92]
Semenza 1998	-1.8971 (0.3704)	1.73	0.15 [0.07, 0.31]
Quick 1999	-0.5621 (0.1978)	2.23	0.57 [0.39, 0.84]
Gasana 2002	0.0000 (0.0578)	2.49	1.00 [0.89, 1.12]
Quick 2002	-0.6539 (0.2799)	2.00	0.52 [0.30, 0.90]
Chiller 2004	-0.4780 (0.1426)	2.36	0.62 [0.47, 0.82]
Crump 2004(arm 1)	-0.2614 (0.1072)	2.43	0.77 [0.62, 0.95]
Crump 2004(arm 2)	-0.1863 (0.1101)	2.42	0.83 [0.67, 1.03]
Garrett 2004	-0.8210 (0.2295)	2.15	0.44 [0.28, 0.69]
Luby 2004b(arm 2)	-0.7985 (0.3062)	1.92	0.45 [0.25, 0.82]
Subtotal (95% CI)		26.12	0.66 [0.57, 0.77]
Test for heterogeneity: Chi² = 59.94, df = 11 (P < 0.00001), I² = 81.6%			
Test for overall effect: Z = 5.18 (P < 0.00001)			
03 Water Quality + Vessel			
Handzel 1998	-0.4005 (0.1093)	2.42	0.67 [0.54, 0.83]
Semenza 1998	-1.8971 (0.3704)	1.73	0.15 [0.07, 0.31]
Quick 1999	-0.5621 (0.1978)	2.23	0.57 [0.39, 0.84]
Roberts 2001	-0.2357 (0.1353)	2.38	0.79 [0.61, 1.03]
Quick 2002	-0.6539 (0.2799)	2.00	0.52 [0.30, 0.90]
Reller 2003(arm 3)	-0.0305 (0.1335)	2.38	0.97 [0.75, 1.26]
Reller 2003(arm 4)	-0.3011 (0.1221)	2.40	0.74 [0.58, 0.94]
Doocy 2004	-2.1203 (0.0408)	2.51	0.12 [0.11, 0.13]
Luby 2004a(arm 1)	-0.5108 (0.1717)	2.30	0.60 [0.43, 0.84]
Luby 2004a(arm 2)	-1.2040 (0.2806)	2.00	0.30 [0.17, 0.52]
Luby 2004b(arm 1)	-0.7985 (0.3123)	1.91	0.45 [0.24, 0.83]
Luby 2004b(arm 3)	-1.0217 (0.3465)	1.80	0.36 [0.18, 0.71]
Lule 2004	-0.2231 (0.1138)	2.42	0.80 [0.64, 1.00]
Subtotal (95% CI)		28.48	0.47 [0.26, 0.86]
Test for heterogeneity: Chi² = 820.99, df = 12 (P < 0.00001), I² = 98.5%			
Test for overall effect: Z = 2.45 (P = 0.01)			
04 Water Quality + Sanitation			
Aziz 1990	-0.2877 (0.0329)	2.51	0.75 [0.70, 0.80]
Messou 1997	-0.5798 (0.2069)	2.21	0.56 [0.37, 0.84]
Xiao 1997	-0.7985 (0.0222)	2.52	0.45 [0.43, 0.47]
Garrett 2004	-0.8210 (0.2295)	2.15	0.44 [0.28, 0.69]
Subtotal (95% CI)		9.38	0.54 [0.38, 0.79]
Test for heterogeneity: Chi² = 166.35, df = 3 (P < 0.00001), I² = 98.2%			
Test for overall effect: Z = 3.22 (P = 0.001)			
05 Water Quality + Improved Water Supply			
Alam 1989	-0.1863 (0.0795)	2.47	0.83 [0.71, 0.97]
Aziz 1990	-0.2877 (0.0329)	2.51	0.75 [0.70, 0.80]
Messou 1997	-0.5798 (0.2069)	2.21	0.56 [0.37, 0.84]
Garrett 2004	-0.8210 (0.2295)	2.15	0.44 [0.28, 0.69]
Subtotal (95% CI)		9.33	0.70 [0.59, 0.84]
Test for heterogeneity: Chi² = 9.02, df = 3 (P = 0.03), I² = 66.7%			
Test for overall effect: Z = 3.96 (P < 0.0001)			
Total (95% CI)		100.00	0.56 [0.47, 0.67]
Test for heterogeneity: Chi² = 2119.14, df = 46 (P < 0.00001), I² = 97.8%			
Test for overall effect: Z = 6.60 (P < 0.00001)			

4.1.5 Ambient Water Quality

Figure 4.1.5 shows trials by ambient microbial water quality (measured pre-intervention or among the control group) prevailing in the study setting. As noted in the Description of Studies, the indicator of microbial water quality varied among the studies but did consistently comprise coliforms or a subset thereof (thermotolerant coliforms, faecal coliforms or *E. coli*). Accordingly, for purposes of this comparison only, each of these indicators is treated homologously and subgrouped on a log scale which corresponds to the WHO risk categories (WHO 1993): 0 CFU/100ml (complying); 1-9 CFU/100ml (low risk), 10-99 CFU/100ml (intermediate risk), and >100 CFU/100ml (high or very high risk).

Twenty-one trials reported such ambient water quality. Only one was conducted in water complying with applicable standards (Colford 2002); none in a low-risk setting; 14 in an intermediate risk setting; and 7 in a high risk setting. Thus, the number of studies in each sub-group is so far too limited to draw meaningful conclusions about the possible impact of ambient water quality.

Figure 4.1.5 Water quality intervention versus control, by ambient water quality



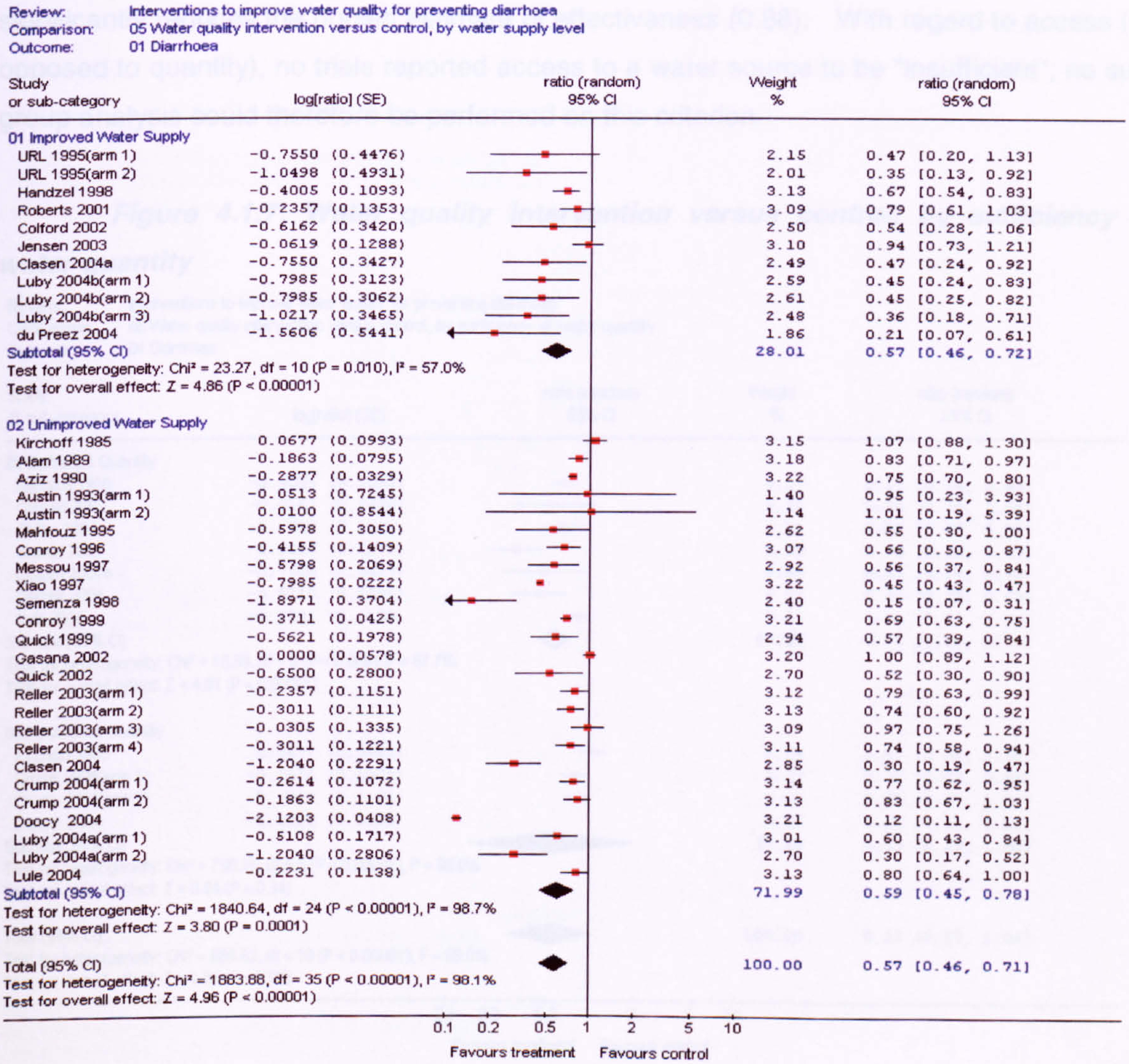
Review: Interventions to improve water quality for preventing diarrhoea
Comparison: 04 Water quality intervention versus control, by ambient water quality
Outcome: 01 Diarrhoea

Study or sub-category	log[ratio] (SE)	Weight %	ratio (random) 95% CI
01 0 colony forming units			
Colford 2002	-0.6162 (0.3420)	2.50	0.54 [0.28, 1.06]
Subtotal (95% CI)		2.50	0.54 [0.28, 1.06]
Test for heterogeneity: not applicable			
Test for overall effect: Z = 1.80 (P = 0.07)			
02 1-9 colony forming units			
Subtotal (95% CI)			Not estimable
Test for heterogeneity: not applicable			
Test for overall effect: not applicable			
03 10-99 colony forming units			
Handzel 1998	-0.4005 (0.1093)	6.60	0.67 [0.54, 0.83]
Semenza 1998	-1.8971 (0.3704)	2.23	0.15 [0.07, 0.31]
Roberts 2001	-0.2357 (0.1353)	6.00	0.79 [0.61, 1.03]
Quick 2002	-0.6539 (0.2799)	3.24	0.52 [0.30, 0.90]
Jensen 2003	-0.0619 (0.1288)	6.15	0.94 [0.73, 1.21]
Reller 2003(arm 1)	-0.2357 (0.1151)	6.46	0.79 [0.63, 0.99]
Reller 2003(arm 2)	-0.3011 (0.1111)	6.56	0.74 [0.60, 0.92]
Reller 2003(arm 3)	-0.0305 (0.1335)	6.04	0.97 [0.75, 1.26]
Reller 2003(arm 4)	-0.3011 (0.1221)	6.30	0.74 [0.58, 0.94]
Clasen 2004	-1.2040 (0.2291)	4.04	0.30 [0.19, 0.47]
Clasen 2004a	-0.7550 (0.3427)	2.49	0.47 [0.24, 0.92]
Crump 2004(arm 1)	-0.2614 (0.1072)	6.64	0.77 [0.62, 0.95]
Crump 2004(arm 2)	-0.1863 (0.1101)	6.58	0.83 [0.67, 1.03]
Lule 2004	-0.2231 (0.1138)	6.49	0.80 [0.64, 1.00]
Subtotal (95% CI)		75.82	0.70 [0.60, 0.80]
Test for heterogeneity: Chi² = 47.90, df = 13 (P < 0.00001), I² = 72.9%			
Test for overall effect: Z = 4.92 (P < 0.00001)			
04 >99 colony forming units			
Kirchoff 1985	0.0677 (0.0993)	6.82	1.07 [0.88, 1.30]
Austin 1993(arm 1)	-0.0513 (0.7245)	0.73	0.95 [0.23, 3.93]
Austin 1993(arm 2)	0.0100 (0.8544)	0.54	1.01 [0.19, 5.39]
URL 1995(arm 1)	-0.7550 (0.4476)	1.67	0.47 [0.20, 1.13]
URL 1995(arm 2)	-1.0498 (0.4931)	1.43	0.35 [0.13, 0.92]
Conroy 1996	-0.4155 (0.1409)	5.87	0.66 [0.50, 0.87]
Quick 1999	-0.5621 (0.1978)	4.63	0.57 [0.39, 0.84]
Subtotal (95% CI)		21.69	0.69 [0.49, 0.96]
Test for heterogeneity: Chi² = 17.56, df = 6 (P = 0.007), I² = 65.8%			
Test for overall effect: Z = 2.17 (P = 0.03)			
Total (95% CI)		100.00	0.69 [0.61, 0.79]
Test for heterogeneity: Chi² = 67.82, df = 21 (P < 0.00001), I² = 69.0%			
Test for overall effect: Z = 5.61 (P < 0.00001)			

4.1.6 Water Supply

Figure 4.1.6 shows the results of trials conducted in settings where the water supply was reported to be "improved" (11 trials) or "unimproved" (25 trials) using established WHO/UNICEF survey criteria (WHO/UNICEF 2000). The pooled ratios from these studies suggest that interventions to improve water quality are equally effective in preventing diarrhoea in settings with improved and unimproved water supply. Once again, however, these pooled estimates of effect show significant heterogeneity.

Figure 4.1.6: Water quality intervention versus control, by water supply level



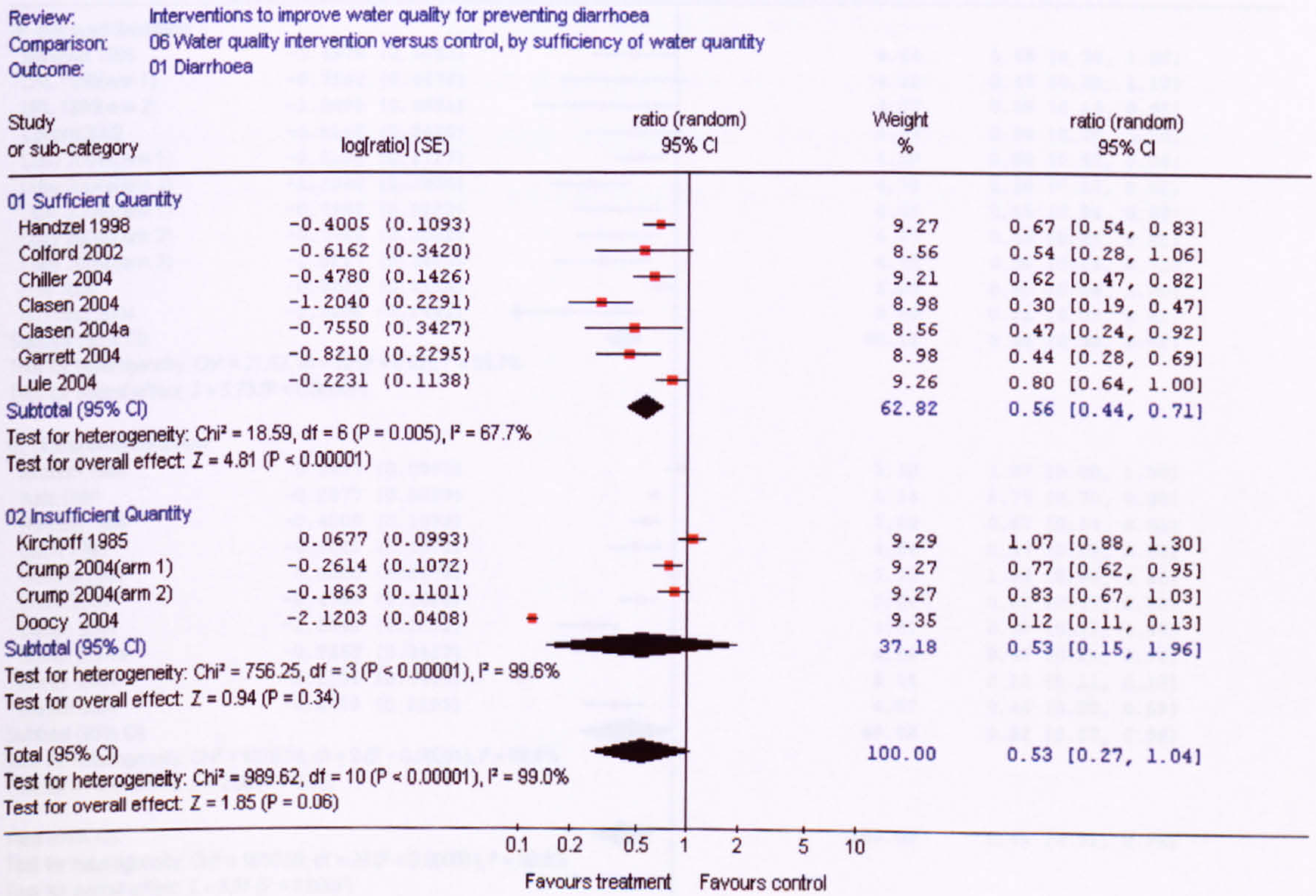
Review: Interventions to improve water quality for preventing diarrhoea
Comparison: 05 Water quality intervention versus control, by water supply level
Outcome: 01 Diarrhoea

Study or sub-category	log[ratio] (SE)	ratio (random) 95% CI	Weight %	ratio (random) 95% CI
01 Improved Water Supply				
URL 1995(arm 1)	-0.7550 (0.4476)		2.15	0.47 [0.20, 1.13]
URL 1995(arm 2)	-1.0498 (0.4931)		2.01	0.35 [0.13, 0.92]
Handzel 1998	-0.4005 (0.1093)		3.13	0.67 [0.54, 0.83]
Roberts 2001	-0.2357 (0.1353)		3.09	0.79 [0.61, 1.03]
Colford 2002	-0.6162 (0.3420)		2.50	0.54 [0.28, 1.06]
Jensen 2003	-0.0619 (0.1288)		3.10	0.94 [0.73, 1.21]
Clasen 2004a	-0.7550 (0.3427)		2.49	0.47 [0.24, 0.92]
Luby 2004b(arm 1)	-0.7985 (0.3123)		2.59	0.45 [0.24, 0.83]
Luby 2004b(arm 2)	-0.7985 (0.3062)		2.61	0.45 [0.25, 0.82]
Luby 2004b(arm 3)	-1.0217 (0.3465)		2.48	0.36 [0.18, 0.71]
du Preez 2004	-1.5606 (0.5441)		1.86	0.21 [0.07, 0.61]
Subtotal (95% CI)			28.01	0.57 [0.46, 0.72]
Test for heterogeneity: Chi² = 23.27, df = 10 (P = 0.010), I² = 57.0%				
Test for overall effect: Z = 4.86 (P < 0.00001)				
02 Unimproved Water Supply				
Kirchoff 1985	0.0677 (0.0993)		3.15	1.07 [0.88, 1.30]
Alam 1989	-0.1863 (0.0795)		3.18	0.83 [0.71, 0.97]
Aziz 1990	-0.2877 (0.0329)		3.22	0.75 [0.70, 0.80]
Austin 1993(arm 1)	-0.0513 (0.7245)		1.40	0.95 [0.23, 3.93]
Austin 1993(arm 2)	0.0100 (0.8544)		1.14	1.01 [0.19, 5.39]
Mahfouz 1995	-0.5978 (0.3050)		2.62	0.55 [0.30, 1.00]
Conroy 1996	-0.4155 (0.1409)		3.07	0.66 [0.50, 0.87]
Messou 1997	-0.5798 (0.2069)		2.92	0.56 [0.37, 0.84]
Xiao 1997	-0.7985 (0.0222)		3.22	0.45 [0.43, 0.47]
Semenza 1998	-1.8971 (0.3704)		2.40	0.15 [0.07, 0.31]
Conroy 1999	-0.3711 (0.0425)		3.21	0.69 [0.63, 0.75]
Quick 1999	-0.5621 (0.1978)		2.94	0.57 [0.39, 0.84]
Gasana 2002	0.0000 (0.0578)		3.20	1.00 [0.89, 1.12]
Quick 2002	-0.6500 (0.2800)		2.70	0.52 [0.30, 0.90]
Reller 2003(arm 1)	-0.2357 (0.1151)		3.12	0.79 [0.63, 0.99]
Reller 2003(arm 2)	-0.3011 (0.1111)		3.13	0.74 [0.60, 0.92]
Reller 2003(arm 3)	-0.0305 (0.1335)		3.09	0.97 [0.75, 1.26]
Reller 2003(arm 4)	-0.3011 (0.1221)		3.11	0.74 [0.58, 0.94]
Clasen 2004	-1.2040 (0.2291)		2.85	0.30 [0.19, 0.47]
Crump 2004(arm 1)	-0.2614 (0.1072)		3.14	0.77 [0.62, 0.95]
Crump 2004(arm 2)	-0.1863 (0.1101)		3.13	0.83 [0.67, 1.03]
Doocy 2004	-2.1203 (0.0408)		3.21	0.12 [0.11, 0.13]
Luby 2004a(arm 1)	-0.5108 (0.1717)		3.01	0.60 [0.43, 0.84]
Luby 2004a(arm 2)	-1.2040 (0.2806)		2.70	0.30 [0.17, 0.52]
Lule 2004	-0.2231 (0.1138)		3.13	0.80 [0.64, 1.00]
Subtotal (95% CI)			71.99	0.59 [0.45, 0.78]
Test for heterogeneity: Chi² = 1840.64, df = 24 (P < 0.00001), I² = 98.7%				
Test for overall effect: Z = 3.80 (P = 0.0001)				
Total (95% CI)			100.00	0.57 [0.46, 0.71]
Test for heterogeneity: Chi² = 1883.88, df = 35 (P < 0.00001), I² = 98.1%				
Test for overall effect: Z = 4.96 (P < 0.00001)				

4.1.7 Water Quantity and Access

Figure 4.1.7 presents the results of trials in settings where the quantity of water was reported to be "sufficient" or "insufficient" using criteria established under humanitarian standards (Sphere Project 2004). The comparison suggests that interventions to improve water quality are effective in settings in which the water quantity is sufficient. Among the 7 trials conducted in such settings, the pooled ratio was 0.56 (95%CI: 0.44 to 0.71). In the 3 trials conducted in settings with "insufficient" water quantity, on the other hand, the protective effect is not statistically significant (pooled ratio of 0.53, 95%CI: 0.15 to 1.96). Excluding Doocy (2004) from the subgroup of trials where water quantity was "insufficient" narrows the confidence interval (0.72 to 1.08) and increases homogeneity (p=0.06) but significantly reduces the pooled estimate of effectiveness (0.88). With regard to access (as opposed to quantity), no trials reported access to a water source to be "insufficient"; no sub-group analysis could therefore be performed on this criterion.

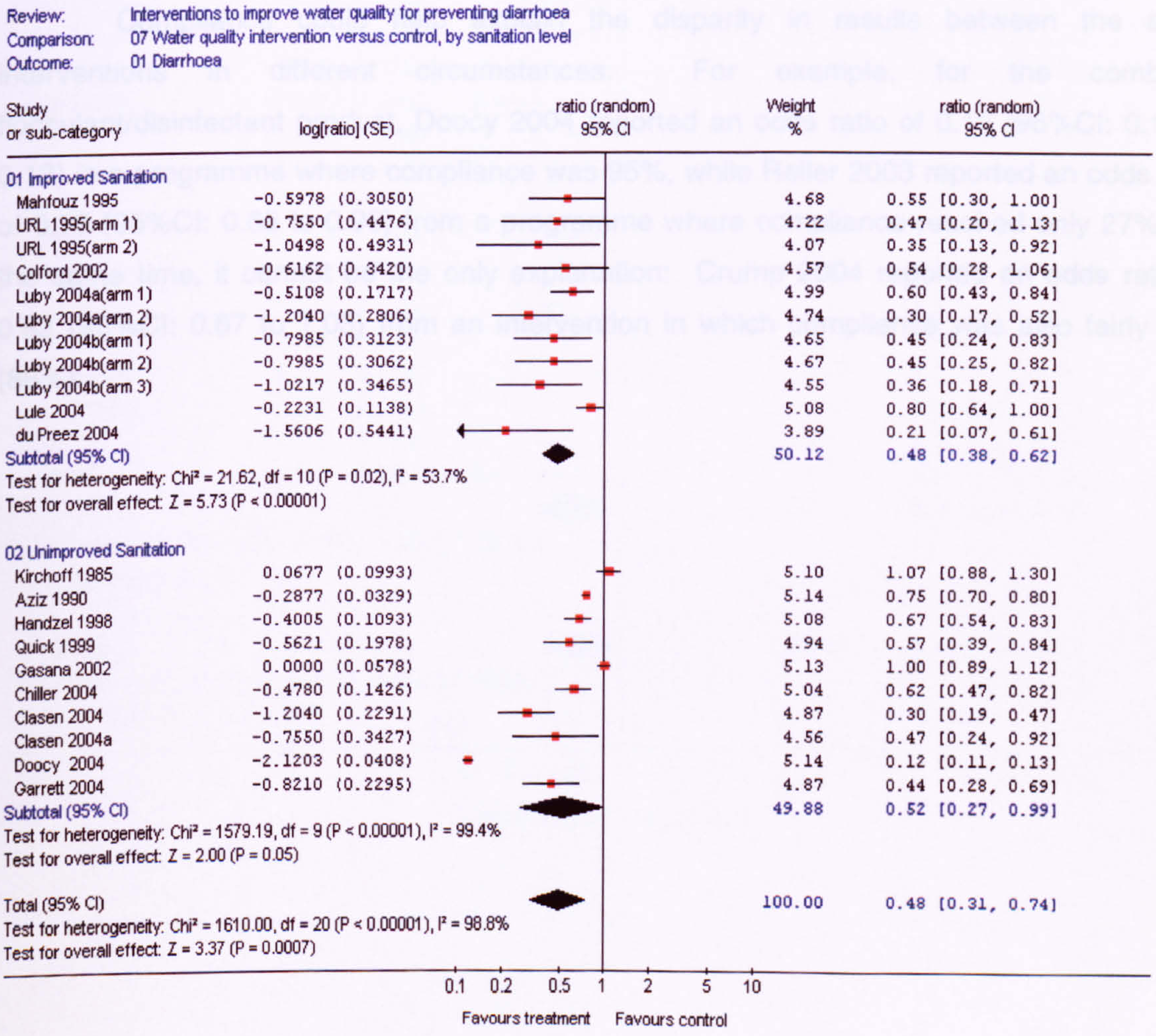
Figure 4.1.7: Water quality intervention versus control, by sufficiency of water quantity



4.1.8 Sanitation

Figure 4.1.8 presents the results of trials in settings where sanitation was reported to be "improved" or "unimproved" using the WHO/UNICEF criteria (WHO/UNICEF 2000). While pooled estimates are characterized by substantial heterogeneity (p<0.0001), the overall evidence does not suggest that interventions to improve water quality are more effective where sanitation was improved (pooled ratio of 0.48, 95%CI: 0.38 to 0.62) than where it remained unimproved (0.52, 95%CI: 0.27 to 0.99). Once again, however, when Doocy (2004) is excluded, the pooled ratio of effectiveness in settings with unimproved sanitation increases to 0.67 (95%CI: 0.55 to 0.81), providing some evidence that water quality interventions are more effective when implemented in settings with improved sanitation.

Figure 4.1.8: Water quality intervention versus control, by sanitation level



Review: Interventions to improve water quality for preventing diarrhoea
Comparison: 07 Water quality intervention versus control, by sanitation level
Outcome: 01 Diarrhoea

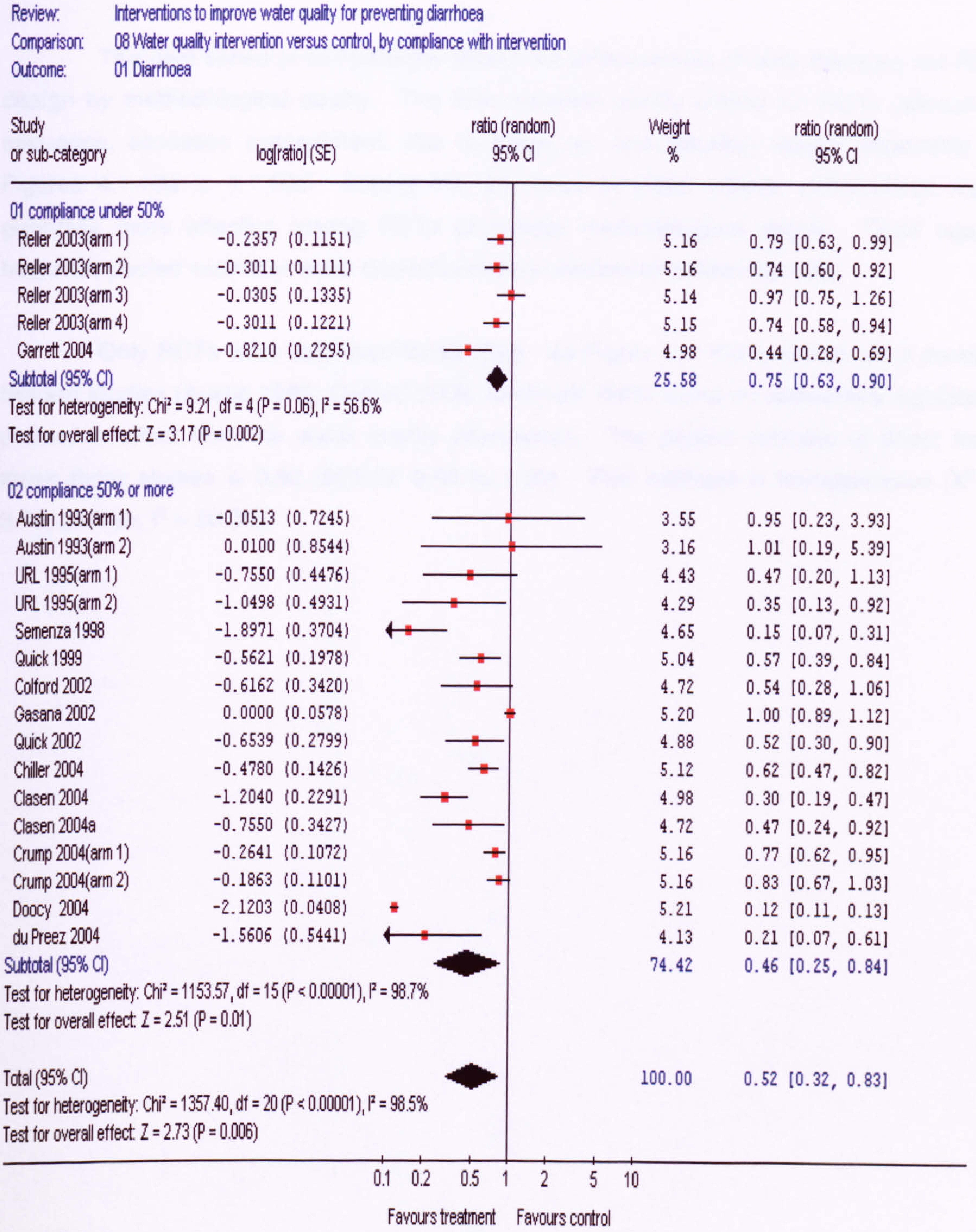
Study or sub-category	log[ratio] (SE)	ratio (random) 95% CI	Weight %	ratio (random) 95% CI
01 Improved Sanitation				
Mahfouz 1995	-0.5978 (0.3050)		4.68	0.55 [0.30, 1.00]
URL 1995(arm 1)	-0.7550 (0.4476)		4.22	0.47 [0.20, 1.13]
URL 1995(arm 2)	-1.0498 (0.4931)		4.07	0.35 [0.13, 0.92]
Colford 2002	-0.6162 (0.3420)		4.57	0.54 [0.28, 1.06]
Luby 2004a(arm 1)	-0.5108 (0.1717)		4.99	0.60 [0.43, 0.84]
Luby 2004a(arm 2)	-1.2040 (0.2806)		4.74	0.30 [0.17, 0.52]
Luby 2004b(arm 1)	-0.7985 (0.3123)		4.65	0.45 [0.24, 0.83]
Luby 2004b(arm 2)	-0.7985 (0.3062)		4.67	0.45 [0.25, 0.82]
Luby 2004b(arm 3)	-1.0217 (0.3465)		4.55	0.36 [0.18, 0.71]
Lule 2004	-0.2231 (0.1138)		5.08	0.80 [0.64, 1.00]
du Preez 2004	-1.5606 (0.5441)		3.89	0.21 [0.07, 0.61]
Subtotal (95% CI)			50.12	0.48 [0.38, 0.62]
Test for heterogeneity: Chi² = 21.62, df = 10 (P = 0.02), I² = 53.7%				
Test for overall effect: Z = 5.73 (P < 0.00001)				
02 Unimproved Sanitation				
Kirchoff 1985	0.0677 (0.0993)		5.10	1.07 [0.88, 1.30]
Aziz 1990	-0.2877 (0.0329)		5.14	0.75 [0.70, 0.80]
Handzel 1998	-0.4005 (0.1093)		5.08	0.67 [0.54, 0.83]
Quick 1999	-0.5621 (0.1978)		4.94	0.57 [0.39, 0.84]
Gasana 2002	0.0000 (0.0578)		5.13	1.00 [0.89, 1.12]
Chiller 2004	-0.4780 (0.1426)		5.04	0.62 [0.47, 0.82]
Clasen 2004	-1.2040 (0.2291)		4.87	0.30 [0.19, 0.47]
Clasen 2004a	-0.7550 (0.3427)		4.56	0.47 [0.24, 0.92]
Doocy 2004	-2.1203 (0.0408)		5.14	0.12 [0.11, 0.13]
Garrett 2004	-0.8210 (0.2295)		4.87	0.44 [0.28, 0.69]
Subtotal (95% CI)			49.88	0.52 [0.27, 0.99]
Test for heterogeneity: Chi² = 1579.19, df = 9 (P < 0.00001), I² = 99.4%				
Test for overall effect: Z = 2.00 (P = 0.05)				
Total (95% CI)			100.00	0.48 [0.31, 0.74]
Test for heterogeneity: Chi² = 1610.00, df = 20 (P < 0.00001), I² = 98.8%				
Test for overall effect: Z = 3.37 (P = 0.0007)				

4.1.9 Compliance with Household Interventions

Figure 4.1.9 shows the measure of effect for the 21 trials that reported on compliance with the intervention. These trials are subdivided between those reporting less than 50% compliance and those reporting 50% or higher compliance. The pooled ratio among the 5 trials reporting <50% compliance was 0.75 (95%CI: 0.63 to 0.90) with some evidence of heterogeneity (X^2 = 9.21, p =0.06, I^2 = 56.6%). Among the 16 trials reporting compliance >50%, the pooled ratio was 0.46 (95% CI: 0.25 to 0.84), however this estimate was characterized by substantial heterogeneity (X^2 = 1153.57, p<0.00001, I^2 =98.7%). Moreover, 4 of the 5 trials included in the low compliance group are from a single study (Reller 2003).

Compliance could help explain the disparity in results between the same interventions in different circumstances. For example, for the combined flocculant/disinfectant product, Doocy 2004 reported an odds ratio of 0.12 (95%CI: 0.11 to 0.13) in a programme where compliance was 95%, while Reller 2003 reported an odds ratio of 0.79 (95%CI: 0.63 to 0.99) from a programme where compliance reached only 27%. At the same time, it cannot be the only explanation: Crump 2004 reported an odds ratio of 0.83 (95%CI: 0.67 to 1.03) from an intervention in which compliance was also fairly high (86%).

Figure 4.1.9: Water quality intervention versus control, by compliance



Review: Interventions to improve water quality for preventing diarrhoea
Comparison: 08 Water quality intervention versus control, by compliance with intervention
Outcome: 01 Diarrhoea

Study or sub-category	log[ratio] (SE)	Weight %	ratio (random) 95% CI
01 compliance under 50%			
Reller 2003(arm 1)	-0.2357 (0.1151)	5.16	0.79 [0.63, 0.99]
Reller 2003(arm 2)	-0.3011 (0.1111)	5.16	0.74 [0.60, 0.92]
Reller 2003(arm 3)	-0.0305 (0.1335)	5.14	0.97 [0.75, 1.26]
Reller 2003(arm 4)	-0.3011 (0.1221)	5.15	0.74 [0.58, 0.94]
Garrett 2004	-0.8210 (0.2295)	4.98	0.44 [0.28, 0.69]
Subtotal (95% CI)		25.58	0.75 [0.63, 0.90]
Test for heterogeneity: Chi² = 9.21, df = 4 (P = 0.06), I² = 56.6%			
Test for overall effect: Z = 3.17 (P = 0.002)			
02 compliance 50% or more			
Austin 1993(arm 1)	-0.0513 (0.7245)	3.55	0.95 [0.23, 3.93]
Austin 1993(arm 2)	0.0100 (0.8544)	3.16	1.01 [0.19, 5.39]
URL 1995(arm 1)	-0.7550 (0.4476)	4.43	0.47 [0.20, 1.13]
URL 1995(arm 2)	-1.0498 (0.4931)	4.29	0.35 [0.13, 0.92]
Semenza 1998	-1.8971 (0.3704)	4.65	0.15 [0.07, 0.31]
Quick 1999	-0.5621 (0.1978)	5.04	0.57 [0.39, 0.84]
Colford 2002	-0.6162 (0.3420)	4.72	0.54 [0.28, 1.06]
Gasana 2002	0.0000 (0.0578)	5.20	1.00 [0.89, 1.12]
Quick 2002	-0.6539 (0.2799)	4.88	0.52 [0.30, 0.90]
Chiller 2004	-0.4780 (0.1426)	5.12	0.62 [0.47, 0.82]
Clasen 2004	-1.2040 (0.2291)	4.98	0.30 [0.19, 0.47]
Clasen 2004a	-0.7550 (0.3427)	4.72	0.47 [0.24, 0.92]
Crump 2004(arm 1)	-0.2641 (0.1072)	5.16	0.77 [0.62, 0.95]
Crump 2004(arm 2)	-0.1863 (0.1101)	5.16	0.83 [0.67, 1.03]
Doocy 2004	-2.1203 (0.0408)	5.21	0.12 [0.11, 0.13]
du Preez 2004	-1.5606 (0.5441)	4.13	0.21 [0.07, 0.61]
Subtotal (95% CI)		74.42	0.46 [0.25, 0.84]
Test for heterogeneity: Chi² = 1153.57, df = 15 (P < 0.00001), I² = 98.7%			
Test for overall effect: Z = 2.51 (P = 0.01)			
Total (95% CI)		100.00	0.52 [0.32, 0.83]
Test for heterogeneity: Chi² = 1357.40, df = 20 (P < 0.00001), I² = 98.5%			
Test for overall effect: Z = 2.73 (P = 0.006)			

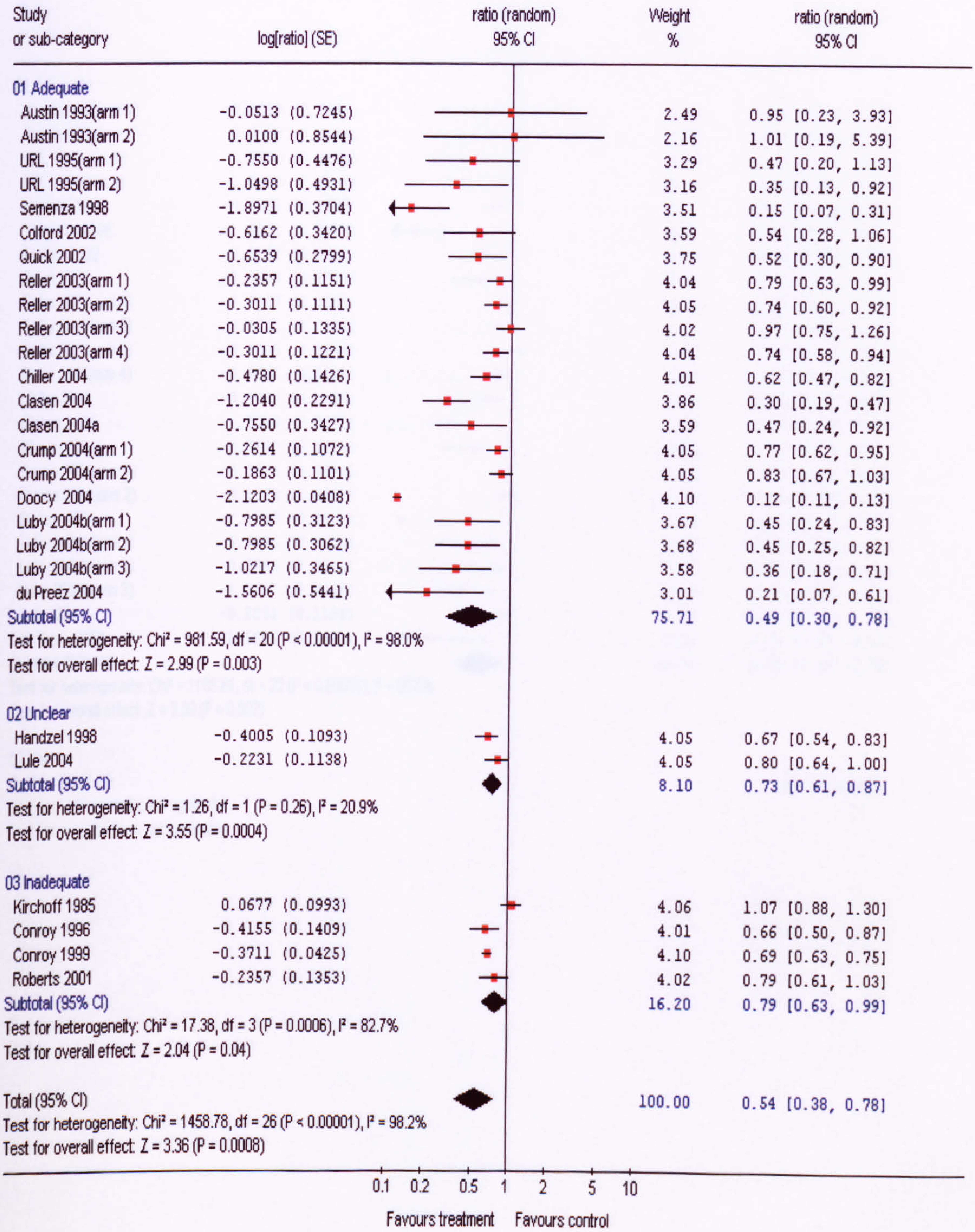
4.1.10 Study Quality

The next series of comparisons shows the effectiveness of trials following the RCT design by methodological quality. The four separate quality criteria for RCTs (allocation sequence, allocation concealment, loss to follow up, and blinding) appear separately in Figures 4.1.10a to 4.1.10d. Among the first three of these criteria, interventions were generally more effective among RCTs of greater methodological quality. Once again, however, pooled estimates were characterized by considerable heterogeneity.

Only RCTs were assessed for blinding. As Figure 4.1.10d indicates, all 3 double-blinded studies (Austin 1993; Colford 2002; Kirchhoff 1985) found no statistically significant protective effect from the water quality intervention. The pooled estimate of effect from these three studies is 0.92 (95%CI: 0.65 to 1.30). That estimate is homogeneous (X^2 = 3.76, p=0.29, I^2 = 20.3%).

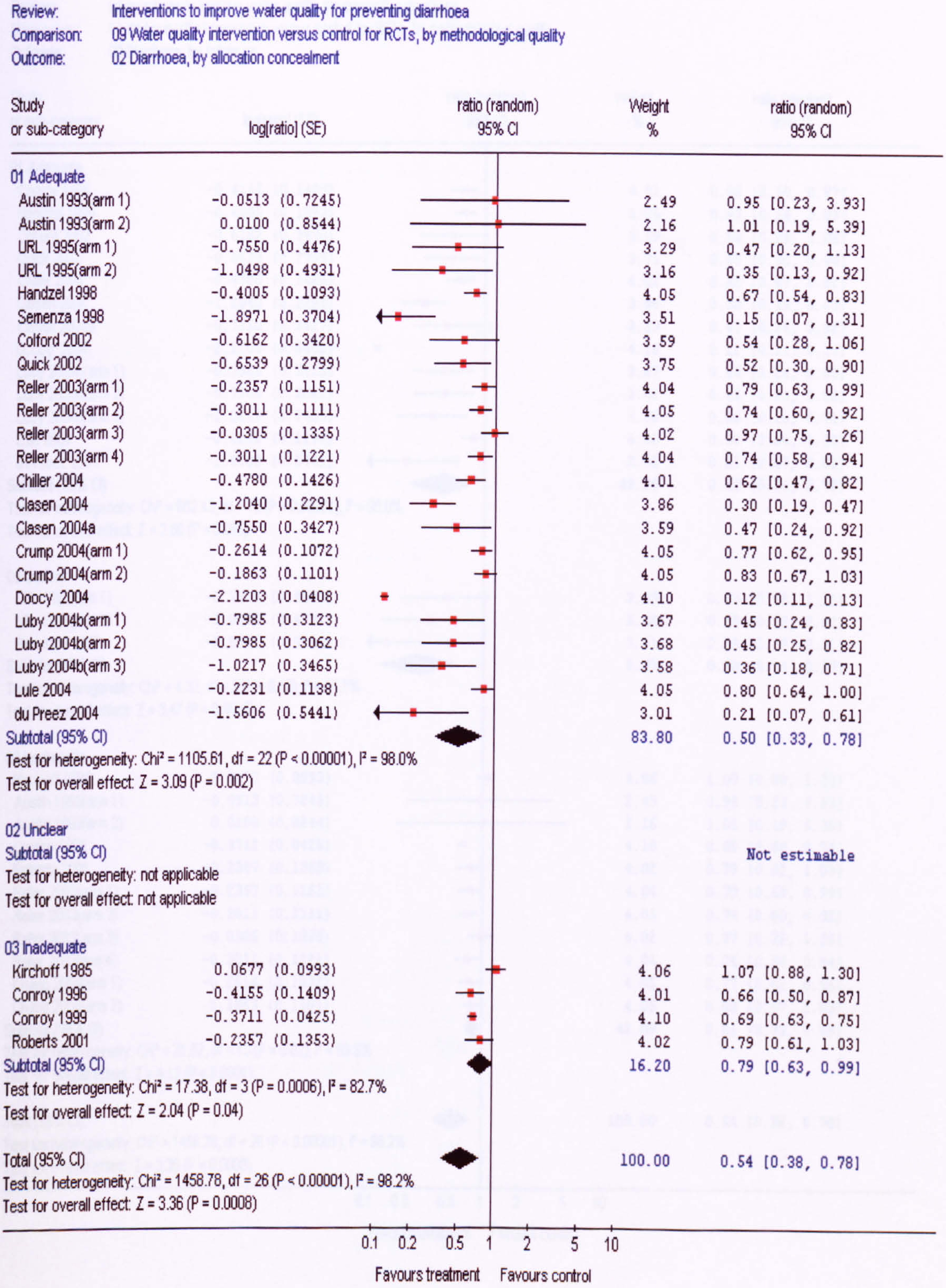
Figure 4.1.10a: Water quality intervention versus control for RCTs, by methodological quality (generation of allocation sequence)

Review: Interventions to improve water quality for preventing diarrhoea
Comparison: 09 Water quality intervention versus control for RCTs, by methodological quality
Outcome: 01 Diarrhoea, by allocation sequence



Study or sub-category	log[ratio] (SE)	ratio (random) 95% CI	Weight %	ratio (random) 95% CI
01 Adequate				
Austin 1993(arm 1)	-0.0513 (0.7245)		2.49	0.95 [0.23, 3.93]
Austin 1993(arm 2)	0.0100 (0.8544)		2.16	1.01 [0.19, 5.39]
URL 1995(arm 1)	-0.7550 (0.4476)		3.29	0.47 [0.20, 1.13]
URL 1995(arm 2)	-1.0498 (0.4931)		3.16	0.35 [0.13, 0.92]
Semenza 1998	-1.8971 (0.3704)		3.51	0.15 [0.07, 0.31]
Colford 2002	-0.6162 (0.3420)		3.59	0.54 [0.28, 1.06]
Quick 2002	-0.6539 (0.2799)		3.75	0.52 [0.30, 0.90]
Reller 2003(arm 1)	-0.2357 (0.1151)		4.04	0.79 [0.63, 0.99]
Reller 2003(arm 2)	-0.3011 (0.1111)		4.05	0.74 [0.60, 0.92]
Reller 2003(arm 3)	-0.0305 (0.1335)		4.02	0.97 [0.75, 1.26]
Reller 2003(arm 4)	-0.3011 (0.1221)		4.04	0.74 [0.58, 0.94]
Chiller 2004	-0.4780 (0.1426)		4.01	0.62 [0.47, 0.82]
Clasen 2004	-1.2040 (0.2291)		3.86	0.30 [0.19, 0.47]
Clasen 2004a	-0.7550 (0.3427)		3.59	0.47 [0.24, 0.92]
Crump 2004(arm 1)	-0.2614 (0.1072)		4.05	0.77 [0.62, 0.95]
Crump 2004(arm 2)	-0.1863 (0.1101)		4.05	0.83 [0.67, 1.03]
Doocy 2004	-2.1203 (0.0408)		4.10	0.12 [0.11, 0.13]
Luby 2004b(arm 1)	-0.7985 (0.3123)		3.67	0.45 [0.24, 0.83]
Luby 2004b(arm 2)	-0.7985 (0.3062)		3.68	0.45 [0.25, 0.82]
Luby 2004b(arm 3)	-1.0217 (0.3465)		3.58	0.36 [0.18, 0.71]
du Preez 2004	-1.5606 (0.5441)		3.01	0.21 [0.07, 0.61]
Subtotal (95% CI)			75.71	0.49 [0.30, 0.78]
Test for heterogeneity: Chi² = 981.59, df = 20 (P < 0.00001), I² = 98.0%				
Test for overall effect: Z = 2.99 (P = 0.003)				
02 Unclear				
Handzel 1998	-0.4005 (0.1093)		4.05	0.67 [0.54, 0.83]
Lule 2004	-0.2231 (0.1138)		4.05	0.80 [0.64, 1.00]
Subtotal (95% CI)			8.10	0.73 [0.61, 0.87]
Test for heterogeneity: Chi² = 1.26, df = 1 (P = 0.26), I² = 20.9%				
Test for overall effect: Z = 3.55 (P = 0.0004)				
03 Inadequate				
Kirchoff 1985	0.0677 (0.0993)		4.06	1.07 [0.88, 1.30]
Conroy 1996	-0.4155 (0.1409)		4.01	0.66 [0.50, 0.87]
Conroy 1999	-0.3711 (0.0425)		4.10	0.69 [0.63, 0.75]
Roberts 2001	-0.2357 (0.1353)		4.02	0.79 [0.61, 1.03]
Subtotal (95% CI)			16.20	0.79 [0.63, 0.99]
Test for heterogeneity: Chi² = 17.38, df = 3 (P = 0.0006), I² = 82.7%				
Test for overall effect: Z = 2.04 (P = 0.04)				
Total (95% CI)			100.00	0.54 [0.38, 0.78]
Test for heterogeneity: Chi² = 1458.78, df = 26 (P < 0.00001), I² = 98.2%				
Test for overall effect: Z = 3.36 (P = 0.0008)				

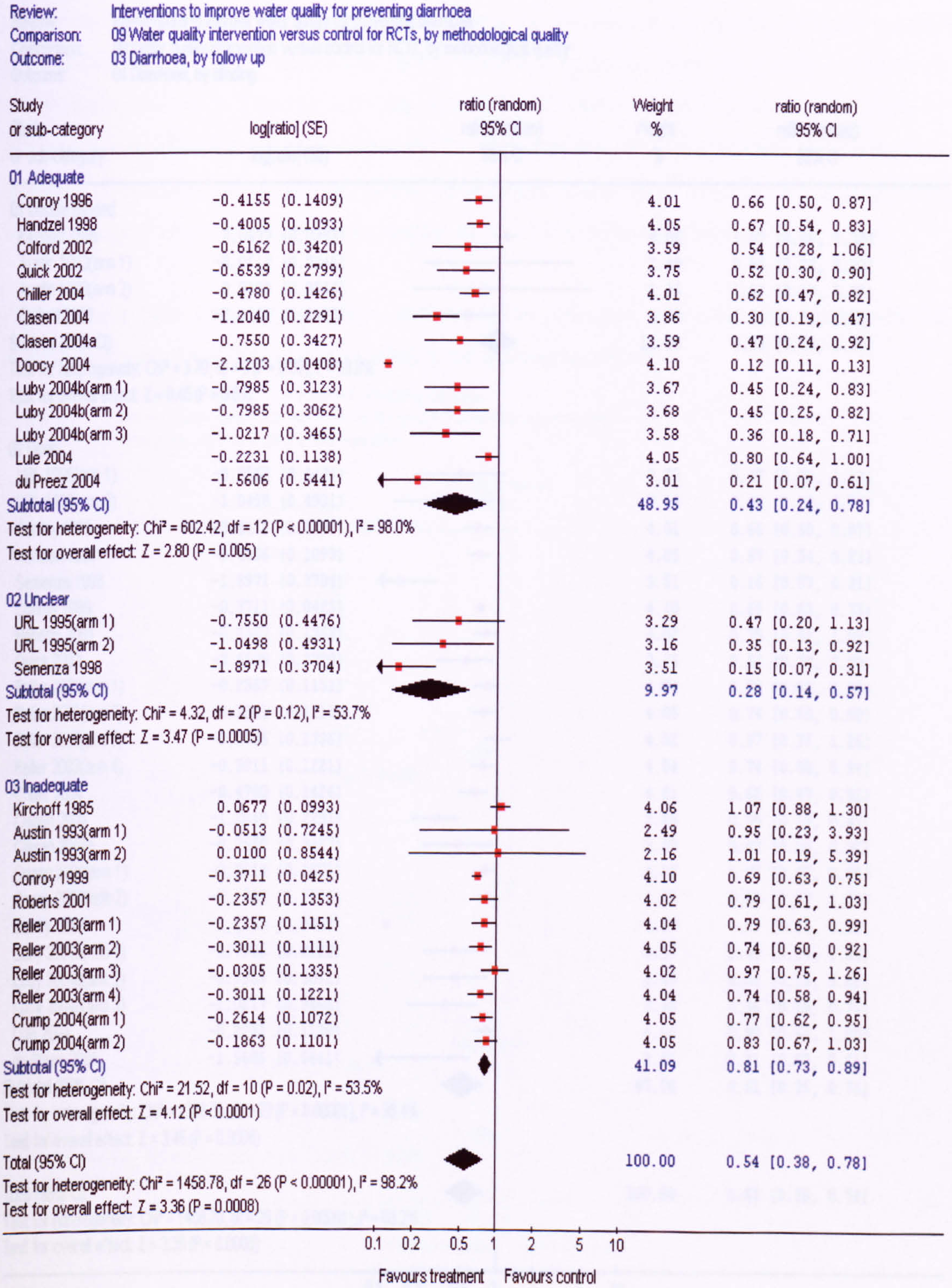
Figure 4.1.10b: Water quality intervention versus control for RCTs, by methodological quality (concealment of allocation sequence)



Review: Interventions to improve water quality for preventing diarrhoea
Comparison: 09 Water quality intervention versus control for RCTs, by methodological quality
Outcome: 02 Diarrhoea, by allocation concealment

Study or sub-category	log[ratio] (SE)	Weight %	ratio (random) 95% CI
01 Adequate			
Austin 1993(arm 1)	-0.0513 (0.7245)	2.49	0.95 [0.23, 3.93]
Austin 1993(arm 2)	0.0100 (0.8544)	2.16	1.01 [0.19, 5.39]
URL 1995(arm 1)	-0.7550 (0.4476)	3.29	0.47 [0.20, 1.13]
URL 1995(arm 2)	-1.0498 (0.4931)	3.16	0.35 [0.13, 0.92]
Handzel 1998	-0.4005 (0.1093)	4.05	0.67 [0.54, 0.83]
Semenza 1998	-1.8971 (0.3704)	3.51	0.15 [0.07, 0.31]
Colford 2002	-0.6162 (0.3420)	3.59	0.54 [0.28, 1.06]
Quick 2002	-0.6539 (0.2799)	3.75	0.52 [0.30, 0.90]
Reller 2003(arm 1)	-0.2357 (0.1151)	4.04	0.79 [0.63, 0.99]
Reller 2003(arm 2)	-0.3011 (0.1111)	4.05	0.74 [0.60, 0.92]
Reller 2003(arm 3)	-0.0305 (0.1335)	4.02	0.97 [0.75, 1.26]
Reller 2003(arm 4)	-0.3011 (0.1221)	4.04	0.74 [0.58, 0.94]
Chiller 2004	-0.4780 (0.1426)	4.01	0.62 [0.47, 0.82]
Clasen 2004	-1.2040 (0.2291)	3.86	0.30 [0.19, 0.47]
Clasen 2004a	-0.7550 (0.3427)	3.59	0.47 [0.24, 0.92]
Crump 2004(arm 1)	-0.2614 (0.1072)	4.05	0.77 [0.62, 0.95]
Crump 2004(arm 2)	-0.1863 (0.1101)	4.05	0.83 [0.67, 1.03]
Doocy 2004	-2.1203 (0.0408)	4.10	0.12 [0.11, 0.13]
Luby 2004b(arm 1)	-0.7985 (0.3123)	3.67	0.45 [0.24, 0.83]
Luby 2004b(arm 2)	-0.7985 (0.3062)	3.68	0.45 [0.25, 0.82]
Luby 2004b(arm 3)	-1.0217 (0.3465)	3.58	0.36 [0.18, 0.71]
Lule 2004	-0.2231 (0.1138)	4.05	0.80 [0.64, 1.00]
du Preez 2004	-1.5606 (0.5441)	3.01	0.21 [0.07, 0.61]
Subtotal (95% CI)		83.80	0.50 [0.33, 0.78]
Test for heterogeneity: Chi² = 1105.61, df = 22 (P < 0.00001), I² = 98.0%			
Test for overall effect: Z = 3.09 (P = 0.002)			
02 Unclear			
Subtotal (95% CI)			Not estimable
Test for heterogeneity: not applicable			
Test for overall effect: not applicable			
03 Inadequate			
Kirchoff 1985	0.0677 (0.0993)	4.06	1.07 [0.88, 1.30]
Conroy 1996	-0.4155 (0.1409)	4.01	0.66 [0.50, 0.87]
Conroy 1999	-0.3711 (0.0425)	4.10	0.69 [0.63, 0.75]
Roberts 2001	-0.2357 (0.1353)	4.02	0.79 [0.61, 1.03]
Subtotal (95% CI)		16.20	0.79 [0.63, 0.99]
Test for heterogeneity: Chi² = 17.38, df = 3 (P = 0.0006), I² = 82.7%			
Test for overall effect: Z = 2.04 (P = 0.04)			
Total (95% CI)		100.00	0.54 [0.38, 0.78]
Test for heterogeneity: Chi² = 1458.78, df = 26 (P < 0.00001), I² = 98.2%			
Test for overall effect: Z = 3.36 (P = 0.0008)			

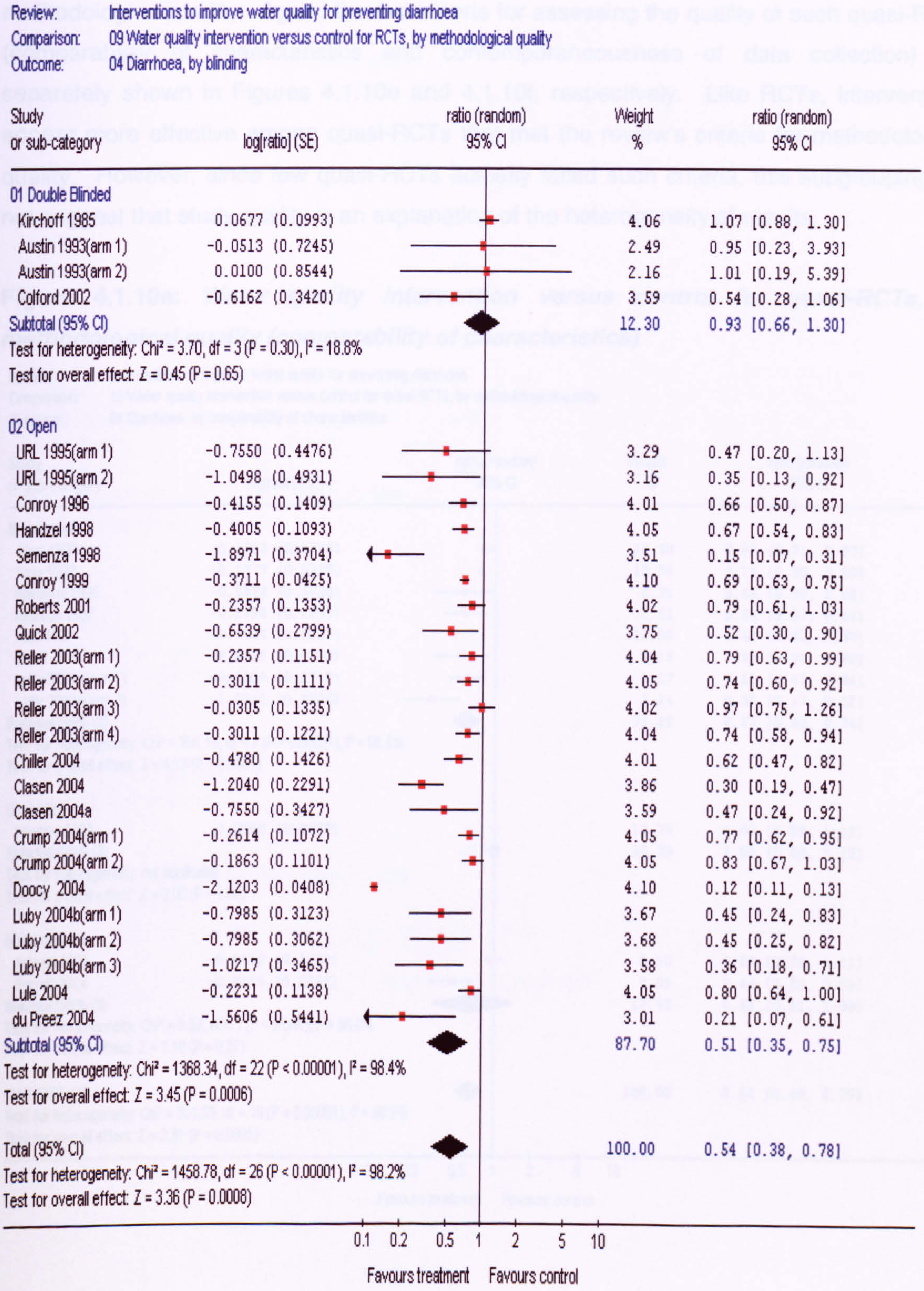
Figure 4.1.10c: ***Water quality intervention versus control for RCTs, by methodological quality (follow up)***



Review: Interventions to improve water quality for preventing diarrhoea
Comparison: 09 Water quality intervention versus control for RCTs, by methodological quality
Outcome: 03 Diarrhoea, by follow up

Study or sub-category	log[ratio] (SE)	Weight %	ratio (random) 95% CI
01 Adequate			
Conroy 1996	-0.4155 (0.1409)	4.01	0.66 [0.50, 0.87]
Handzel 1998	-0.4005 (0.1093)	4.05	0.67 [0.54, 0.83]
Colford 2002	-0.6162 (0.3420)	3.59	0.54 [0.28, 1.06]
Quick 2002	-0.6539 (0.2799)	3.75	0.52 [0.30, 0.90]
Chiller 2004	-0.4780 (0.1426)	4.01	0.62 [0.47, 0.82]
Clasen 2004	-1.2040 (0.2291)	3.86	0.30 [0.19, 0.47]
Clasen 2004a	-0.7550 (0.3427)	3.59	0.47 [0.24, 0.92]
Doocy 2004	-2.1203 (0.0408)	4.10	0.12 [0.11, 0.13]
Luby 2004b(arm 1)	-0.7985 (0.3123)	3.67	0.45 [0.24, 0.83]
Luby 2004b(arm 2)	-0.7985 (0.3062)	3.68	0.45 [0.25, 0.82]
Luby 2004b(arm 3)	-1.0217 (0.3465)	3.58	0.36 [0.18, 0.71]
Lule 2004	-0.2231 (0.1138)	4.05	0.80 [0.64, 1.00]
du Preez 2004	-1.5606 (0.5441)	3.01	0.21 [0.07, 0.61]
Subtotal (95% CI)		48.95	0.43 [0.24, 0.78]
Test for heterogeneity: Chi² = 602.42, df = 12 (P < 0.00001), I² = 98.0%			
Test for overall effect: Z = 2.80 (P = 0.005)			
02 Unclear			
URL 1995(arm 1)	-0.7550 (0.4476)	3.29	0.47 [0.20, 1.13]
URL 1995(arm 2)	-1.0498 (0.4931)	3.16	0.35 [0.13, 0.92]
Semenza 1998	-1.8971 (0.3704)	3.51	0.15 [0.07, 0.31]
Subtotal (95% CI)		9.97	0.28 [0.14, 0.57]
Test for heterogeneity: Chi² = 4.32, df = 2 (P = 0.12), I² = 53.7%			
Test for overall effect: Z = 3.47 (P = 0.0005)			
03 Inadequate			
Kirchoff 1985	0.0677 (0.0993)	4.06	1.07 [0.88, 1.30]
Austin 1993(arm 1)	-0.0513 (0.7245)	2.49	0.95 [0.23, 3.93]
Austin 1993(arm 2)	0.0100 (0.8544)	2.16	1.01 [0.19, 5.39]
Conroy 1999	-0.3711 (0.0425)	4.10	0.69 [0.63, 0.75]
Roberts 2001	-0.2357 (0.1353)	4.02	0.79 [0.61, 1.03]
Reller 2003(arm 1)	-0.2357 (0.1151)	4.04	0.79 [0.63, 0.99]
Reller 2003(arm 2)	-0.3011 (0.1111)	4.05	0.74 [0.60, 0.92]
Reller 2003(arm 3)	-0.0305 (0.1335)	4.02	0.97 [0.75, 1.26]
Reller 2003(arm 4)	-0.3011 (0.1221)	4.04	0.74 [0.58, 0.94]
Crump 2004(arm 1)	-0.2614 (0.1072)	4.05	0.77 [0.62, 0.95]
Crump 2004(arm 2)	-0.1863 (0.1101)	4.05	0.83 [0.67, 1.03]
Subtotal (95% CI)		41.09	0.81 [0.73, 0.89]
Test for heterogeneity: Chi² = 21.52, df = 10 (P = 0.02), I² = 53.5%			
Test for overall effect: Z = 4.12 (P < 0.0001)			
Total (95% CI)		100.00	0.54 [0.38, 0.78]
Test for heterogeneity: Chi² = 1458.78, df = 26 (P < 0.00001), I² = 98.2%			
Test for overall effect: Z = 3.36 (P = 0.0008)			

Figure 4.1.10d: Water quality intervention versus control for RCTs, by methodological quality (blinding)

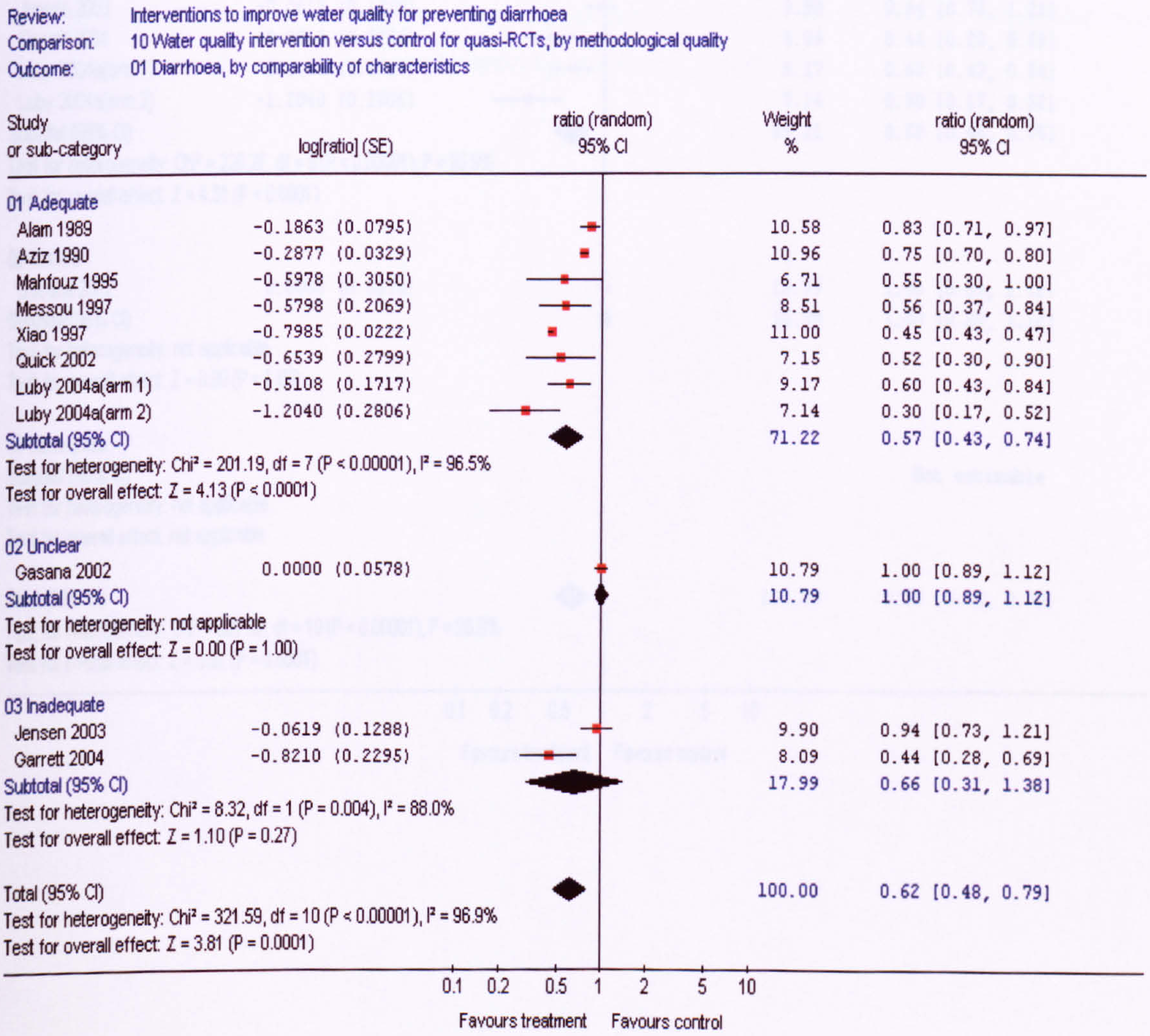


Review: Interventions to improve water quality for preventing diarrhoea
Comparison: 09 Water quality intervention versus control for RCTs, by methodological quality
Outcome: 04 Diarrhoea, by blinding

Study or sub-category	log[ratio] (SE)	ratio (random) 95% CI	Weight %	ratio (random) 95% CI
01 Double Blinded				
Kirchoff 1985	0.0677 (0.0993)		4.06	1.07 [0.88, 1.30]
Austin 1993(arm 1)	-0.0513 (0.7245)		2.49	0.95 [0.23, 3.93]
Austin 1993(arm 2)	0.0100 (0.8544)		2.16	1.01 [0.19, 5.39]
Colford 2002	-0.6162 (0.3420)		3.59	0.54 [0.28, 1.06]
Subtotal (95% CI)			12.30	0.93 [0.66, 1.30]
Test for heterogeneity: Chi² = 3.70, df = 3 (P = 0.30), I² = 18.8%				
Test for overall effect: Z = 0.45 (P = 0.65)				
02 Open				
URL 1995(arm 1)	-0.7550 (0.4476)		3.29	0.47 [0.20, 1.13]
URL 1995(arm 2)	-1.0498 (0.4931)		3.16	0.35 [0.13, 0.92]
Conroy 1996	-0.4155 (0.1409)		4.01	0.66 [0.50, 0.87]
Handzel 1998	-0.4005 (0.1093)		4.05	0.67 [0.54, 0.83]
Semenza 1998	-1.8971 (0.3704)		3.51	0.15 [0.07, 0.31]
Conroy 1999	-0.3711 (0.0425)		4.10	0.69 [0.63, 0.75]
Roberts 2001	-0.2357 (0.1353)		4.02	0.79 [0.61, 1.03]
Quick 2002	-0.6539 (0.2799)		3.75	0.52 [0.30, 0.90]
Reller 2003(arm 1)	-0.2357 (0.1151)		4.04	0.79 [0.63, 0.99]
Reller 2003(arm 2)	-0.3011 (0.1111)		4.05	0.74 [0.60, 0.92]
Reller 2003(arm 3)	-0.0305 (0.1335)		4.02	0.97 [0.75, 1.26]
Reller 2003(arm 4)	-0.3011 (0.1221)		4.04	0.74 [0.58, 0.94]
Chiller 2004	-0.4780 (0.1426)		4.01	0.62 [0.47, 0.82]
Clasen 2004	-1.2040 (0.2291)		3.86	0.30 [0.19, 0.47]
Clasen 2004a	-0.7550 (0.3427)		3.59	0.47 [0.24, 0.92]
Crump 2004(arm 1)	-0.2614 (0.1072)		4.05	0.77 [0.62, 0.95]
Crump 2004(arm 2)	-0.1863 (0.1101)		4.05	0.83 [0.67, 1.03]
Doocy 2004	-2.1203 (0.0408)		4.10	0.12 [0.11, 0.13]
Luby 2004b(arm 1)	-0.7985 (0.3123)		3.67	0.45 [0.24, 0.83]
Luby 2004b(arm 2)	-0.7985 (0.3062)		3.68	0.45 [0.25, 0.82]
Luby 2004b(arm 3)	-1.0217 (0.3465)		3.58	0.36 [0.18, 0.71]
Lule 2004	-0.2231 (0.1138)		4.05	0.80 [0.64, 1.00]
du Preez 2004	-1.5606 (0.5441)		3.01	0.21 [0.07, 0.61]
Subtotal (95% CI)			87.70	0.51 [0.35, 0.75]
Test for heterogeneity: Chi² = 1368.34, df = 22 (P < 0.00001), I² = 98.4%				
Test for overall effect: Z = 3.45 (P = 0.0006)				
Total (95% CI)			100.00	0.54 [0.38, 0.78]
Test for heterogeneity: Chi² = 1458.78, df = 26 (P < 0.00001), I² = 98.2%				
Test for overall effect: Z = 3.36 (P = 0.0008)				

Comparisons were also generated to show the effectiveness of quasi-RCTs by methodological quality. Again, the two criteria for assessing the quality of such quasi-RCTs (comparability of characteristics and contemporaneousness of data collection) are separately shown in Figures 4.1.10e and 4.1.10f, respectively. Like RCTs, interventions appear more effective among quasi-RCTs that met the review's criteria for methodological quality. However, since few quasi-RCTs actually failed such criteria, this subgrouping did not suggest that study quality is an explanation of the heterogeneity of results.

Figure 4.1.10e: ***Water quality intervention versus control for quasi-RCTs, by methodological quality (comparability of characteristics)***



Review: Interventions to improve water quality for preventing diarrhoea
Comparison: 10 Water quality intervention versus control for quasi-RCTs, by methodological quality
Outcome: 01 Diarrhoea, by comparability of characteristics

Study or sub-category	log[ratio] (SE)	Weight %	ratio (random) 95% CI
01 Adequate			
Alam 1989	-0.1863 (0.0795)	10.58	0.83 [0.71, 0.97]
Aziz 1990	-0.2877 (0.0329)	10.96	0.75 [0.70, 0.80]
Mahfouz 1995	-0.5978 (0.3050)	6.71	0.55 [0.30, 1.00]
Messou 1997	-0.5798 (0.2069)	8.51	0.56 [0.37, 0.84]
Xiao 1997	-0.7985 (0.0222)	11.00	0.45 [0.43, 0.47]
Quick 2002	-0.6539 (0.2799)	7.15	0.52 [0.30, 0.90]
Luby 2004a(arm 1)	-0.5108 (0.1717)	9.17	0.60 [0.43, 0.84]
Luby 2004a(arm 2)	-1.2040 (0.2806)	7.14	0.30 [0.17, 0.52]
Subtotal (95% CI)		71.22	0.57 [0.43, 0.74]
02 Unclear			
Gasana 2002	0.0000 (0.0578)	10.79	1.00 [0.89, 1.12]
Subtotal (95% CI)		10.79	1.00 [0.89, 1.12]
03 Inadequate			
Jensen 2003	-0.0619 (0.1288)	9.90	0.94 [0.73, 1.21]
Garrett 2004	-0.8210 (0.2295)	8.09	0.44 [0.28, 0.69]
Subtotal (95% CI)		17.99	0.66 [0.31, 1.38]
Total (95% CI)		100.00	0.62 [0.48, 0.79]

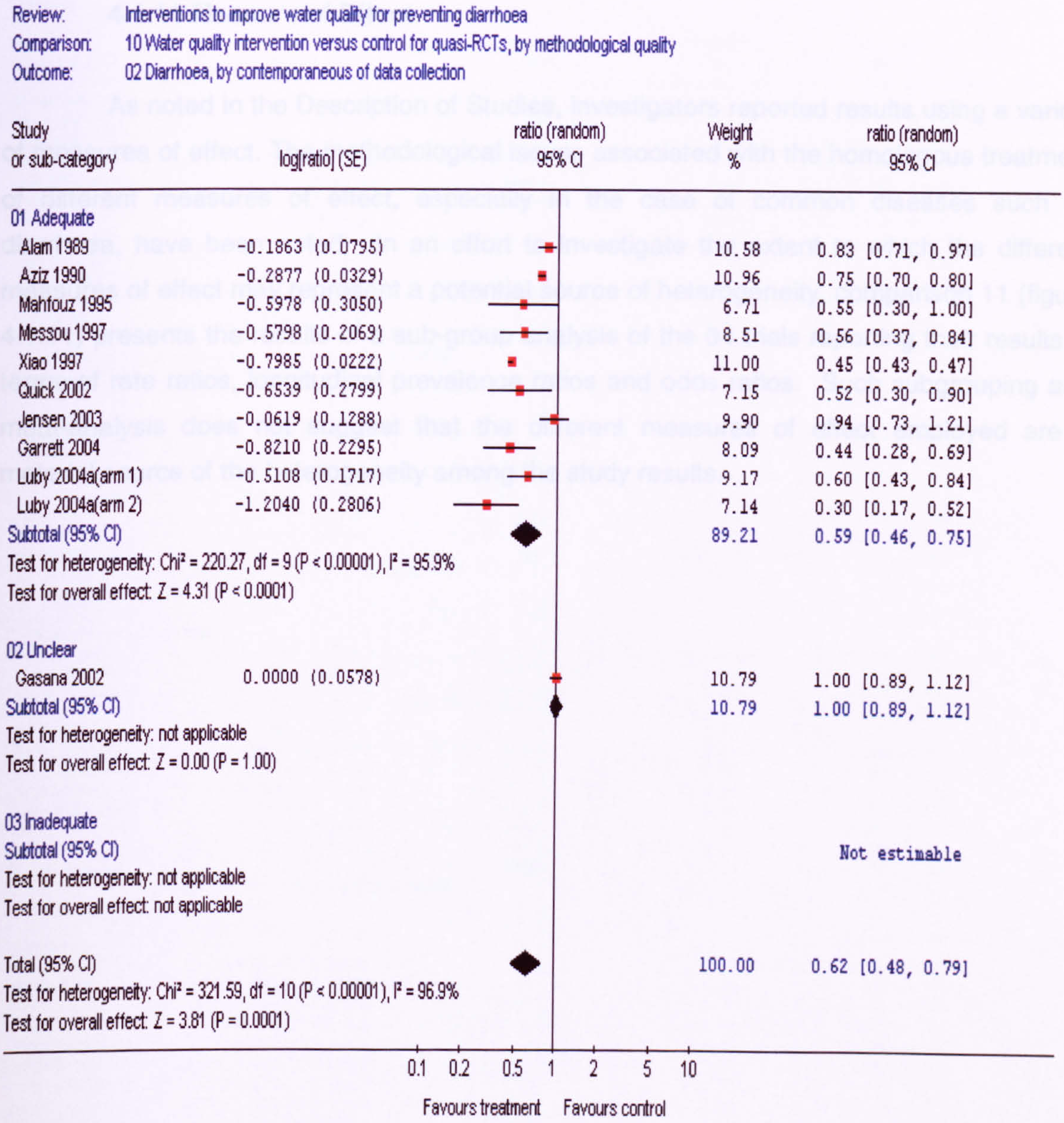
01 Adequate subtotal:
Test for heterogeneity: Chi² = 201.19, df = 7 (P < 0.00001), I² = 96.5%
Test for overall effect: Z = 4.13 (P < 0.0001)

02 Unclear subtotal:
Test for heterogeneity: not applicable
Test for overall effect: Z = 0.00 (P = 1.00)

03 Inadequate subtotal:
Test for heterogeneity: Chi² = 8.32, df = 1 (P = 0.004), I² = 88.0%
Test for overall effect: Z = 1.10 (P = 0.27)

Total:
Test for heterogeneity: Chi² = 321.59, df = 10 (P < 0.00001), I² = 96.9%
Test for overall effect: Z = 3.81 (P = 0.0001)

Figure 4.1.10f: Water quality intervention versus control for quasi-RCTs, by methodological quality (contemporaneousness of data collection)



Review: Interventions to improve water quality for preventing diarrhoea
Comparison: 10 Water quality intervention versus control for quasi-RCTs, by methodological quality
Outcome: 02 Diarrhoea, by contemporaneous of data collection

Study or sub-category	log[ratio] (SE)	Weight %	ratio (random) 95% CI
01 Adequate			
Alam 1989	-0.1863 (0.0795)	10.58	0.83 [0.71, 0.97]
Aziz 1990	-0.2877 (0.0329)	10.96	0.75 [0.70, 0.80]
Mahfouz 1995	-0.5978 (0.3050)	6.71	0.55 [0.30, 1.00]
Messou 1997	-0.5798 (0.2069)	8.51	0.56 [0.37, 0.84]
Xiao 1997	-0.7985 (0.0222)	11.00	0.45 [0.43, 0.47]
Quick 2002	-0.6539 (0.2799)	7.15	0.52 [0.30, 0.90]
Jensen 2003	-0.0619 (0.1288)	9.90	0.94 [0.73, 1.21]
Garrett 2004	-0.8210 (0.2295)	8.09	0.44 [0.28, 0.69]
Luby 2004a(arm 1)	-0.5108 (0.1717)	9.17	0.60 [0.43, 0.84]
Luby 2004a(arm 2)	-1.2040 (0.2806)	7.14	0.30 [0.17, 0.52]
Subtotal (95% CI)		89.21	0.59 [0.46, 0.75]
02 Unclear			
Gasana 2002	0.0000 (0.0578)	10.79	1.00 [0.89, 1.12]
Subtotal (95% CI)		10.79	1.00 [0.89, 1.12]
03 Inadequate			
Subtotal (95% CI)			Not estimable
Total (95% CI)		100.00	0.62 [0.48, 0.79]

01 Adequate: Test for heterogeneity: $Chi^2 = 220.27$, df = 9 ($P < 0.00001$), $I^2 = 95.9\%$
Test for overall effect: $Z = 4.31$ ($P < 0.0001$)

02 Unclear: Test for heterogeneity: not applicable
Test for overall effect: $Z = 0.00$ ($P = 1.00$)

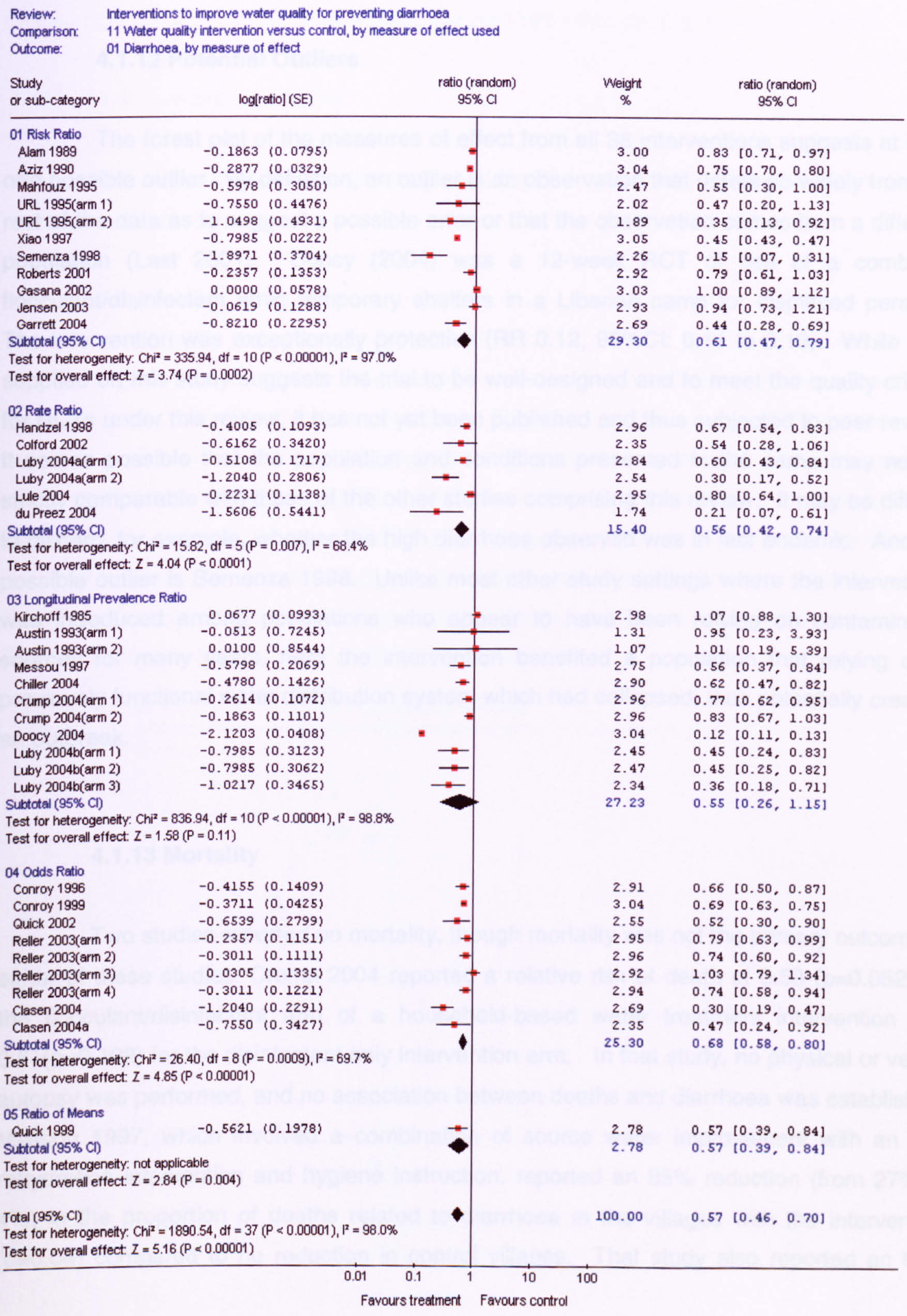
03 Inadequate: Test for heterogeneity: not applicable
Test for overall effect: not applicable

Total: Test for heterogeneity: $Chi^2 = 321.59$, df = 10 ($P < 0.00001$), $I^2 = 96.9\%$
Test for overall effect: $Z = 3.81$ ($P = 0.0001$)

4.1.11 Measure of Effect

As noted in the Description of Studies, investigators reported results using a variety of measures of effect. The methodological issues associated with the homologous treatment of different measures of effect, especially in the case of common diseases such as diarrhoea, have been noted. In an effort to investigate the extent to which the different measures of effect may represent a potential source of heterogeneity, comparison 11 (figure 4.1.11) presents the results of a sub-group analysis of the 34 trials reporting their results in terms of rate ratios, longitudinal prevalence ratios and odds ratios. Such subgrouping and meta-analysis does not suggest that the different measures of effect employed are a material source of the heterogeneity among the study results.

Figure 4.1.11: Water quality intervention versus control, by measure of effect



Review: Interventions to improve water quality for preventing diarrhoea
Comparison: 11 Water quality intervention versus control, by measure of effect used
Outcome: 01 Diarrhoea, by measure of effect

Study or sub-category	log[ratio] (SE)	ratio (random) 95% CI	Weight %	ratio (random) 95% CI
01 Risk Ratio				
Alam 1989	-0.1863 (0.0795)		3.00	0.83 [0.71, 0.97]
Aziz 1990	-0.2877 (0.0329)		3.04	0.75 [0.70, 0.80]
Mahfouz 1995	-0.5978 (0.3050)		2.47	0.55 [0.30, 1.00]
URL 1995(arm 1)	-0.7550 (0.4476)		2.02	0.47 [0.20, 1.13]
URL 1995(arm 2)	-1.0498 (0.4931)		1.89	0.35 [0.13, 0.92]
Xiao 1997	-0.7985 (0.0222)		3.05	0.45 [0.43, 0.47]
Semenza 1998	-1.8971 (0.3704)		2.26	0.15 [0.07, 0.31]
Roberts 2001	-0.2357 (0.1353)		2.92	0.79 [0.61, 1.03]
Gasana 2002	0.0000 (0.0578)		3.03	1.00 [0.89, 1.12]
Jensen 2003	-0.0619 (0.1288)		2.93	0.94 [0.73, 1.21]
Garrett 2004	-0.8210 (0.2295)		2.69	0.44 [0.28, 0.69]
Subtotal (95% CI)			29.30	0.61 [0.47, 0.79]
Test for heterogeneity: Chi² = 335.94, df = 10 (P < 0.00001), I² = 97.0%				
Test for overall effect: Z = 3.74 (P = 0.0002)				
02 Rate Ratio				
Handzel 1998	-0.4005 (0.1093)		2.96	0.67 [0.54, 0.83]
Colford 2002	-0.6162 (0.3420)		2.35	0.54 [0.28, 1.06]
Luby 2004a(arm 1)	-0.5108 (0.1717)		2.84	0.60 [0.43, 0.84]
Luby 2004a(arm 2)	-1.2040 (0.2806)		2.54	0.30 [0.17, 0.52]
Lule 2004	-0.2231 (0.1138)		2.95	0.80 [0.64, 1.00]
du Preez 2004	-1.5606 (0.5441)		1.74	0.21 [0.07, 0.61]
Subtotal (95% CI)			15.40	0.56 [0.42, 0.74]
Test for heterogeneity: Chi² = 15.82, df = 5 (P = 0.007), I² = 68.4%				
Test for overall effect: Z = 4.04 (P < 0.0001)				
03 Longitudinal Prevalence Ratio				
Kirchoff 1985	0.0677 (0.0993)		2.98	1.07 [0.88, 1.30]
Austin 1993(arm 1)	-0.0513 (0.7245)		1.31	0.95 [0.23, 3.93]
Austin 1993(arm 2)	0.0100 (0.8544)		1.07	1.01 [0.19, 5.39]
Messou 1997	-0.5798 (0.2069)		2.75	0.56 [0.37, 0.84]
Chiller 2004	-0.4780 (0.1426)		2.90	0.62 [0.47, 0.82]
Crump 2004(arm 1)	-0.2614 (0.1072)		2.96	0.77 [0.62, 0.95]
Crump 2004(arm 2)	-0.1863 (0.1101)		2.96	0.83 [0.67, 1.03]
Doocy 2004	-2.1203 (0.0408)		3.04	0.12 [0.11, 0.13]
Luby 2004b(arm 1)	-0.7985 (0.3123)		2.45	0.45 [0.24, 0.83]
Luby 2004b(arm 2)	-0.7985 (0.3062)		2.47	0.45 [0.25, 0.82]
Luby 2004b(arm 3)	-1.0217 (0.3465)		2.34	0.36 [0.18, 0.71]
Subtotal (95% CI)			27.23	0.55 [0.26, 1.15]
Test for heterogeneity: Chi² = 836.94, df = 10 (P < 0.00001), I² = 98.8%				
Test for overall effect: Z = 1.58 (P = 0.11)				
04 Odds Ratio				
Conroy 1996	-0.4155 (0.1409)		2.91	0.66 [0.50, 0.87]
Conroy 1999	-0.3711 (0.0425)		3.04	0.69 [0.63, 0.75]
Quick 2002	-0.6539 (0.2799)		2.55	0.52 [0.30, 0.90]
Reller 2003(arm 1)	-0.2357 (0.1151)		2.95	0.79 [0.63, 0.99]
Reller 2003(arm 2)	-0.3011 (0.1111)		2.96	0.74 [0.60, 0.92]
Reller 2003(arm 3)	0.0305 (0.1335)		2.92	1.03 [0.79, 1.34]
Reller 2003(arm 4)	-0.3011 (0.1221)		2.94	0.74 [0.58, 0.94]
Clasen 2004	-1.2040 (0.2291)		2.69	0.30 [0.19, 0.47]
Clasen 2004a	-0.7550 (0.3427)		2.35	0.47 [0.24, 0.92]
Subtotal (95% CI)			25.30	0.68 [0.58, 0.80]
Test for heterogeneity: Chi² = 26.40, df = 8 (P = 0.0009), I² = 69.7%				
Test for overall effect: Z = 4.85 (P < 0.00001)				
05 Ratio of Means				
Quick 1999	-0.5621 (0.1978)		2.78	0.57 [0.39, 0.84]
Subtotal (95% CI)			2.78	0.57 [0.39, 0.84]
Test for heterogeneity: not applicable				
Test for overall effect: Z = 2.84 (P = 0.004)				
Total (95% CI)			100.00	0.57 [0.46, 0.70]
Test for heterogeneity: Chi² = 1890.54, df = 37 (P < 0.00001), I² = 98.0%				
Test for overall effect: Z = 5.16 (P < 0.00001)				

4.1.12 Potential Outliers

The forest plot of the measures of effect from all 38 interventions suggests at least one possible outlier. By definition, an outlier is an observation that differs so widely from the rest of the data as to suggest a possible error or that the observation comes from a different population (Last 2001). Doocy (2004) was a 12-week RCT of use of a combined flocculant/disinfectant amid temporary shelters in a Liberian camp for displaced persons. The intervention was exceptionally protective (RR 0.12, 95%CI: 0.11 to 0.13). While data supplied on this study suggests the trial to be well-designed and to meet the quality criteria for RCTs under this review, it has not yet been published and thus subjected to peer review. It seems possible that the population and conditions presented in the camp may not be strictly comparable with those of the other studies comprising this review. It may be difficult to discern, for example, whether the high diarrhoea observed was in fact endemic. Another possible outlier is Semenza 1998. Unlike most other study settings where the intervention was introduced among populations who appear to have been relying on contaminated sources for many years, here the intervention benefited a population that relying on a previously functional water distribution system which had collapsed, thus potentially creating an outbreak.

4.1.13 Mortality

Two studies reported on mortality, though mortality was not the primary outcome of either of these studies. Crump 2004 reported a relative risk of death of 0.53 (p=0.052) for the flocculant/disinfectant arm of a household-based water treatment intervention and 0.61(p=0.108) for the disinfectant only intervention arm. In that study, no physical or verbal autopsy was performed, and no association between deaths and diarrhoea was established. Messou 1997, which involved a combination of source water improvement with an oral rehydration intervention and hygiene instruction, reported an 85% reduction (from 27% to 4%) in the proportion of deaths related to diarrhoea in the villages with the intervention (p=0.04) compared to no reduction in control villages. That study also reported an 85%

reduction (from 5.3% to 0.8%) in the case fatality rate associated with diarrhoea morbidity among intervention villages (p=0.04) with no corresponding decline in control villages.

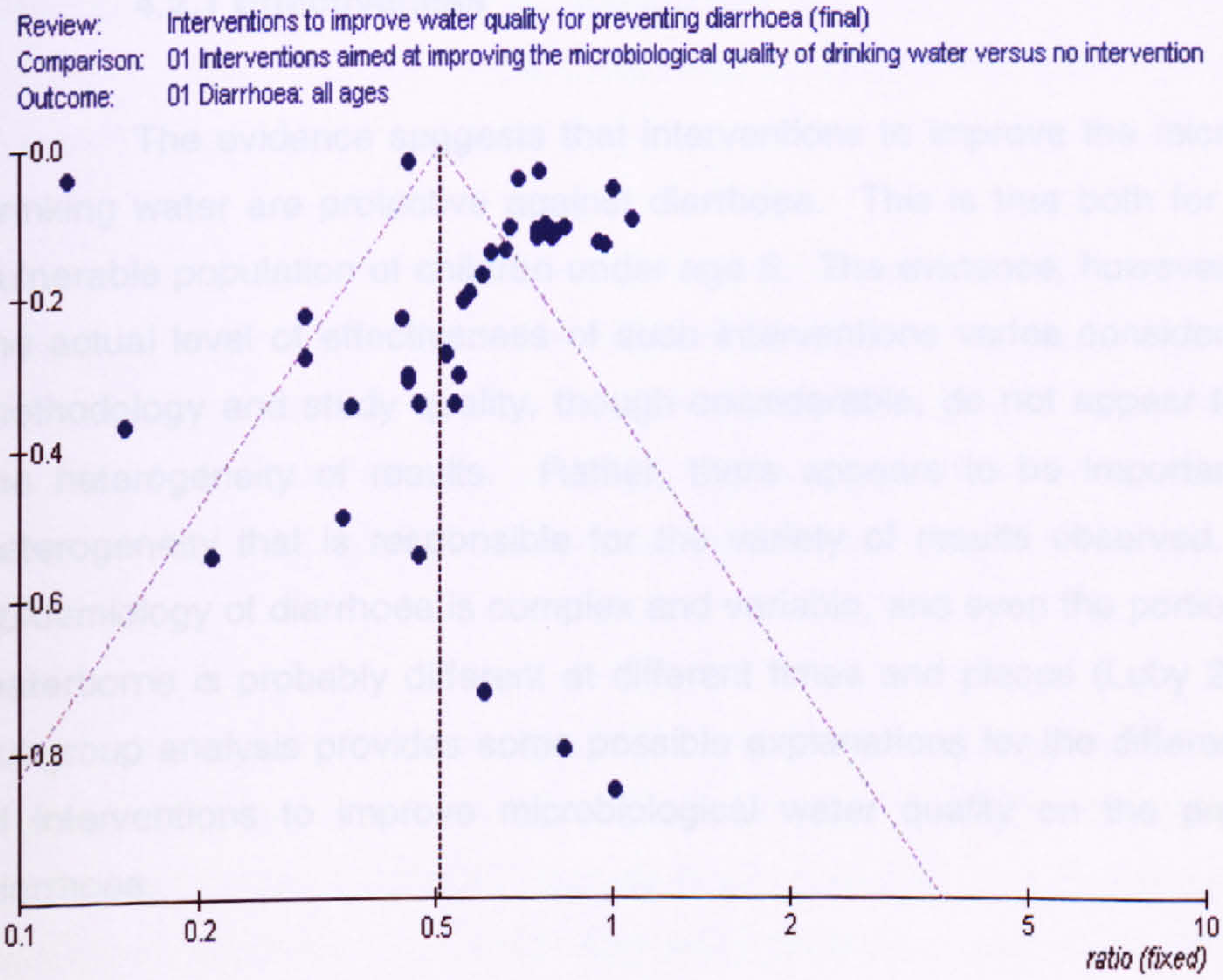
4.1.14 Adverse Events

No adverse events were reported from the interventions described in studies included in the review.

4.1.15 Publication Bias

Figure 4.1.15 presents a funnel plot of the estimate of effect of the trials and the standard error (reflecting the study precision). The asymmetrical shape of the funnel plot is suggestive of publication bias. However, funnel plot asymmetry may also be due to clinical and methodological heterogeneity. Since we found substantial evidence of such heterogeneity, it cannot be concluded that funnel plot demonstrates evidence of publication bias in this case. While statistical tests of publication bias have been proposed, these are not yet well accepted (Egger 2001) and accordingly the results are not presented here.

Figure 4.1.15: Funnel plot for publication bias



4.1.16 Sensitivity Analysis

Because this review is chiefly descriptive, no sensitivity analysis is presented. As discussed above, however, the pooled estimate for household combined flocculation/disinfection and impact of water quantity are shown with and without the inclusion of the studies identified as potential outliers. Comparisons 04 to 11 are useful in judging sensitivity based on certain subgrouping criteria.

4.2 Discussion

This review assesses the impact of interventions to improve microbial water quality on diarrhoeal disease. Thirty studies covering 38 interventions and more than 53,000 subjects met the review's inclusion criteria. Substantial clinical and methodological heterogeneity among the studies allowed only limited meta-analysis. Our focus, therefore, has been primarily descriptive. Where appropriate, however, we have endeavoured to interpret the evidence, while at the same time noting some of the issues that necessarily limit the conclusions that can be drawn therefrom.

4.2.1 Effectiveness

The evidence suggests that interventions to improve the microbiological quality of drinking water are protective against diarrhoea. This is true both for all ages and for the vulnerable population of children under age 5. The evidence, however, is not absolute and the actual level of effectiveness of such interventions varies considerably. Differences in methodology and study quality, though considerable, do not appear to completely explain the heterogeneity of results. Rather, there appears to be important underlying clinical heterogeneity that is responsible for the variety of results observed. The aetiology and epidemiology of diarrhoea is complex and variable, and even the portion of diarrhoea that is waterborne is probably different at different times and places (Luby 2004). Nevertheless, subgroup analysis provides some possible explanations for the differences in effectiveness of interventions to improve microbiological water quality on the prevention of endemic diarrhoea.

First, household interventions, though also varying considerably in results, are considerably more effective in preventing diarrhoea than interventions at the water source. This finding offers a possible explanation for the apparent inconsistency between the growing number of studies on household interventions that have demonstrated levels of effectiveness that are twice or thrice the levels reported by Esrey and colleagues (Esrey 1985; Esrey 1991). Esrey's reviews extended only to studies investigating improvements of water quality at the source, not at the household level. The 15% to 17% median reduction in diarrhoea that they reported is within the range of our findings for source-based interventions. Household-based interventions appear capable of significantly higher levels of effectiveness. Among household interventions, the evidence to date suggests that filters offer the most consistent and effective results.

Second, there is some evidence that effectiveness is enhanced by compliance with the intervention. While this may appear intuitive, it suggests a dose-response association between compliance and results, one of the Bradford Hill criteria for evidence of a causal relationship. It also implies the need to address compliance as part of any intervention to improve water quality. This may involve both the inherent acceptability and appeal of the hardware components of the intervention as well as programmatic support to increase utilization. To the extent that interventions are deployed at the household rather than community level, this also implies the need to address compliance during routine activities outside the home such as school and work.

Third, while there is strong evidence that water quality interventions are effective in settings in which water quantity is sufficient (i.e., more than 15L per person per day), there is some evidence that this may not carry through to settings with insufficient water quantity. If substantiated by further research, this may have important implications in determining the locations that would be suitable for interventions that improve water quality but do not affect quantity.

While sufficient quantities of water may be a condition to the effectiveness of water quality interventions, the evidence does not imply that an "improved" supply of water as defined by the WHO/UNICEF survey (i.e., consisting of a household connection, public standpipe, borehole, protected dug well, protected spring, or rainwater collection) is essential in order for water quality interventions to prevent diarrhoea. This finding affirms the strategy of the WHO to pursue household water treatment and safe storage as a means of accelerating the health gains of safe drinking water even though it may not reduce the 1.1 billion currently without access to improved water supplies.

Fourth, although there is evidence that water quality interventions are more effective in settings with "improved" sanitation (i.e., connection to a public sewer or septic system, pour-flush latrine, simple pit latrine, ventilated improved pit latrine), such interventions are nevertheless protective even where sanitation has not yet been improved. This is in contrast to conclusions that interventions to improve water quality are effective only where sanitation has already been addressed (Esrey 1986; vanDerslice 1995).

Finally, subgroup analysis did not demonstrate that the effectiveness of a water quality intervention to prevent diarrhoea is enhanced by adding hygiene instruction, a separate vessel to treat or store water, or by improving sanitation or water supply. This apparent lack of synergistic effect among common interventions targeting diarrhoeal disease was also observed by Fewtrell and colleagues (2004). This is consistent with the separate finding that except with respect to water quantity, the effectiveness of a water quality intervention does not depend on baseline conditions with regard to other environmental parameters that are associated with diarrhoea, such as improved sanitation and water supply. At the same time, it challenges conventional wisdom about the need for an integrated approach—combining water, hygiene and sanitation—to achieve meaningful gains in preventing diarrhoea. It also implies that the cost and effort of combining the water quality intervention with improved hygiene, water storage, water supply or sanitation may not be justified on the basis of a synergistic effect on diarrhoeal disease alone. This is explored further in Section 10.2.4.

4.2.2 Study Design

As noted above, studies that meet this review's quality criteria show a greater overall level of effectiveness than those that do not. However, three points must be made regarding study quality and any comparisons based on the quality criteria used in this review. First, this review included both RCTs and quasi-RCTs, and by necessity, employed different quality criteria for each of these two types of study design. The quality criteria may not yield conclusions about the quality of the two types of designs that are strictly comparable. Second, because household-based interventions tended to use the RCT design while source-based interventions exclusively used the quasi-RCT design, there is an important bias that may affect the comparison. If, as suggested, the criteria for study quality for RCTs and quasi-RCTs are not strictly comparable, this bias would affect the comparison of household versus source water interventions. Finally, with four criteria for assessing quality for RCTs, conclusions about study quality could also lead to an unintentional bias. For example, among the 3 blinded studies, only 1 was deemed adequate on even 2 other quality criteria applicable to RCTs. The application of these criteria would thus skew the results against blinded trials.

Only 3 of 19 RCTs were blinded, and in each case the intervention had no statistically significant protective effect. This must give pause to any definitive conclusion about the potential value of water quality intervention in the prevention of diarrhoea. The authors of each of these studies, however, suggest possible explanations for their findings. Colford was the only study conducted in a developed country setting and the water already complied with US standards (Colford 2002). Kirchhoff 1985, though a pioneering RCT of a potentially important household intervention, had a study population of only 112 persons (smallest of all 38 trials included in this review) and failed each of the other three other criteria of methodological quality. Austin also suggests possible methodological issues (Austin 1992). Future trials should take steps to address this issue by following a blinded design wherever possible.

4.2.3 Study Quality and Methodology

The review found significant heterogeneity in the effectiveness of interventions to improve water quality to prevent diarrhoea, and we used subgrouping to investigate the possible sources of that heterogeneity. Subgroup analysis suggests that there are clinical sources of heterogeneity based on the point at which the intervention is deployed (water source versus household) and among the various household interventions themselves. However, given the heterogeneity within most of these subgroups, and the differences in study design and methodology employed in the included trials, we cannot rule out the possibility that such heterogeneity is also methodological. There are several reasons why it may be difficult here to distinguish these clinical and methodological sources of heterogeneity.

First, the study design of the trials included in this review is not independent of the type of intervention used in the trial. As noted in the Description of Studies, all 6 studies involving interventions at the source are quasi-RCTs, while 19 of 23 point-of-use interventions used an RCT design. Although this mainly reflects the difficulty in randomising users of source water interventions, the skewing of design between the two types of interventions could possibly account for differences in the results observed.

Second, study length was not independent of the point of intervention, and may in fact be responsible for much of the difference observed in the effectiveness of source- and household-based interventions . The median duration of trials of interventions at source was more than 6 times longer than those involving interventions at the household level. Four of 6 such source-based intervention studies were of 3 years' duration or longer, while only 3 of the 32 household-based interventions covered even one year. Where, as here, compliance with the intervention is shown to significantly enhance its effectiveness, it is reasonable to expect that longer term trials where compliance may be difficult to maintain would yield an overall lower measure of effectiveness than shorter term trials. Moreover, seasonality, which is well known to play a major role in diarrhoea incidence (Blum 1983), could be responsible for important differences in the effectiveness of interventions measured over different periods of time. Failure to include at least 12 months' data on diarrhoea may overstate or understate the annual burden of disease in the underlying population and correspondingly influence the measure of effect. The impact that study length may have contributed to the differences in results from the trials included in this review should not be underestimated. Only longer RCTs of household-based interventions will help clarify how much study length affected the results of the systematic review.

Third, compliance with the intervention was probably not independent of the point of intervention. Household-based interventions all require some effort on the part of the householders to treat their water, to have treated water consistently available, to avoid recontaminating it, and to refrain from drinking from untreated sources. Each of these conditions creates an opportunity for non-compliance. Most source-based interventions, on the other hand, extended to the household's entire water supply without any additional compliance steps on the part of the intervention population. Thus, compliance was probably higher among groups using source rather than household-based interventions. If compliance is naturally lower among household-based interventions, than this bias may be a natural concomitant. But if compliance can be improved (as it apparently was in some studies), then the higher natural compliance with source interventions may overstate the their effectiveness compared to interventions at home.

Fourth, participants are more conscious of interventions carried out in their home than those at a distant water source or treatment works. This could lead to bias in studies that are not blinded. We also note the risk of courtesy bias and Hawthorne effect that may conspire to overstate the effectiveness of the interventions covered by this review, particularly non-blinded studies of household-based interventions which were often research-driven with perhaps more intensive investigator presence. Finally, unlike the source-based interventions, some of the household-based interventions used in the studies were commercially-developed and company representatives were sometimes on site or otherwise involved in the research.

Fifth, water availability should be considered in interpreting our results. Interventions at the source are frequently designed primarily to improve the water quantity and availability rather than quality. On the other hand, as noted in the Background section above, such improvements in water supply may be a separate and possibly more significant contributor to health than water quality. In the case of the household-based interventions, the fact that most of these appear to have been undertaken in settings where there was already sufficient water quantity may limit the generalisability of their results to locations where water supplies are adequate.

Finally, as noted above, the interventions employed in these studies are known to have varying levels of microbiological performance against different types of diarrhoea causing organisms, particularly under different water conditions. In a setting in which diarrhoea was mainly viral, ceramic filters would be only marginally protective. Similarly, where cryptosporidium or another chlorine-resistant agent is an important cause of diarrhoea, chlorination may provide little if any protection. Even within these categories of interventions, there are important differences in microbiological performance. For example, the filtration subgroup includes ceramic filters that are not generally effective against viruses and reverse-osmosis filters that are. Similarly, while the sodium hypochlorite used in most chlorination studies has certain antimicrobial capacity, other chlorine studies used mixed oxidants (Quick 1999) that have been shown to have broader biocidal effect (Venczel 1997a). Since none of the studies included in this review continuously monitored the full range of diarrhoea pathogens present in the drinking water of the study population and few studies attempted to determine clinically the apparent causes of diarrhoea in such population, it is difficult to compare the interventions based on their microbiological performance. This difference in field performance also illustrates another potential flaw in pooling for analysis seemingly similar interventions such as filtration and chlorination.

4.3 Conclusions and implications

With 38 trials from 30 studies, all of which are RCTs or quasi-RCTs, there is now considerably more evidence on which to assess the effectiveness of water quality interventions on diarrhoea than was available for previous reviews. Overall, these studies suggest that interventions to improve the microbiological quality of drinking water, particularly at the household level, are more effective in preventing diarrhoea in endemic settings than reported by previous reviews. In this respect, our results call into question the dominant paradigm established by Esrey and colleagues on the value of water quality interventions vis a vis other environmental approaches to the prevention of diarrhoeal disease.

The results also make clear, however, that single estimates of the effectiveness of water quality interventions against endemic diarrhoea, appealing as they may be to policy makers, donors and programme implementers, are not warranted by the evidence. Studies have shown a wide range of results, including a number of trials where no statistically significant protective effect was observed. While there are important differences in study quality and methodology, it appears that much of the heterogeneity among the trials included in this review is attributable to important underlying differences in the populations, settings and interventions that our subgroup analysis could only partially explain. Further research will be necessary to define more precisely the conditions and circumstances under which these interventions are most effective. However, because the proportion of diarrhoea that is waterborne varies in different times and places (Luby 2004), we may never be able to eliminate heterogeneity or fully define the impact of water quality interventions on this insidious disease.

Rigorous, multi-arm RCTs in different settings that compare various approaches to improving drinking water quality will help clarify the potential for water quality interventions to prevent endemic diarrhoea. It is particularly important that such trials be blinded, if possible, not only for the methodological reasons that favour blinded trials generally but also because of the mixed effectiveness achieved in blinded water quality intervention studies to date. There is also a need for longer-term studies, especially on household-based interventions. Our results also demonstrate a need for additional studies on the extent to which these water quality interventions affect mortality and not just morbidity. The difference in results between source and household interventions, and the range of results among the various core household approaches themselves, suggest the need to understand better how water quality interventions with similar microbiological performance nevertheless may result in different levels of effectiveness in preventing disease. This also implies the need to explore and assess the extent to which new technologies for improving water quality may be suitable for use among remote and low-income settings where the burden of diarrhoeal disease is highest. Differences in programmatic approaches to optimise the adoption and long-term utilization of these interventions should also be investigated.

Ultimately, however, the value of water quality interventions in preventing diarrhoeal disease depends not only on their effectiveness but also on their affordability, acceptability, sustainability and scalability within a vulnerable population. Unlike microbiology and epidemiology, this will require research skills that are not well-developed in public health. Comprehensive cost-effectiveness and cost-benefit analyses will help establish the priority that should be attached to water quality interventions by the public sector and non-governmental organizations. The cost-effectiveness analysis in Part II of this thesis is intended to help policymakers compare interventions on not only on the basis of effectiveness, but the combination of effectiveness and cost, thus providing a more complete basis on which to establish priorities and allocate limited resources. Finally, since household interventions appear particularly effective, the private sector, which has particular capacity for addressing the needs of householders, should be explored as a potential source for developing effective, low-cost water treatment interventions on a wide scale.

PART II
COST AND COST EFFECTIVENESS

Chapter 5: Introduction and Methods

5.1 Introduction

The Cochrane review on interventions to improve water quality for preventing diarrhoea provides important information on the effectiveness of certain interventions against a leading disease. As discussed in Chapter 1, however, the ultimate impact of such interventions is not merely a function of their effectiveness but also their cost as this affects the likelihood that they will be implemented and on how wide a scale.[15] Combining information on effectiveness and cost in a cost-effectiveness analysis (CEA) provides policy makers with a valuable basis on which to compare and ultimately select from an array of possible interventions. This part describes the methodology (Chapter 5) and results (Chapter 6) of such a CEA commissioned by the WHO in order to compare household-based water treatment interventions *inter se* and with conventional source-based interventions.

In recent years, the economic evaluation of health interventions has become an important area of inquiry and analysis. Leading institutions have refined methods and developed guidelines for the conduct of CEAs (Drummond 1996; Weinstein 1996; Murray 2000). In re-examining its own approach, the WHO undertook various studies, including an assessment of the major considerations respecting the cost-effectiveness of environmental health interventions (Hutton 2000). Among the findings of that investigation were the alarming lack of CEAs with respect to environmental interventions and the failure of health ministries to consider the costs and benefits of such interventions in setting policy. That study also found certain challenges in conducting CEAs of environmental interventions, including the difficulty in assessing costs and cost offsets, and the uncertainty of results arising from methodological difficulties, lack of reliable data and non-generalisability of data between settings. While the WHO has attempted to address these issues in developing its

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[15] While effectiveness and cost are perhaps the most important considerations in evaluating such interventions, acceptability, affordability, scalability and sustainability are also key considerations. These are discussed in Chapter 10.

own guidelines for CEAs, the methodology is still in development and its reliability should not be overestimated.

In a review published in 2001, 24 studies addressing the economic aspects of water and sanitation interventions were identified (Hutton 2001). Fifteen of these are WTP studies, 3 were cost-of-illness studies, and most of the rest covered sanitation or interventions other than drinking water or microbial water quality. Only Briscoe (1984) and Varley (1998), both of which were discussed in Chapter 1, deal specifically with the cost-effectiveness of interventions to improved drinking water supplies, and even these have certain limitations. Briscoe mainly deals with methodological issues, presenting data to support his contention that water and sanitation interventions are as cost-effective as oral rehydration in reducing the incidence of diarrhoeal diseases. Varley's analysis is of a hypothetical city using data collected from various countries. Since Hutton's review, only two additional CEAs of water supply interventions have been published (WHO 2002; Cairncross 2004)[16]. Cairncross and Valdmanis estimated CERs of US$94 and US$223 per DALY averted for handpump/standpost and household connections, respectively. Using costs based on water sector regulation, advocacy and promotion, the CER was US$47. They used the US$150/day averted threshold discussed in footnote 26, concluding that the handpump/standpost option was cost effective, while the household connection (unless using the lower regulatory-based cost estimate) was not.

The 2002 World Health Report concluded that "the intervention which is consistently the most cost-effective across regions and would be classified as very cost-effective in all areas where it was evaluated was the provision of disinfection capacity at point of use. On purely cost-effectiveness grounds it would be the first choice where resources are scarce." It also noted that adding basic low technology water and sanitation to this option would also be either very cost-effective or cost-effective in most settings, but that moving to the ideal of piped water supply and sewage could not be considered a cost-effective means of improving health in poor areas of the world. The actual data on which these conclusions are based can be found on the WHO-CHOICE database (http://www3.who.int/whosis/menu.cfm?path=whosis,cea&language=english).

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[16] CEAs of related interventions have also been published recently, including a latrine revision programme in Kabul (Meddings 2004), hygiene promotion (Borghi 2002; Christoffers 2004), zinc as an adjunct therapy for acute childhood diarrhea (Robberstad 2004) and various interventions for achieving the MDGs discussed in Section 6.8 below.

The WHO's conclusions regarding the cost effectiveness of point-of-use disinfection were an important impetus for household based water treatment. They are also a reason to compare chlorination with other approaches to household-based water treatment. At the same time, they provide an opportunity to revisit the assumptions on which these conclusions were based and to place the cost-effectiveness of household-based water treatment in a context with conventional public interventions to improve water supplies, such as stand posts, dug wells and boreholes. That is the purpose of this Part II.

5.2 Qualifications

In considering the results of the CEA which follows ("this CEA"), four qualifications should be noted. First, insofar as the effectiveness data on which this CEA is based concerns only the prevention of diarrhoea, this analysis reports only on the cost-effectiveness of selected interventions to prevent diarrhoea. Thus, it does not address diseases such as typhoid, hepatitis A and E and polio that may be transmitted by the ingestion of unsafe water but whose pathology does not consist of diarrhoea. While the burden of disease associated with diarrhoea dwarfs any other waterborne disease, these other diseases cannot be ignored. Moreover, because the Cochrane review was limited to endemic diarrhoea, the impact of such interventions on epidemic diarrhoea will not be included in the DALYs averted. By the same token all benefits other than health impacts will be ignored below. In these respects, this CEA will understate the true impact of such interventions.

Second, the comparison of household-based interventions with conventional improvements in water supplies (household taps, protected wells, rainwater harvesting, etc.) presents at least three potential problems. First, as discussed above, these interventions are in an important sense more than interventions to improve water quality—they also typically increase water quantity and availability. To the extent that quantity and availability impact diarrhoeal disease, this is captured in the effectiveness estimates from the Cochrane review. However, it is likely that increased quantity and access provides other health benefits, such as reducing water-washed diseases such as trachoma, improving personal hygiene thereby further impacting faecal-oral diseases, and saving time which may translate into improved nutrition and attention to risk factors at home (Esrey 1991; Cairncross & Valdmanis 2004). Since household-based interventions do not typically increase the quantity or availability of water, they would not offer comparable benefits. Second, because the Cochrane review identified only 6 trials of source interventions, no subgrouping within this category was possible to draw out possibly important differences in the effectiveness of the various types of source-based interventions. Esrey (1991) observed, and Cairncross & Valdmanis (2004) recently emphasized with further data, that larger reductions in diarrhoea were achieved from improvements in water supply that piped water into or near the home than those involving protected wells, tubewells or standpipes. As discussed more fully below, household connections are excluded from this CEA since the effectiveness data from the Cochrane review did not include any studies involving interventions to improve household connections (with the arguable exception of Jensen (2003), who introduced chlorine into an existing distribution system that included household connections). For assessments of the cost effectiveness of household connections, readers are referred to Cairncross & Valdmanis (2004).

Third, insofar as a CEA addresses only a specific health outcome, it will not encompass the non-health benefits of these conventional improvements in water supply. As Hutton & Haller (2004) concluded in their CBA, most of the benefits associated with improvements in water supply are associated with time savings and improved productivity. Household treatment of drinking water provides few benefits other than health, and as the Cochrane review concluded, even the health benefits are not clearly available in settings where there is not already a minimum level of water quantity available. Thus, while the CEA can help focus attention on optimal solutions to reduce diarrhoea, it must be read with a CBA to understand the overall impact of the possible interventions.

Finally, cost and cost-effectiveness, important as they are for setting health priorities, must be considered in the context of other economic and non-economic criteria, especially if the goal is to achieve a sustainable solution by having some or all of the cost of safe drinking water borne by the beneficiaries. Among the other economic criteria are affordability and perceived value. The fact that a point-of-use water treatment product may improve water quality at a lower cost per unit (person, household, day, litre, etc.) than some alternative product may be important to government planners, funders and policy makers. But to consumers being asked to pay for the product, the overriding consideration may be whether they have enough money on hand that day to buy it (Prahalad 2005). Such "ability to pay" may depend not on the cost as determined by economic analysis, but on the price at that time and place that the householder must pay.[17] A bottle of dilute sodium hypochlorite that costs $1.50 and can last a family six months has a significantly lower unit cost than a sachet of flocculant/ disinfectant priced at $0.10 and lasting less than a week. Nevertheless, as companies who market to the poor have frequently found, consumers with limited cash may nevertheless prefer the sachets because they find them to be more affordable. Similarly, consumers' "willingness to pay" depends largely on their current cash position, other priorities, assessment of the risk to be avoided, perceived utility of the proposed solution, etc., economic factors that are not strictly related to cost (Whittington 1990; Merrett, 2002). Rogers (2004) has shown that non-economic factors, such as compatibility, complexity and observability, also influence consumer attitudes and practices with respect to adoption of an innovative product. Policy makers and programme implementers must consider these factors in addition to basic cost and cost effectiveness if they expect to secure some measure of cost recovery in scaling up household water treatment.

5.3 Generalized Cost Effectiveness Analysis and WHO CHOICE

As its name implies, cost effectiveness is a measure of the cost of a particular intervention and its effectiveness with respect to a certain health outcome. Effectiveness requires an assessment of the fatal and non-fatal health outcomes that occur when an intervention is introduced. In general, interventions might change the incidence, duration of time within different health states, or the case fatality rate. Because interventions to improve water quality are preventive, the main outcome is first a reduction in the number of diarrhoea episodes and then a reduction in the number of deaths. As noted in Chapter 1, a common measure of the population health effect of the intervention is disability life years (DALYs) averted as a result of the intervention. DALYs are a time-based measure of health that include the impact of interventions on years of life lost (YLL) due to premature mortality and years of life lived with a non-fatal health outcome, weighted by the severity of the outcome.

There are a variety of methodologies for conducting CEAs (Gold 1996). Often, they are undertaken as part of an intervention study and therefore assess effectiveness and costs of one or two intervention arms in a particular setting, e.g., permethrin-treated bed

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[17] It is well known that lower-income populations pay a "poverty premium" for basic products and services such as water. Prahalad and Hammond (2002), for example, found that the price per unit of volume that the poor in Mumbai's Dharavi slum pay for water from a vendor was 37 times the municipal price charged in a neighbouring middle-class area receiving piped water.

nets in an area of intense malarial transmission in Western Kenya (Wiseman 2003) improved treatment for sexually transmitted diseases in preventing HIV-1 in Mwanza, Tanzania (Gilson 1997), and in-house residual spraying vs. insecticide-treated nets in Surat, India (Bhatia 2004)). Such an approach, however, is restricted to assessing the efficiency of adding a single new intervention to the existing set, or substituting one for another, both in a manner that is context-specific.

An alternative approach developed and now used by the WHO is known as "generalized cost-effectiveness analysis". The basic approach has been described (Murray 2000; Tan-Torres Edejer 2003). It has been utilized in a number of recent CEAs, including cataract surgery (Baltussen 2004), use of injection in health care settings (Dziekan 2003), interventions to lower blood pressure and cholesterol (Murray 2003), interventions to reduce depression (Chisholm 2004) and interventions to reach the MDGs for childhood survival (Tan-Torres Edejer 2005). Unlike other approaches to CEA, generalized CEA allows for a comparison of current interventions as well as interventions being considered for implementation on a sector-wide basis for a group of populations with comparable health systems and epidemiological profiles (Murray 2000).

Generalized CEA is used by the Global Programme on Evidence for Health Policy (GPE) under WHO-CHOICE (Choosing Interventions that are Cost Effective) (http://www.who.int/choice/en/). WHO-CHOICE assembles regional databases on costs, health impact and cost-effectiveness. It produces and publishes sets of regional cost-effectiveness estimates, for up to 50 interventions each quarter, of interventions against more than a dozen diseases, including diarrhoea. By employing generalized CEA in a manner that is compatible with the WHO-CHOICE methodology, health analysts not only can use the tools developed by the programme, but also draw on these databases to provide and compare cost and effectiveness data. More importantly, they can compare their results with other interventions against diarrhoea and other important diseases. By adopting this standardized approach, the results can be compared with a wide range of environmental and other interventions, providing important evidence for setting health priorities and allocating investments. WHO has developed a comprehensive guide for conducting generalized CEA (Tan-Torres Edejer 2003). Additional information, including software programs for collecting and analyzing costs (Cost-It), estimating the health impact of the intervention on a given population over time (PopMod), and calculating cost effectiveness ratios with uncertainty intervals (MCLeague) are also available on the WHO-CHOICE website.

In general, the process for conducting a generalized CEA at the country level consists of four basic steps. These include (i) defining the interventions to be investigated, as well as the counterfactual (null) or baseline state; (ii) estimating the effectiveness of the interventions; (iii) modelling the study population based on demographic, exposure and risk data, using the effectiveness data to determine the DALYs averted by each intervention compared to the counterfactual; (iv) estimating the costs associated with the interventions; and (iv) calculating the cost per DALY averted and interpreting the results. These basic steps, together with certain special considerations relevant to conducting a CEA in the context of water quality interventions to prevent diarrhoeal disease, are summarized below.

5.4 Defining the Interventions and Baseline

CEA compares the effect of one or more interventions against the counterfactual state of an alternative intervention. In generalized CEA, this alternative is the null, or the situation in which the intervention did not exist. The first step in the methodology is to determine the interventions to be investigated and to describe them precisely enough so that accurate information can be obtained regarding their costs and effectiveness. Among other things, it is important to that the interventions be defined with reference to the setting in which they will be undertaken, the population (including coverage level) to which they will be targeted, and the time horizon over which the interventions will be delivered.

As described in Chapter 1, a wide variety of interventions have been implemented to improve the microbiological quality of drinking water, including central water treatment leading to household connections, protected communal wells and springs, and, increasingly, household water treatment. In order for a CEA to yield useful comparisons of possible choices of interventions, the data respecting the cost and effectiveness of such interventions must be comparable. As described in Chapter 3, the studies included in the Cochrane review provided data on the effectiveness of only certain interventions to improve water quality: source-based interventions and four types of household-based interventions (chlorination, filtration, solar disinfection and flocculation/disinfection). As noted in Section 5.1, the studies on source-based interventions extended only to improving wells, boreholes and systems leading to communal tap stands, not to household connections. Because of the evidence from observational studies that household connections may be more effective than other source-based interventions in preventing diarrhoea, household connections are excluded from this analysis (Cairncross & Valdmanis 2004). Accordingly, this CEA will compare three forms of source-based interventions (tap stands, dug wells and boreholes) with the aforesaid four types of household-based interventions.

In generalized CEA, the subject is evaluated against a counterfactual or null. Because generalized CEA is designed to allow analysts to consider what would happen if all resources were reallocated, the counterfactual assumes that none of these interventions are implemented and all related interventions cease forthwith. However, in the present case, it was agreed after consultations with the WHO that the counterfactual would be the current status of water supplies. This is because, unlike a withdrawal of say a vaccination programme in favour of an alternative intervention, a reversal of water supply infrastructure is illogical; countries are not going to dismantle existing systems. Thus, the counterfactual in this case consists of the status quo. For purposes of this CEA, this is based on the most recent Global Water Supply and Sanitation Assessment (WHO/UNICEF 2000).

The time horizon over which to evaluate the interventions against the baseline must also be determined. While many interventions are evaluated over a year, this favours programs with relatively small start up costs even if they may have higher costs and lower effectiveness over the longer term when brought to scale. A long term (>25 years) is perhaps more accurate, but is beyond the planning cycle of policy makers. As a result, WHO recommends that when using generalized CEA, interventions be evaluated over a period of 10 years. The total cost of implementation thus includes annualized start-up costs prior to this 10-year period as well as 10 full years of implementation cost. As discussed more fully below, analysts should not necessarily assume that costs or effectiveness are uniform during this 10-year period.

5.5 Estimating Health Effects of the Interventions

The next step was to evaluate the impact of the interventions against the counterfactual. Like costs, it is possible to estimate the effectiveness of an intervention based on an individual trial. In its own estimate of the effectiveness of point-of-use disinfection for the *2002 World Health Report*, the WHO estimate assumed a 45% reduction in diarrhoeal disease as a result of the intervention. This was based on a single study (Quick 1999).[18] However, as the studies of water quality interventions have demonstrated, individual trials have shown a wide range of effectiveness in water quality interventions to prevent diarrhoea. Systematic reviews which are designed to reflect all available evidence on the effectiveness of a given intervention and to minimize bias provide a better basis on which to estimate effectiveness (Tan-Torres Edejer 2003). The current CEA is based on the Cochrane review presented in Part I. The effectiveness estimates are summarized in Table 5.5. The limitations and qualifications applicable to such pooled estimates and described in Sections 4.2 and 4.3 above should be borne in mind in considering the results of this CEA.

Table 5.5. Summary of pooled estimates of effect of water quality interventions for the prevention of endemic diarrhoea—all ages (from Chapter 4)

Intervention type (no. of trials)	Estimate of effect (random effects model)	Equivalent reduction (%) (1-estimate of effect)
Source (6)	0.73	27
Household (32)	0.53	47
Filtration (6)	0.37	63
Chlorination (16)	0.63	37
Solar Disinfection (2)	0.69	31
Flocculation/Disinf (ex Doocy)* (6)	0.69	31

*Identified in the systematic review as a probable outlier.

Many intervention studies have been conducted in such controlled or closely-supervised settings that their results are more indicative of efficacy rather than effectiveness (Hanson 2003). Experience has shown that the uptake, utilization rates and longer-term utilization of household-based interventions may be significantly less than anticipated, even if supported by substantial programmatic effort. These rates also vary by intervention. Moreover, intervention studies are often conducted over relatively short periods of time, or in populations that are not representative of a national population. Finally, these studies often report effectiveness compared to controls who practice other interventions, and thus do not reflect the null scenario. For these reasons, these rates of effectiveness, though representing the best available evidence to date and valid for comparing water quality

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[18] See, for example, http://www3.who.int/whosis/cea/interventiontable/WS/TableG.xls This compares to the Cochrane review's pooled estimate from 16 studies of household chlorination interventions of 37%.

interventions with other possible health options, should perhaps be discounted when applied locally to reflect more closely the outcomes that can actually be anticipated in practice, in the longer term and at full scale.

5.6 Estimating the Health Impact (DALYs Averted)

In order to estimate the impact of health interventions on an evolving population over time, WHO has developed PopMod, a software modelling programme (Lauer 2003). The programme tracks a given population over a period of 100 years. Users enter the incidence or prevalence, remission and case-fatality rates associated with a given disease such as diarrhoea, both under the null (baseline) conditions and with one or more interventions in place. In this way, it is possible to establish the population-level health gain (or disease burden averted) as a result of a given intervention relative to doing nothing (the null). Like Cost-It, PopMod can be downloaded from the WHO-CHOICE website, together with instructions and guidance on its use.

The steps in compiling the model for the present CEA follow the approach prescribed by WHO Choice. The population is also risk-adjusted for their exposure to faecal-oral diseases using the methodology described by Prüss (2002) and followed in the 2002 World Health Report (WHO 2002) and Hutton & Haller (2004) cost benefit analysis. Here the model was executed by Laurence Haller, a technical advisor at WHO and a co-author of their CBA. The main steps can be summarized as follows:

Step 1: Population figures by sex and age are entered using WHO estimates from the GBD 2000. In the present case, this was limited to 11 of 17 WHO epidemiological sub-regions (Table 5.4). The other regions were excluded from the analysis since nearly 100% of the population in these regions currently has access to regulated, piped-in water supplies.

Step 2: The population was then distributed among the various exposure scenarios for water and sanitation (Prüss 2002). Six exposure scenarios are defined, ranging from scenario I (ideal situation, corresponding to the absence of transmission of diarrhoeal disease through water, sanitation and hygiene) to scenario VI (no improved water supply and no basic sanitation in a country which is not extensively covered by those services, and where water supply is not routinely controlled). Allocation of populations to the various exposure scenarios was based on the Global Water Supply and Sanitation Assessment (WHO/UNICEF 2000).[19]

Step 3: The relative risk of diarrhoea was then entered for each sub-population resulting from Step 2. This was based on WHO estimates for risks associated with unsafe water (Prüss-Űstün 2004). These, in turn, are based on published reviews, large surveys and multi-country studies. [20]

Step 4: POPMOD is then run to estimate the healthy life years for each sub-population. This follows a simplified three-box model that (i) adjusts the susceptible population by the birth rate and mortality rate, (ii) calculates morbidity by applying the disease incidence rate and remission rate against the susceptible population, (iii) and calculates mortality based on the diarrhoeal disease case fatality rate. This provides the counterfactual or baseline rate prior to the introduction of the interventions. For non-fatal outcomes, the population model also contains a "health state valuation" (formerly, a "disability factor") to account for the percentage of disability for persons living with and ultimately recovering from diarrhoea.

Step 5: The incidence of disease is then adjusted to reflect the reduction in risk associated with each water quality intervention under investigation. Under this model, the household-based interventions were extended to populations in exposure scenarios IV-VI, while the source-based interventions were extended to populations in exposure scenarios V and VI only.[21] In order to provide complete results, the model was run

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[19] For a complete description of the exposure scenarios, see Section 1.3 of Appendix 5.2.

[20] Cairncross & Valdmanis (2004) suggest an alternative set of relative risks which they developed independently based on more conservative assumptions. However, in most respects relevant here, the two models are similar. In order to allow for comparability with other WHO economic evaluations, including the 2002 World Health Report and the Hutton & Haller CBA, the present analysis follows the Prüss assumptions.

[21] Exposure scenarios VI (no improve water supply and no basic sanitation in a country which is not extensively covered by those services, and where water supply is not routinely controlled), Vb (improved water supply and no basic sanitation in a country which is not extensively covered by those services, and where water supply is not routinely controlled), and Va (improved sanitation but no improved water supply in a country which is not extensively covered by those services and where water supply is not routinely controlled) are the settings in which source-based water interventions are appropriate; they already exist in exposure scenario IV (improved water supply and improved sanitation in a country which is not extensively covered by those services, and where water supply is not routinely controlled). As described in Part I, however, household-based interventions are

assuming 100% coverage for each intervention. Where the costs are linear (no positive or negative economies of scale in coverage), these figures can easily be adjusted to show the costs and CERs at more realistic coverage levels. POPMOD is then run again, with the difference in incidence rates impacting morbidity and mortality throughout the sub-populations The difference between the number of healthy life years lived by the population with and without the intervention is the number of DALYs averted (or healthy life years gained) as a result of that intervention.

It should be noted that the because of uncertainties in the projections, the model does not include an increase in the population over time or a change in the diarrhoea rates except as a result of the intervention.

Table 5.6: WHO Epidemiological Sub-regions included in CEA

Region*	Mortality Stratum**	Countries
AFR	**D**	Algeria, Angola, Benin, Burkina Faso, Cameroon, Cape Verde, Chad, Comoros, Equatorial Guinea, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Madagascar, Mali, Mauritania, Mauritius, Niger, Nigeria, Sao Tome And Principe, Senegal, Seychelles, Sierra Leone, Togo
AFR	**E**	Botswana, Burundi, Central African Republic, Congo, Cote d'Ivoire, Democratic Republic of the Congo, Eritrea, Ethiopia, Kenya, Lesotho, Malawi, Mozambique, Namibia, Rwanda, South Africa, Swaziland, Uganda, United Republic of Tanzania, Zambia, Zimbabwe
AMR	**B**	Antigua and Barbuda, Argentina, Bahamas, Barbados, Belize, Brazil, Chile, Colombia, Costa Rica, Dominica, Dominican Republic, El Salvador, Grenada, Guyana, Honduras, Jamaica, Mexico, Panama, Paraguay, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Surinam, Trinidad and Tobago, Uruguay, Venezuela
AMR	**D**	Bolivia, Ecuador, Guatemala, Haiti, Nicaragua, Peru
EMR	**B**	Bahrain, Cyprus, Iran, Jordon, Kuwait, Lebanon, Libyan Arab Jamahiriya, Oman, Qatar, Saudi Arabia, Syrian Arab Republic, Tunisia, United Arab Emirates
EMR	**D**	Afghanistan, Djibouti, Egypt, Iraq, Morocco, Pakistan, Somalia, Sudan, Yemen
EUR	**B**	Albania, Armenia, Azerbaijan, Bosnia and Herzegovina, Bulgaria, Georgia, Kyrgyzstan, Poland, Romania, Slovakia, Tajikistan, The former Yugoslav Republic of Macedonia, Turkey, Turkmenistan, Uzbekistan, Yugoslavia
EUR	**C**	Belarus, Estonia, Hungary, Kazakhstan, Latvia, Lithuania, Republic of Moldova, Russian Federation, Ukraine

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frequently implemented in settings described by exposure scenario IV, and the model must therefore reflect such coverage. Since large portions of the population in certain WHO epidemiological subregions fall into exposure scenario IV, the aggregate cost of extending coverage to such regions will be less than that of certain household-based interventions even though the annual per capita cost of coverage is less.

Region*	Mortality Stratum**	Countries
SEAR	**B**	Indonesia, Sri Lanka, Thailand
SEAR	**D**	Bangladesh, Bhutan, Democratic People's Republic of Korea, India, Maldives, Myanmar, Nepal
WPR	**B**	Cambodia, China, Lao People's Democratic Republic, Malaysia, Mongolia, Philippines, Republic of Korea, Viet Nam, Cook Islands, Fiji, Kiribati, Marshall Islands, Micronesia, Nauru, Niue, Palau, Papua New Guinea, Samoa, Solomon Islands, Tonga, Tuvalu, Vanuatu

*AFR=Africa; AMR=Americas; EMR= Eastern Mediterranean; EUR=Europe; SEAR=South East Asia; WPR=Western Pacific

**B=low adult, low child morality; C=high adult, low child mortality; D=high adult, high child mortality; E=very high adult, high child mortality

5.7 Estimating the Cost of the Interventions

Only a few published accounts present cost data for interventions to improve water quality. The cost of source-based interventions, such as public stand posts, dug wells and boreholes, is perhaps better established than for household-based interventions. As a starting point, Hutton & Haller (2004) and Cairncross & Valdmanis (2004) both used the initial investment (construction) costs per capita from the Global Water Supply and Sanitation 2000 Report (WHO/UNICEF 2000) (Figure 5.7). Hutton & Haller then estimated the useful life of the systems (20 years), added 5% for operation and maintenance, and an additional 5% (dug wells and boreholes) or 10% (stand posts) for water resource protection to arrive at an annual cost per person reached. The results are summarized in Table 5.7. Cairncross & Valdmanis, while raising a question about the household connection estimates, use US$40 per capita as the midrange figure for the three main types of public water points (stand posts, dug wells and boreholes). They then amortized this over the same 20 years, and added $1 per year for operation and maintenance, for a total cost of US$3 per person per year.[22]

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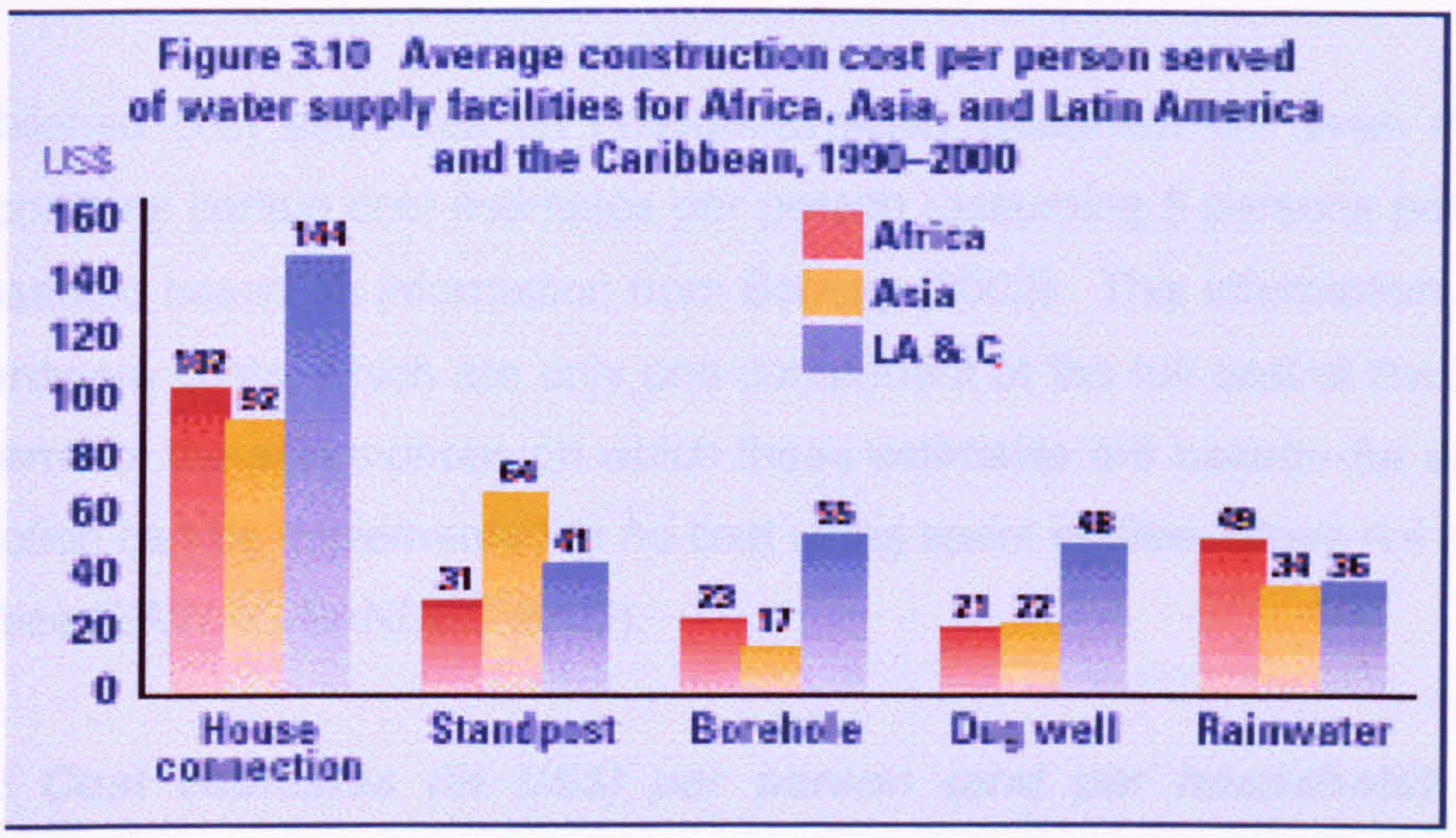
[22] Cairncross & Valdmanis (2004) also suggested an alternative cost of US$0.02 to US$0.10 per person per year, arguing (after Varley) that because investments in water supply an sanitation are made by non-health sectors, the actual cost should consist only of the regulatory, advocacy and promotion expenses, and not the construction and O&M costs. However, because this CEA adopts a "societal perspective" in which all costs must be included regardless of who assumes responsibility for payment, these costs must be included in the analysis.

Figure 5.7: Construction costs per person for selected water improvements in three regions



Source: WHO/UNICEF 2000

Table 5.7a: Annual costs per person for improvements in water supply

Intervention	**Annual Cost per person reached (US$ year 2000)**		
	Africa	**Asia**	**Latin America & Caribbean**
Standpost	2.40	4.95	3.17
Borehole	1.70	1.26	4.07
Dug Well	1.55	1.63	3.55

Source: *adapted from Hutton & Haller (2004)*

The Global Assessment acknowledges that its figures are rough estimates, and that local costs may vary widely based on population density and ease of access to water resources. There are, however, other reasons why these figures may not represent the full economic cost of these interventions. First, they appear to include only the direct costs of labour and material, and not indirect (overhead) costs (management personnel, office and warehouse facilities, transportation, communication, etc.) that would be incurred by the governmental or other organization implementing the intervention. Second, these figures do not include "software" costs that may be associated with the intervention. Many of the studies of such source-based improvements included in the Cochrane review included software components (e.g., Alam 1989; Aziz 1990; Messou 1997; Xiao 1997). Finally, the 20-year expected life of these systems may be excessive, even if the cost estimate is grossed up by an amount for operation and maintenance. Five years after installing pumps on tubewells in Bangladesh, Hoque (1995) found 18% of the pumps no longer functioning. In South Africa, Mathekgana (2001) found stand pipes working only 70% of the time.

Published cost estimates on household water treatment are even more limited. Table 5.7b contains certain cost estimates per person (assuming 5 persons per household) and per household based on information from Sobsey (2002). This information, however, is limited to hardware costs, which are only one component of the full cost of the intervention. Moreover, some of the assumptions on which these estimates are based—for example, that solar disinfection can be implemented at no cost using spent bottles—does not conform with current practice (EAWAG/SANDEC 2002).

Table 5.7b: Cost estimates (in US$) per person (and per household) for certain household water treatment systems

System	Initial Cost of Hardware	Annual Operating Cost
Chlorination (CDC Safewater Water System)	$1.60 ($8.00)	$0.60 ($3.00), but depends on local cost of chlorine
Ceramic Filtration	$5.00 ($25.00)	$1.00 ($5.00)
Solar Disinfection (Sodis)	None (assumes use of spent bottles)	None (assumes use of spent bottles)
Flocculation/Disinfection	$5.00 to $10.00 for vessel, etc.	$7.00-$11.00 ($35.00-$55.00) for chemicals

Source: adapted from Sobsey (2002)

Table 5.7c presents a second set of estimates collected by Lantange (2005). Once again, however, the cost data include only part of the full economic cost of an intervention using the specified option. In addition, like the above estimates, certain assumptions do not reflect the way the interventions were used in the health outcome trials from which the effectiveness data is derived. As discussed more fully in Section 6.2, for example, Lantange's estimate of 2 sachets per family per day for the combined flocculant-disinfectant, translates into 14 sachets per family per week, 14 times the amount claimed by Procter & Gamble, the manufacturer, to be necessary and more than that used in all but one effectiveness trial.

Table 5.7c: Cost estimates (in US$) per family for certain household water treatment systems

Household Water Treatment Option	Project Location and Implementer	Time Frame of Cost	Cost of Product paid by family or NGO purchasing it	Full Cost of Product (including delivery, installation, distribution, education, and marketing)
Chlorination	Zambia, PSI	Monthly purchase	1 bottle at $0.12 per family per month	$0.37 per bottle ($0.25 non-product cost subsidized by donor)
Chlorination	Haiti, JSWF	One time installation, plus Monthly purchase	1 bottle at $0.09 per family per month	$7 start-up fee per family to NGO $0.09 per family per month to family
Ceramic Filtration	Nicaragua, Potters for Peace	One-time cost	$10	Unknown
Solar Disinfection	Bolivia, PCI	Ongoing education	None - minimal	$11 per family for two years to NGO
Filtration and Chlorination	Haiti, GWI	One-time installation, plus Monthly maintenance fee	$12	$0.50 per month per family to NGO
Flocculation and Chlorination	Many, Emergency Response	Daily purchase	60 sachets at $2.10 total per family per month to NGO	Unknown

Source*: adapted from Lantange (2005)*

Finally, Table 5.7d presents more recent estimates for household water treatment options garnered from the programme implementers. Once again, these are only hardware costs and thus do not include much of the programmatic costs that Esrey (1985) and others have indicated can represent the greater share of cost in introducing and supporting certain water interventions. They even fail to include all of the hardware components often necessary for implementation of the system, such as special vessels for water storage in the case of the sodium hypochlorite and PUR interventions, and mixing and decanting apparatus for PUR. Accordingly, like those in Table 5.7b, these estimates fall short of what is needed for a CEA even though they are frequently cited as the true cost of the intervention.[23]

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[23] As described in Section 5.1, however, hardware costs can be presented in various units of measurement, including per capita, per volume, per month, etc. All of these provide potentially valuable information respecting the affordability of the option, a factor of critical significance when sustainability must depend on some measure of cost recovery. Thus, PSI, a social marketer of household water treatment products, markets and sells both diluted sodium hypochlorite for household-based chlorination of drinking water following the CDC Safe Water System (SWS) and PUR® sachets of combined flocculant-disinfectant. Even though the one-year household cost for using the PUR system is more than 22 times that of the SWS, PSI has found that some householders nevertheless prefer to use the PUR product because they can purchase a single portion for less than one-fourth the price of a bottle of WaterGuard (Clasen 2006).

Table 5.7d: Cost estimates (in US$) for certain household water treatment systems

Product	**Unit Cost**	**Volume of Water Treated**	**$/10,000L of Water Treated**	**First Year Cost[1]**	**Three Year Cost[1]**
WaterGuard™ (PSI brand of sodium hypochlorite[1]	$0.45	1,000	$4.50	$4.10	$12.32
Gravity filter with two 24 cm Katadyn® candles[3]	$25.00	100,000L	$2.50	$25.00	$25.00
Gravity filter with two 15cm Stefani® candles[4]	$15.00	20,000L	$7.50	$15.00	$30.00
Sodis Solar Disinfection[5]	$0.40	730L	$5.48	$0.80	$2.40
Procter & Gamble PUR® Sachet[6]	$0.10	10L	$100.00	$91.25	$273.75

Table assumptions and sources:

1. Based on 25L/day/household, or 9,125L/year.
2. 150ml bottle of 1.25% sodium hypochlorite designed to treat 1000L sold at retail in Tanzania and assuming full cost recovery (not subsidized); production cost is $0.17 per bottle (Clasen, 2006a).
3. $8.75 per candle, plus $7.50 for vessels and valves. 50,000L capacity per candle according to manufacturer. Replace entire system after 3 years. (Clasen 2004)
4. $3.75 per candle, plus $7.50 for vessels and valves. 5,000L capacity per candle according to manufacturer. Replace candles each year. Replace vessels and valve after 3 years. (Clasen 2004)
5. $0.10 per bottle (mean price based data from 6 countries) x recommended 4 bottles per household, used for 6 months; capacity based on 2 x 2L bottles (alternate 2 bottles in sun, 2 bottles in household each day) (M. Wegelin personal communication).
6. Manufacturer's suggested retail price of $0.10 per sachet. Assumes no further expenditure for mixing and storing vessels.

In estimating the cost of point-of use disinfection for the 2002 World Health Report, the WHO used certain estimates from the CDC intervention for household-based disinfection using sodium hypochlorite. The sales price of one litre of chlorine solution (which treats 1000 litres of water) was estimated at US$0.0942 in Asia, US$0.13 in Africa and US$0.273 in Latin America and the Caribbean. To calculate the annual cost per person, the estimate assumed 20L of treated water per person per day, or 7300L per year, requiring 7.3L bottles of chorine. This was grossed up to 8.76 bottles to allow for 20% wastage. Multiplying the number of bottles per person per year times the annual cost yields an estimated cost per person per year of US$0.83 in Asia, US$1.14 in Africa, US$2.39 in Latin America.[24] As can be seen, these estimates include only hardware costs. Curiously, the intervention is described in the WHO CHOICE database[25] as "disinfection at point of use with education" (emphasis added.) However, the cost estimates do not include any costs associated with education.

The WHO CHOICE database has some information on cost of selected generic inputs used in health interventions. For example, the database has information on the costs of personnel at various levels of responsibility, cost of warehouse and office facilities, vehicle and other transportation costs, media costs, and the cost of certain commodities. These represent an important resource for determining how local costs may differ from global, regional or other national estimates. However, in order to use such costs in a CEA, it is necessary to know the quantities of all such inputs required for the intervention.

For all of these reasons, the accuracy and completeness of existing cost information on household-based interventions was deemed inadequate to serve as the basis for a rigorous CEA. Accordingly, the starting point for this CEA was to solicit the cost information directly from those involved in the implementation of programs involving such interventions. Detailed guidelines (Appendix 5.1) and a worksheet (Appendix 5.2) were developed by the writer in consultation with L. Haller and B. Johns of WHO and D. Walker of LSHTM in order to ensure the consistent accumulation and reporting of costs and cost offsets. The worksheet also requested specific information on quantities as well as costs. This was designed to provide analysts with the opportunity to calculate costs in different countries based on the local costs for the inputs necessary to implement the intervention. In December 2004, the guidelines and worksheet were sent to 12 implementers of household-based water treatment interventions identified by surveys conducted by the International Network to Promote Household Water Treatment and Safe Storage.

For purposes of CEA, costs are usually divided between programme costs and patient or individual costs. As described more fully in the worksheet contained in Appendix 5.2, programme costs incorporate all resources used to start up and maintain the

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[24] These figures are derived from the spreadsheets supporting the WHO-CHOICE cost-effectiveness estimates. They can be found on the WHO-CHOICE database for each of the epidemiological sub-regions: http://www3.who.int/whosis/cea/cea_results_prog_costs.cfm?intInterventionID=50409 .
[25] http://www3.who.int/whosis/menu.cfm?path=whosis,cea,cea_prices&language=english

intervention over the period of implementation. Programme costs include administrative and technical personnel needed to develop and run the programme, materials and supplies, media, transport and capital items such as vehicles and office space (Johns 2003). Individual costs are those expenditures incurred by the targeted population at the point of delivery.

Under the WHO CHOICE procedure, programme costs are reported at the national, regional, community and household level, while individual costs are reported at the household level only. Confusion may arise as to whether certain costs incurred at the household level should be reported as programme costs or individual costs. Where a programme itself pays the cost of an item deployed in the household (e.g., a filter) and provides the same to the householder free of charge without any reimbursement or payment by the household, it is reported only as a programme cost at the household level. On the other hand, if the householder is required to pay all or a part of the cost of the item, the amount paid by the household was reported as an individual cost. Any subsidy or other non-reimbursed portion of the item must still be reported as a programme cost.

In collecting information on costs, it is also useful to include data on cost savings (cost offsets or costs averted) that have been demonstrated as a result of the implementation of the intervention. In the context of water quality interventions, these typically involve two categories of economic savings: health costs and other household savings. Health costs averted include health sector and patient costs saved due to less treatment of diarrhoeal diseases. WHO supplied this information from its own database based on the coverage and effectiveness. Improvements in water supply may offer time savings in collecting water, while both source and household-based interventions may also offer savings when introduced as an alternative, say, to boiling (potential savings in fuel expenditures and time to collect/procure wood or other fuel for boiling water) or purchasing drinking water. The guidelines and worksheet sought information from programme implementers on such non-health cost offsets.

Cost-It (cost intervention templates) is a software programme developed by WHO-CHOICE to record and analyze cost data. Set up as a spreadsheet into which cost information can be inserted, the programme automatically calculates the economic cost of interventions. Among other things, Cost-It includes macros for converting costs from any given year into a base year chosen by the analyst; it also allows costs to be adjusted for different levels of capacity. The software may be downloaded from the WHO-CHOICE website. User guides are also available.

Finally, it is noted that under the "societal" perspective used in generalized CEA, all costs related to the intervention are included in the analysis, regardless of whether they are incurred by the government, a donor, a programme implementer or the beneficiary. Such a perspective is consistent with notions of economic efficiency and more readily allows interventions to be compared on the basis of cost-effectiveness, regardless of the party responsible for payment. At the same time, analysts must note that some interventions may be better suited than others for full or partial cost recovery. Thus, as described more fully below, certain water quality interventions, such as bottles of sodium hypochlorite, may consist of products or services for which the users pay all or part of the cost, while others, such as communal tapstands, are paid for by the government. From a societal perspective, the cost of such interventions may be similar, and the CEA may thus yield a similar cost-effectiveness ratio. However, from the governmental or householder perspective, these interventions will have significantly different "costs" due to the different allocation of responsibility for payment. This must, of course, be considered in the overall analysis of the options.

5.8 Presenting and Interpreting the Results

Once the cost of each intervention is estimated per person per year, it is simply a matter of multiplication to determine the aggregate cost of extending that intervention at a given level of coverage over a given population. The model makes adjustment for economies of scale. That aggregate cost is then divided by the number of DALYs averted in that population to determine the CER (cost per DALY averted). In presenting the results, future costs and health effects are typically discounted to reflect their present values (Tan-Torres 2003). Subject to the discussion below regarding sensitivity analysis, WHO-CHOICE recommends discounting both costs and health effects by 3%. Results are reported for the actual cost estimate as well as the range.

The Commission on Macroeconomics and Health (CMH) has defined interventions that have a cost-effectiveness ratio of less than three times the gross domestic product

(GDP) per capita as "cost-effective" (WHO 2001).[26] Interventions that avert a DALY (or, conversely, gain a healthy life year, or HLY) at a cost that is less than the gross domestic product (GDP) per capita are defined as "very cost effective", and those that avert a DALY at a cost less than 3 times this amount are considered "cost effective". Interventions whose CERs are higher than this are considered "not cost effective." Table 5.8 shows the threshold established in International Dollars for the year 2000.[27] Converting $Is to US$s must be made on an individual country basis. For illustration, however, using the conversion factors for Kenya and India as indicative of the PPP for regions Afr-D and Sear-D, respectively, the corresponding US$ threshold for interventions to be considered "highly cost-effective" would be US$346 ($I1576 x 0.22) for Afr-E and US$ 275 ($I1449 x 0.19) for Sear-D.

Table 5.8: CMH classification of highly cost effective, cost-effective and not cost-effective interventions (I$ for year 2000)

	International dollars ($I)		
	Highly cost-effective	**Cost-effective**	**Not cost-effective**
WHO region	1 x GDP	3 x GDP	> 3x GDP
AfrD	1381	4143	>4143
AfrE	1576	4728	>4728
AmrA	31477	94431	>94431
AmrB	7833	23499	>23499
AmrD	3837	11511	>11511
EmrB	7870	23610	>23610
EmrD	2393	7179	>7179
EurA	23927	71781	>71781
EurB	5873	17619	>17619
EurC	6916	20748	>20748
SearB	3915	11745	>11745
SearD	1449	4347	>4347
WprA	27534	82602	>82602
WprB	4186	12558	>12558

Source: T. Adam, personal communication

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[26] The World Bank's 1993 World Development Report established a threshold of US$150/DALY averted based on then current data. Thus, CERs under US$150 per DALY averted were considered cost effective. While this threshold is still cited, a threshold based on national GDP is more useful in guiding national decisions.

[27] For an explanation of International Dollars ($I) and the manner for converting them to any currency, including US dollars (US$), see footnote 33 and the accompanying text.

APPENDIX 5.1

GUIDELINES FOR REPORTING COSTS FOR A COST EFFECTIVENESS ANALYSIS OF WATER QUALITY INTERVENTIONS

1.1 Perspective; Rather than limit this analysis to the costs incurred by the Ministry of Health (MoH), programme implementer, community, householder, etc., this analysis will assume a "societal perspective". Accordingly, all costs should be included, regardless of which entity bears the costs and the level at which they are incurred. It is acknowledged that some intervention programs require a contribution by householders, say in the purchase of hardware that will reduce the net cost of a MoH or programme implementer. The actual payer will be identified in the presentation of the cost data, thus allowing for proper planning by analysts and policy makers.

1.2 Avoiding Double Counting. While it is important to accumulate all costs associated with the intervention, it is also important not to double count and therefore overestimate costs. Such double counting may occur when, for example, a cost initially incurred by a programme implementer (say, for chlorine) and thus reported as a programmatic cost is subsequently sold to the householder and thus also reported under patient costs. In cases such as these, responders should net out any reimbursement/revenue from the householder, thus reporting the actual net outlay at the programmatic level, and report the amount paid by the householder under patient costs. The sum will thus represent one full cost, regardless of subsidy or payer.

1.3 Economic Definition of Costs. In order to capture the true cost of an intervention, CEAs generally use an economic definition of cost (i.e., all resources consumed by an intervention, whether or not actually paid for) rather than accounting or financial cost (actual expenditure). This means that costs should include the full market value of (i) donated goods and services, (ii) subsidized or artificially-valued goods or services, including volunteer time, (iii) capital items such as buildings or transportation, even if the same was not fully used; and (iv) the opportunity cost or value forgone, if any, by not utilizing the same resources in the most valuable alternative use.

1.4 Ingredients Approach. The ingredients approach requires a delineation of each of the various component costs (and quantities) of an intervention rather than simply specifying the overall aggregate costs. By presenting all of the constituent inputs of cost, analysts we be able to make adjustments in their own estimates for programme implementation based on their particular setting. They will also be able to validate some of their own assumptions about cost.

1.5 Capacity Utilization. Unit cost will depend significantly on utilization of capital and labour. Capacity utilization is defined as the proportion of the total target workload time a resource is actually used. A computer used for 5 hours in a 10 hour workday has a capacity utilization of 50%. To establish comparability in a CEA, it is useful to standardize at a particular level of utilization. WHO-CHOICE seeks to inform policy on the optimum mix of interventions, and therefore assumes a relatively high level of efficiency. The WHO CEA guidelines recommend using 80% capacity utilization as the norm. This same 80% utilization rate should be used in providing costs for this analysis.

1.6 Coverage Levels; Scaling Up. Cost effectiveness analysis normally involves the extrapolation of a given intervention to a larger population. Thus, it is necessary in assembling cost information to obtain precise data on the number of persons covered by a programme in order to determine the project this cost over the larger population (see Average Cost, Marginal Cost and Incremental Cost below). This naturally presents issues associated with scaling up. It is reasonable to assume some economies of scale in growing a programme as a result of spreading fixed costs over a larger base. Further assumptions about reducing costs per person covered, however, must be justified based on existing experience, since variable costs, by definition, already vary with coverage. Actual practice has shown that as coverage expands to remote areas, the marginal cost of providing the intervention to each additional person will generally increase due to higher transportation and personnel costs to reach remote and less-intensively populated regions (Johns 2004)

1.7 Costs for Goods and Services. Costs for goods (materials, supplies, equipment, etc.) and contracted services used in an intervention should reflect the full economic value of such goods and services at international prices, delivered to the intervention site. For imported goods, the price should include fully loaded commercial cost, export packing, insurance, international transportation, import duties and clearance costs, taxes, handling and local transportation to the programme site. In computing the commercial cost of the good, bulk purchasing should be assumed, so that the lowest internationally listed price may be used. Contracted services should be an all-in price, including any meals, lodging, transportation or other expenses payable. Because the analysis is based on economic cost rather than financial cost, the full arms' length cost of any donated goods or services should be included in the base cost. For locally-purchased goods, the actual price paid or payable may be used for the base cost assuming this is arms' length and representative of the cost at which the good could be procured by programme implementers. As noted, Worksheets should provide detailed description of the goods, including quantities, in addition to costs.

1.8 Costs of Personnel. Personnel costs should include the fully-loaded cost of all personnel engaged in the intervention, including salary or wages, vacation and benefits, insurance, taxes, allowances and contributions toward savings plans or pension schemes, national insurance, etc. Cost should also include meals, lodging, transportation, per diems and other expenses payable over and above salary or wages. Since personnel costs vary greatly by level of expertise and region, Worksheets should specify the job level and minimum qualifications. Worksheets should also state the quantities of personnel time required at each level (person days or person months) and the cost per unit.

1.9 Shared Overheads. Since programme cost analysis is designed to provide information on the cost of introducing each intervention singly, it is necessary to break out intervention-specific costs, including overheads, which may otherwise be shared with other activities. For this purpose, joint costing rules or some other method based on allocation related to usage of the overhead item may be used. For example, indirect overhead attributable to personnel, buildings, transportation, equipment and similar items may be allocated on the basis of the percentage of time used in connection with the intervention. Note the discussion below regarding the exclusion of central administration costs and certain professional training.

1.10 Costs Averted (Savings). We will also attempt to identify and separately collect two categories of direct economic savings that can be netted against the gross cost of an intervention: health costs averted and other household savings. Health costs averted include health sector and patient costs saved due to less treatment of diarrhoeal diseases.

WHO will supply this information from its own database based on the coverage and effectiveness provided, and thus there is no need for programme implementers to provide this information in the Worksheet. Point-of-use water treatment may also offer savings at the household level when introduced as an alternative, say, to boiling (potential savings in fuel expenditures and time to collect/procure wood or other fuel for boiling water) or purchasing drinking water. To the extent that programme implementers have reliable field data on such savings, they are asked to provide the same in the Worksheet which may then be used as cost offsets to household water treatment generally.

2. Estimating Costs

2.1 Average, Marginal and Incremental Costs. Three different cost approaches may be presented. Average cost is total cost divided by the number of persons covered by the intervention. Marginal cost is the cost of covering each additional person. Incremental cost is the cost of covering each person assuming that the intervention can be added to an existing programme. Unless actual experience supports presenting costs in terms of marginal or incremental costs, costs will be analyzed on the basis of average cost. Accordingly, we will divide the total cost provided by the number of persons to whom coverage extends and assume this as a reasonable measure for extrapolation.

2.2 Currency. Wherever possible, costs should be expressed in the same currency, preferably in US$, Euros or Sterling. The CEA will present the overall cost effectiveness in a common currency, either US dollars or International dollars (see purchasing power parity below).

2.3 Purchasing Power Parity. Costs in local currency can be converted into International dollars using purchasing power parity (PPP) exchange rates. PPP exchange rates reflect the number of units of a country's currency required to buy the same amount of goods and services in the domestic market of a reference country. An international dollar is a hypothetical currency that is used as a means of translating and comparing costs from one country to another. The WHO-CHOICE "Cost-It" programme will be used to make this conversion. Worksheets should, however, identify the source and currency of purchased goods or services to help determine PPP.

2.4 Discounting for Time Incurred. Costs will be adjusted to reflect base year 2002, so that more recent programs do not artificially reflect higher prices due to accumulated inflation. The most common adjustment is the World Bank Gross Domestic Product deflator. Where this is not available, Consumer Price Indices may be used to compute deflators. If costs provided in Worksheets do not reflect such common year adjustments, it is important to state the year in which such costs were incurred in order to allow for such adjustments. The WHO-CHOICE "Cost-It" programme, to be used by the investigators to record and analyze cost data, includes macros that will adjust the costs to such base year. Accordingly, we can do the base year conversion if we know the year in which the costs were incurred.

2.5 Sub-regional Cost Estimates. In order to provide the most accurate information possible to country analysts and policy-makers, WHO-CHOICE endeavours to provide cost estimates (and corresponding cost-effectiveness) for each of the WHO epidemiological sub-regions. The Worksheet used to obtain specific cost information calls on programme implementers to provide specific information on the setting(s) for which such information is provided in order to assist in calculating region-specific information. Where information is not available for certain sub-regions, the quantity information may be used with the WHO cost database to obtain sub-regional cost estimates.

3. Classification of Costs.

3.1 Start-up and Post Start-up. Programs typically include both start-up costs (those incurred between the decision to implement the intervention and deployment to the first beneficiary) and post start-up costs (for the full period of the intervention). Costs for the start-up period should be separately reported as an aggregate amount for the entire start-up period, even if more than one year. Cost for the post start-up period should be reported as an annual estimate for continuing to run the programme once fully implemented after the start-up period.

3.2 Cost Level. WHO-CHOICE methodology breaks down costs in the administrative and organizational level of the health system in which they are incurred. In this analysis, we require cost reporting at the national, regional, community and household level. The level at which the costs are ascribed should correspond to the beneficiaries for which that level is responsible. Individual costs should be collected at the household level.

3.3 Fixed versus Variable Costs. Fixed costs are those that do not vary with the number of people covered by the intervention. Fixed costs include costs such as administration and monitoring that are necessary to set up and run a programme no matter how many people are covered. Variable costs, on the other hand, increase as a function of the increase in the number of people covered by the intervention. Examples of variable costs are hardware and chemical costs for water treatment, personnel engaged in providing instruction, transportation, supervision, etc. Media campaign costs may be fixed or variable depending on the circumstances. In order to extrapolate the cost of extending coverage of the intervention to a larger population, it is necessary for programme implementers to distinguish between the fixed and variable costs of the programme.

3.4 Capital versus Recurrent Costs. WHO-CHOICE methodology also requires factor inputs to be classified as capital or recurrent. Following standard accounting practices, capital goods are those that have a useful life of more than one year, such as vehicles, buildings and equipment. For such capital costs, respondents may provide the annual cost thereof (actual cost less residual value amortized over estimated useful and discounted at 3% per annum. Alternatively, provide such cost, residual value and estimated useful life, and the authors will calculate the discounted annual cost. Recurrent costs are those whose useful life is one year or less, such as salaries, supplies and maintenance. If less than one year (e.g., consumables that must be replaced each month), these should be multiplied by the number of units used on an annual basis and reported in terms of their equivalent annual cost.

3.5 Cost Categories. The Worksheet provides examples of programme and patient (householder) costs that are used by WHO-CHOICE to help identify and break down all relevant cost inputs for a given intervention. Definitions for these categories are also provided. These cost categories are illustrative of the types of costs that may comprise an intervention, and should not be deemed exclusive. Wherever possible, Worksheets should include further identification of the precise nature of each cost input in order to provide analysts with more information for local estimates.

4. Excluded Costs.

While the intent is to identify and capture all costs that are associated with the intervention, WHO CHOICE excludes certain costs.

4.1 Central Costs. WHO CHOICE excludes central administration costs. These are defined as costs that are part of the overall planning and management of the health system that are unrelated to the development and implementation of particular interventions.

4.2 Current Level of Education of Health Professionals. An additional cost that could arguably be included in programme costs but which WHO CHOICE excludes is certain professional education costs. If the skills required to deliver an intervention are available in the country, training costs to develop those skills are excluded in programme costs. This is based on the fact that a reallocation of health system resources would not affect these costs.

4.3 Research Costs. Many of the interventions that are the subject of this CEA are novel or under development. Accordingly, their implementation may have been in the context of, or accompanied by, a research component. To the extent that such research costs are wholly independent from the intervention itself, and its implementation programme, they should not be included in the computation of programme costs. On the other hand, costs associated with supervising, monitoring, auditing, documenting, assessing and evaluating an intervention are not purely research costs and should be included.

APPENDIX 5.2

ASSESSMENT OF COSTS FOR SELECTED HOUSEHOLD WATER TREATMENT INTERVENTIONS

WORKSHEET

General Instructions:

1. Complete a separate worksheet for the intervention model (technology and distribution method) assigned to you.
2. Create a separate document using this worksheet, complete and save it as a MS Word® .doc file with an identification as to the intervention, programme administrator and country setting (e.g., SWS-PSI-Kenya.doc) for the programme.
3. Read the accompanying Guidelines in advance and complete each item in accordance with such Guidelines.
4. Contact T. Clasen with any questions (thomas.clasen@lshtm.ac.uk).

1. Setting.

Describe the setting in which the programme was undertaken. Include all information requested.

1.1 Name of Country	
1.2 Name of Region or Primary Community	
1.3 Predominant Exposure Scenario existing in the programme setting <u>before introduction of the intervention programme</u> (for definitions, refer to Prüss et al., 2002) **CHOOSE ONLY ONE PREDOMINANT SCENARIO**	__VI (no improve water supply and no basic sanitation in a country which is not extensively covered by those services, and where water supply is not routinely controlled. __Vb (improved water supply and no basic sanitation in a country which is not extensively covered by those services, and where water supply is not routinely controlled) __Va (improved sanitation but no improved water supply in a country which is not extensively covered by those services and where water supply is not routinely controlled) __IV (Improved water supply and improved sanitation in a country which is not extensively covered by those services, and where water supply is not routinely controlled) __III (improved water supply and improved sanitation in a country which is not extensively covered by those services, and where water supply is not routinely controlled, plus household water treatment) __II (regulated water supply and full sanitation coverage, with partial treatment for sewage, corresponding to a situation typically occurring in developed countries) __I (ideal situation, corresponding to the absence of transmission of diarrhoeal disease through water, sanitation

	and hygiene)
1.4 Month and Year of commencement of intervention programme	Month ____________________ Year ________________

2. Intervention.

Identify the main approach and any additional components included in the intervention.

2.1 Household water treatment (HWTS).	__ Chlorination __ Ceramic Filtration __ Solar Disinfection __ Combined Flocculation/Disinfection
2.2 Additional components of intervention programme.	__Storage vessel __Educational to encourage adoption or use of HWTS __Hygiene instruction (independent of HWTS) __Other (describe) __________________________ ____________________________________ ____________________________________

3. Coverage

In order to estimate the cost per person covered by the intervention programme, provide information on coverage.

3.1 Number of persons actually included in the intervention programme.	
3.2 Number of households actually include in the intervention programme.	
3.3 Average number of persons per household included in the intervention programme.	
3.4 Maximum coverage assuming no increase in fixed costs and 80% utilization (see Guidelines Section 1.5).	

Certain Definitions for Reporting Quantities and Costs

Descriptions for use in completing quantities and costs:

1. Capital Costs[28]

1.1 Building: Report purchased or constructed building space allocated to the programme in square meter surface area and annual cost per square meter (note that rented space is recurrent cost in B.8 below)

1.2 Transport: Report the number and types of vehicles or other transport, and the amortizable annual value thereof based on a 5 year useful life with no residual value.

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[28] For capital costs, respondents may provide the annual cost thereof (actual cost less residual value amortized over estimated useful and discounted at 3% per annum. Alternatively, they may provide such cost, residual value and estimated useful life, and the authors will calculate the discounted annual cost.

1.3 Equipment: Report the number and types of hardware used in the intervention, as well as the number and types of computers, other office equipment and furnishing, implements, tools, etc.

1.4 Other: Any other capital goods (goods whose useful life is more than one year)

2. Recurrent Costs (annual cost)

2.1 Personnel: Report the number (in person years), annual cost and type using the following categories: programme director, programme manager, finance director, IT other manager, logistics director, accountant, supplies manager, clerical officer/administrative assistant, secretary/assistant/receptionist, typist, data entry clerk, other (porter, messenger, etc.); medical officer, public health officer, registered nurse, health educator/trainer, social worker, other field worker; transportation manager, maintenance worker, construction worker, driver, security personnel, other worker.

2.2 Materials/ Supplies: Chemicals, other consumables, office supplies, IEC materials, etc.

2.3 Media: Report the annual quantity (minutes for broadcast media and page part or piece for print media), unit cost and type (television time, radio time, newspaper adverts, posters, flyers/leaflets)

2.4 Transport: For rented transport, state the quantity, type (truck/car/SUV or motorcycle/moped) and unit operating cost per Km

2.5 Equipment: For rented equipment, report the number and types of equipment, and the annual rental cost

2.6 Maintenance: Report the annual maintenance costs to the extent not covered by personnel or supplies.

2.7 Utilities: Report the allocated annual charges for electricity, water, gas, phone and any other utilities; include the unit cost for each item

2.8 Rented Space: For rented space, report the type of space (office, warehouse, outdoor storage) the quantity (in square meters) the unit cost and the annual cost

2.9 Other Report any other recurrent costs allocable to the programme and not otherwise included in the above

4. Individual (Household) Costs and Costs Averted (Savings)

Report any and all costs of the intervention incurred by the target population. These costs should be accumulated at the household level. Include annual quantities for the population covered by the programme, description and unit costs. Expand this spreadsheet as necessary by adding rows under each cost category.

	Quantity	**Description**			**Unit Cost**	**Annual Cost**
4.1 Capital costs[3]		**Item**	**Useful Life**	**Residual Value**		
4.1.1 Equipment						
4.1.2 Other						
4.2 Recurrent costs						
4.2.1 Supplies						
4.2.2 Labour						
4.2.3 Utilities						

Cost Savings (refer to Guidelines, Section 1.10)

Item Descriptions (e.g., reduced fuel for boiling, reduced purchases of water)	**Quantity**	**Unit Cost**	**Annual Cost**

5. Programme Costs

Report all costs of the intervention incurred other than by the target population. These costs should be accumulated and allocated to the national (N), regional (R), community(C) and household (H) level. Include annual quantities for the population covered by the programme, description and unit costs. Code for the party responsible for payment as follows: National or local government (G), Donor or other funding agency (D), programme implementer (P). Do not include householder expenditures that were separately reported as patient costs in Section 4 above. Expand these spreadsheets as necessary by adding rows under each cost category.

5a. Start Up Programme Costs

	Quantity	Description			Level Code	Payer Code	Unit Cost	Annual Cost
5.1 Capital costs[3]		**Item**	**Useful Life**	**Residual Value**	**Use N, R, C or H for each**	**Use G, D or P for each**		
5.1.1 Building								
5.1.2 Transport								
5.1.3 Equipment								
5.1.4 Other								
5.2 Recurrent costs								
5.2.1 Personnel								
5.2.2 Materials & Supplies								
5.2.3 Media & IEC								
5.2.4 Transportation								
5.2.5 Equipment								
5.2.6 Maintenance								
5.2.7 Utilities								
5.2.8 Rented Space								
5.2.9 Other Recurrent								

5b. Post Start Up Costs

	Quantity	Description			Level Code	Payer Code	Unit Cost	Annual Cost
5.1 Capital costs[3]		Item	Useful Life	Residual Value	Use N, R, C or H for each	Use G, D or P for each		
5.1.1 Building								
5.1.2 Transport								
5.1.3 Equipment								
5.1.4 Other								
5.2 Recurrent costs								
5.2.1 Personnel								
5.2.2 Materials/Supplies								
5.2.3 Media & IEC								
5.2.4 Transportation								
5.2.5 Equipment								
5.2.6 Maintenance								
5.2.7 Utilities								
5.2.8 Rented Space								
5.2.9 Other Recurrent								

6. Contact Information

	Name	Address, email and phone
6.1 Person in charge of intervention programme		
6.2 Person completing worksheet		
6.3 Person to contact for additional information		

The foregoing information is true, correct and complete and based on actual documentation or reasonable estimates after due inquiry.

____
(Signature)
Date

____
Name______________________
Title ______________________

Chapter 6
Cost and Cost-Effectiveness: Results and Discussion

6.1 Cost Estimates

As noted above in Chapter 5, in December 2004 detailed guidelines and worksheets were forwarded to all known implementers of the four household-based water treatment methods for which we had effectiveness data from the Cochrane review. These requests were followed up over the course of several months and at the annual meeting of the International Network to Promote Household Water Treatment and Safe Storage in May/June 2005. Despite these efforts and repeated follow-up communications, few programme implementers actually completed the worksheet. In most cases, they provided limited information from existing reports, internal records, field worker accounts, and in one case, a draft paper. Numerous exchanges with the programme implementers and their field personnel ultimately yielded cost information that was sufficient for purposes of this analysis. The sources of cost information and the manner for calculating the point estimate and range of costs is described in this Section.[29]

6.1.1 Chlorination (Safe Water System-SWS)

Chlorinating water at the household level is represented by the Safe Water System (SWS) developed by the US Centers for Disease Control and Prevention (CDC). A website on the SWS provides background information on the system (www.cdc.gov/safewater). While the intervention is the most broadly implemented of the household treatment methods, it was nevertheless difficult to obtain rigorous cost data. Outside of emergency response, the SWS is generally implemented under the social marketing model in programs where the product is sold to consumers through commercial distribution chains. In most cases, the programme implementers recover only a percentage of their costs through product sales; the balance of their costs is covered by donors or other sources.

PSI currently implements the SWS in 19 countries, mainly in Africa and Asia. PSI provided production costs and pricing on its products showing a mean cost of goods sold (includes the cost of purchasing the sodium hypochlorite and packaging, as well as "related

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[29] In this Section 6.1, unless otherwise noted, the symbol "$" refers to year 2002 US dollars.

procurement fees") of $0.23 (range $0.13 in India to $0.48 in Burkina Faso). The mean suggested consumer price was $0.46 (range $0.15 in Madagascar to $0.50 in Burkina Faso). These data suggest considerable variability in the hardware costs for the SWS intervention that should be considered carefully when costing this option at the national level. One bottle is designed to treat the drinking water needs of a family of 6 persons for 1 month. Thus, at the consumer level, the mean cost per capita per year would be $0.92 (range $0.26 to $0.96). However, it cannot be determined from the data supplied whether such a suggested consumer price would cover the full cost of implementing the SWS programme in the countries covered. PSI also provided information from its 2004 annual report showing its gross allocated cost for 8 country programs operating in 2003. This shows gross programme costs $5,298,291 and sales of $3,332,492. This suggests a substantial shortfall in cost recovery that must be covered by donations or other sources. Thus, this information is insufficient to determine the full cost of the SWS as implemented.

Dr. Robert Quick from the CDC provided a draft copy of a paper (Banerjee 2005) providing certain cost information on a social marketing programme in Zambia implemented by the Society for Family Health (SFH), a local NGO, and PSI. This analysis provided the most complete cost data on the SWS programme. Aggregate costs were first categorized by activity (production, marketing, distribution and overhead), and then separated into variable (raw material, labour, fuel, vehicle maintenance, per diem and distribution) and fixed (all other) costs. In the case of shared assets, fixed costs were allocated to the SWS programme based on a stepped down procedure. Capital costs were amortized in accordance with their estimated useful life; recurrent costs were calculated on an annual basis. Salaries of local staff and a resident expatriate technical advisor were included.

Among other things, the paper describes cost trends for both hardware and programmatic costs over a period of 5 years (1998 start-up to 2003). In Zambia in 2003, the total cost of delivering the intervention to 850,000 persons per year was $558,879 or $0.66 per person per year. This was based on a production cost for a 250ml bottle of 0.5% sodium hypochlorite solution of $0.12, marketing costs of $0.07, distribution costs of $0.09 and overhead costs of $0.05. It should be noted that Zambia's production cost is at the low end of PSI's range among the countries in which it currently implements the SWS programme. The total cost to the consumer of $0.33 per bottle covers a household of 6 for one month, yielding an annual cost per person of $0.66 ($0.33 x 12 / 6). Thus, this programme is designed to cover all costs associated with the delivery of the intervention. Based on the foregoing, the estimated the cost of the SWS intervention per person per year used in this analysis is $0.66. This is comparable to the $0.62/per person per year fully-loaded cost estimated by Lantange (2005).

This cost reflects full capacity, and thus should serve as the low end of any cost range. At its inception, aggregate costs were $3.78 per person per year. Over the four-year period from start-up, Society for Family Health was able to reduce such aggregate costs per bottle by 82%, from $1.88 to $0.33. As may be suspected, most of the saving was the result of spreading fixed cost over a larger production volume: fixed cost per unit fell from $1.50 in 1999 to $0.14 in 2003, a reduction of 90%. However, even average variable costs fell over the period by 53%, reflecting greater efficiencies and the inevitably high costs of start-up. Because this CEA is intended to reflect the interventions as fully implemented, the point estimate will reflect this scaled-up cost. This benefits a more mature technology, like the SWS, which has a longer history as a public health intervention than ceramic filtration or combined flocculation/disinfection. At the same time, it does suggest that other household water treatment options may also benefit by lower unit costs as they scale up. To reflect the initial start-up cost of $3.78 per person per year, the analysis will present a range from this initial cost to the scaled up cost of $0.66 per person per year.

6.1.2 Flocculant/Disinfectant (PUR)

Proctor & Gamble Company (P&G), the manufacturer of PUR sachets, provided cost estimates based on current programme activity. Data from three programs were provided, two from on-going social marketing programs in Kenya (SWAK) and Uganda (PSI) and the third from an emergency intervention in a Liberian refugee camp (Johns Hopkins University, School of Public Health). The emergency programme, while of interest, does not reflect an on-going intervention in a development context. Moreover, that programme was specifically identified as an outlier in the Cochrane review on which the health impact data were based. Accordingly, the cost estimates from the emergency programme were not used.

The sachets are sold by P&G at $0.035, plus an additional $0.005 for shipping, bringing the cost to $0.04. In Uganda, the sachets are subject to a duty of 32%, bringing the cost to $0.0528. In the social marketing programs, the sachets are sold at retail to the consumer at $0.09 in Kenya and $0.10 in Uganda. According to Dr. Greg Allgood, who runs the PUR sachet programme for P&G, this margin between cost and consumer retail price is designed to cover the programme implementer's full cost. Projections from PSI Uganda show such full cost recovery, but only after large initial subsidies from P&G and others during years 1-3 after programme implementation. However, since this CEA is intended to reflect economies of scale, the average of these two costs ($0.095) is used to reflect the total cost of delivering the intervention.

According to Dr. Allgood, these programs are designed to deliver one sachet per family per week. Assuming an average of 5 persons per household (per the Uganda projections), this would mean that the programme would be delivered at a cost of $0.988 per person per year as follows: $0.095 per sachet x 52 sachets per year / 5 persons per household = $0.988. There are two questions, however, regarding the validity of this estimate. First, while the $0.095 price per sachet is intended to cover all programme costs, there is no actual programme experience to date in which full cost recovery has been achieved. The PSI Uganda projections show the need for subsidies of $467,229 in year 1, $152,004 in year 2, and $100,000 in year 3. After that time, the projections contemplate no further subsidies. However, it is necessary to include the full $719,233 of subsidies during the start-up phase into the programme cost. As per WHO practice, these should be amortized over an assumed 10-year life of the programme. As the programme in Uganda is projected to cover 10.5 million persons by its midpoint (year 5), this subsidy represents an additional $0.007 per year of programme cost ($719,233 / 10 years / 10,500,000 persons), resulting in a total of $0.995.

Second, and potentially more problematic, is the assumption that householders will achieve the estimated health impact from this intervention by purchasing only one sachet per household per week. Since a sachet treats only 10L of water, this means the intervention provides only 0.28 L of treated water per person per day (10L / 5 persons/7 days). Dr. Allgood notes that this is the actual sales experience of social marketing programs, noting that families purchase the product only when diarrhoea is perceived as a risk and provide the treated water only to the most vulnerable members of the family (i.e., children under 5). In this way, he believes that 1 sachet per week per family will yield the reduction in diarrhoea estimated by the Cochrane review. However, the health intervention studies of PUR included in the review reported a higher use of the product. Reller (2003) reported householders using 6 sachets per week for households averaging 6 persons, and Chiller (2004) reported "over 10" sachets per week for households of averaging 6 persons. Crump (2005) and Luby (2004) did not report the number of sachets used, but according to Dr. Allgood, the number was 3 and 12, respectively for households of 11 and 10, respectively. However, Crump also reported that residual chlorine was observed from households allocated to the PUR intervention in 86% of scheduled visits and 44% of unscheduled visits, suggesting perhaps a higher rate of product usage then 1 sachet per week. Moreover, the highest rate of diarrhoeal disease reduction was reported by Luby, the study using the highest number of sachets per week.[30]

Since the effectiveness estimates are thus based on a higher level of product utilization, the cost estimates should reflect a similarly higher rate. Thus, for purposes of the programme cost estimates, the estimated utilization for purposes of this CEA assumes 5 sachets per week per household. This increases the cost to $4.95 per person per year ($0.095 per sachet + 0.007 programme subsidy x 5 sachets/week x 52 weeks/5 persons per household). The reported range in cost will reflect this difference in utilization rates (from 1 sachet per household per week at $0.995/year to the estimated 5 sachets per household per week $4.97/year) to capture this potential difference in programme implementation.

6.1.3 Ceramic Filtration

The cost estimates for ceramic filters are based on three sets of data, two from International Development Enterprises (IDE) programs in Cambodia using a locally-manufactured filter following the Potters-for-Peace design, and one from Food for the Hungry International in Bolivia using a locally-fabricated candle-type filter system with local buckets and taps and imported commercial filter elements from Brazil. According to programme implementers, the plastic components (vessel, taps) have a design life of 5

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[30] In the trial reported by Doocy (2004), householders received up to 21 sachets per week. Since this was an emergency setting, participants also received a bucket and large mixing spoon for preparation, a decanting cloth, a funnel to aid in the transfer from the preparation bucket to the storage container, and a storage container with a narrow opening and lid that conforms with CDC safe water storage recommendations. However, because Doocy is deemed an outlier and not included in the effectiveness estimate in this CEA, the costs from such trial are also excluded from this analysis. It is likely that the costs of any emergency implementation of water treatment interventions will be higher than the estimates used herein which are based on non-emergency conditions.

years and the ceramic elements have a design life of 2 years (PFP design) and 1 year (Brazilian candle).

IDE provided the most comprehensive cost estimates for its programmes, one of which operates following a social marketing model and the other a donor-funded, public health model. The total filter cost in each case is $7.50 or $2.75 per year over 5 years ($0.66 per year for plastic components and $2.09 per year for ceramic components). The social marketing model sells the filter for this $7.50 to the consumer, while the health programme sells it for $2.30 and provides a $5.20 per unit subsidy. Households have an average of 5.1 persons, resulting in an annual per person cost of $0.53. IDE reports that these costs reflect initial production and expects in the future to reduce prices to reflect lower costs due to economies of scale and other efficiencies. The reported useful life of the filter system was 2 years for the ceramic filter element and 5 years for the plastic vessel, lid and tap.

This cost, however, reflects only the actual production cost of the hardware, and not the cost of setting up the factory or running the intervention programme. The start-up cost for the factory is $20,000. Assuming production at 80% of capacity, the factory can produce approximately 25,000 units annually. IDE also reported non-capital costs averaging $2,427 for programme start-up. Amortizing these start-up costs over a 10 year programme life, the start-up cost adds an additional $0.09 per person per year ($22,427 / 10 years / 25,000 units). In addition, IDE reported annual post-start-up costs for the programme of $39,498 for the social marketing programme which covers 12,241 persons ($3.23 per person), and $53,657 for the subsidized programme which covers 20,661 persons ($2.60 per person). They note that these costs include total programming, including careful targeting of the intervention and supplemental hygiene instruction. Thus, the total annual cost per person for the IDE programs is $3.85 for the social marketing programme ($0.53 filter cost + $0.09 factory cost +$3.23 programme cost) and $3.22 for the subsidized programme ($0.53 filter cost + $0.09 factory cost +$2.60 programme cost).

In Bolivia, FFI paid $21.10 for candle-style filters, consisting of $13.37 for the plastic components and $7.73 (including transportation and customs duties) for the ceramic candles. The average useful life of such filter was 1 year for the ceramic filter elements and 5 years for the balance of the system. The annualized filter cost was $10.40 and the average household size was 5.4 persons for an average cost of $1.93 per person covered. The filters were assembled on site by the actual householders who used them, and no cost was allocated to this amount since it took place at an evening meeting when householders were not otherwise engaged in an economically productive activity. FFI did not provide any additional programmatic costs associated with the programme. When pressed on this, they asserted that the filters were delivered at a single meeting by existing programme staff that were present in the community in connection with other health interventions and thus no additional out-of-pocket cost was incurred in the delivery of the intervention. However, it seems reasonable to assume that at least some staff time was devoted to this intervention. It also seems reasonable that personnel and other costs will be incurred in delivering replacement candles each year. Adding $0.50 per unit per year to cover such staff time increases the programme cost by $0.09 per person ($.50 per filter per year / 5.4 persons using each filter), for a total annual programme cost of $2.02.

The mean cost of all three programs is thus $3.03 ($3.85 + $3.22 + $2.02 / 3) and the range is $2.02 to $3.85

6.1.4 Solar Disinfection (Sodis)

Foundation Sodis, the founder and chief technical advisors and advocates for the Sodis solar disinfection programme, provided cost data for seven programs in Indonesia, India (2), Pakistan, Uzbekistan, Nepal and Kenya (Martin Weglin, personal communication). All of the programs are donor funded with no out-of-pocket cash contribution by the target population. The programs date from May 2002 to January 2005.

Programme costs consist of a hardware (capital) component and a combination of external and local partner programmatic support. The only capital good consists of PET bottles provided to the householders. The mean cost of the bottles over the 7 programs was $0.10 (range $0.03 (Indonesia) to $0.15 (Tamil Nadu, India)) and the mean number of bottles used per person is 1.6. The mean life of the bottle is 4 months. This results in a mean annual capital cost of $0.45 per person over all seven programs for which data is available. The range in capital costs per person per year was $0.08 (Indonesia) to $0.64 (Kenya). The mean aggregate programme cost was $56,622 with a mean coverage of 157,938 persons (31,518 households x 5 persons per household), for a mean programmatic cost per person per year of $0.36. The range for programme costs was $0.19 (Assam, India) to $0.77 (Indonesia). According to Sodis personnel, this programme cost is a one-time investment for training. However, actual experience has shown that in the absence of continuing programmatic support, utilization of the system diminishes significantly after just 2 years (Martin Weglin, personal communication). Accordingly, we assume for this calculation that the programmatic costs must be re-incurred every 2 years. Thus, the mean annual per person programme cost is $0.18 (0.5 x $0.36) and the range is $0.10 to $0.39 (0.5 x $0.19 to $0.77).

Combining the capital and programmatic costs yields a mean total cost per person per year of $0.63 ($0.45 for bottles + $0.18 for programmatic support). The range is from $0.48 (Indonesia) to $0.88 (Kenya).

6.1.5 Source-Based Interventions

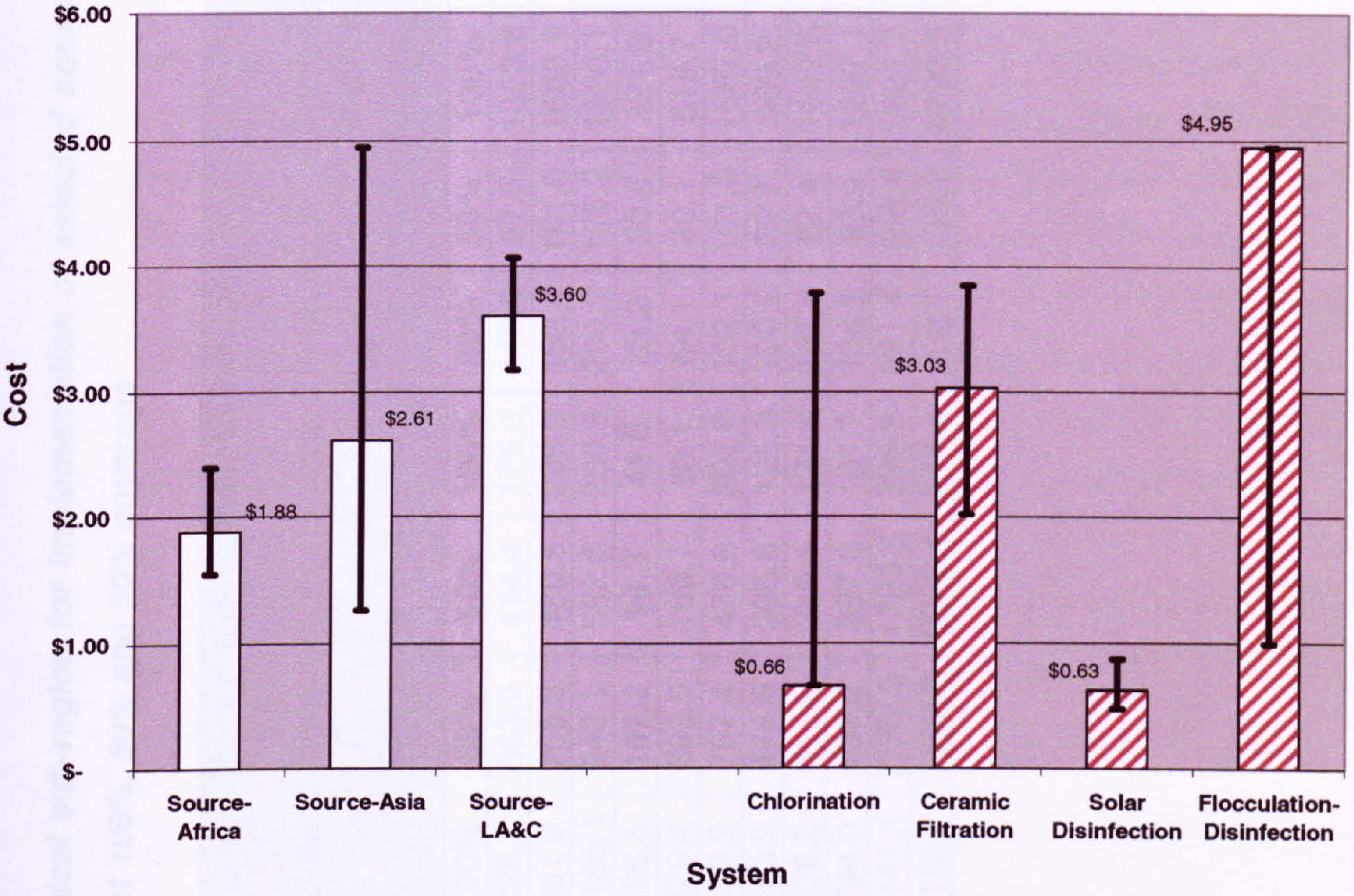
While the principal objective of this cost-effectiveness analysis is to evaluate the cost-effectiveness of household-based water treatment interventions, the availability of effectiveness data from the Cochrane review also provides the opportunity to compare these interventions with conventional source-based interventions to improve water quality if cost estimates for such interventions are available. In doing so, it is noted that a CEA, which measures only the health outcome of the intervention of interest, does not capture the substantial other benefits that source-base improvements in water supplies may provide that household-based interventions do not. These include substantial savings in time when, for example, water is piped in and delivered to a community tap stand from remote sources from which it previously had to be carried. Such other non-health benefits are captured in CBAs, rather than CEAs, as they were for example by Hutton & Haller (2004).

Of the six studies of source-based interventions covered by the review, 3 involved improving public wells or boreholes (Alam 1989, Aziz 1990, Xaio1997), and 3 involved improved communal treatment and/or distribution to public tapstands (Gassana 2002, Jensen 2003, Messou 1997). As described in Section 5.7, recent economic evaluations of such source-based interventions are based on the initial cost of such investments as compiled for the Global Water Supply and Sanitation Report (WHO/UNICEF 2000) and certain assumptions regarding the useful life, operation and maintenance, education and training and water source protection costs associated with each such intervention. As noted, these estimates do not include any cost for programmatic support and their useful life may be overestimated based on actual experience. Nevertheless, in the interest of providing conclusions that are consistent with other WHO estimates and in the absence of reliable information on programming costs and actual life, these estimates will be used for purposes of this analysis. In order to arrive at a single cost for such source interventions, the mean cost for each of type (standpost, borehole and dug well) as reported in Table 5.7a was computed for each geographical region (Africa, Asia and Latin America/Caribbean), and such regional mean cost was then allocated to the corresponding WHO epidemiological sub-region.

6.1.6 Overall Estimates

Figure 6.1.6 reflects the overall cost estimates to be used in the cost-effectiveness analysis. The figure sets forth the point estimate as well as the range in cost. As described above, the point estimate for household-based interventions represents the best available estimate of the true annual cost per person covered by the intervention, while the range reflects certain variations in such cost based on economies of scale (chlorination and filtration), optimal versus actual utilization (flocculation/disinfection) and geographical differences in cost (solar disinfection). The point estimates for the source-based estimates represent the mean of the three geographical regions and the range represents the highest and lowest cost based on those geographical estimates. It is important to recognize that the basis for the range thus differs depending on the intervention.

Figure 6.1.6 Annual cost per person (point estimates) and range of annual cost (narrow bars) for source-based (solid bars) and household-based (hatched bars) interventions to improve water quality[31]



Applying these costs across the population in the 11 epidemiological sub-regions covered by this CEA results in the gross costs set forth in Table 6.1.5. For completeness, the table shows aggregate costs at 100%, 80% and 50% coverage for each of the interventions. As described in footnote 26 above, source-based interventions are applied to populations without improved water supply (exposure scenarios V and VI), while household-based interventions extend not only to these but also to populations with improved but unregulated supplies (exposure scenario IV). In those subregions where large portions of the population fall within such exposure category IV, the aggregate cost of extending household-based interventions is greater than source-based interventions despite the lower per capita cost of coverage for household-based interventions.

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[31] As described in the text, point estimates represent the annual cost per person covered by each intervention as implemented, while the range shows the potential variation in cost due to different factors in such implementation (geographical location, extent of scaling up, type of product, amount of product used, etc.).

Table 6.1.6: ***Gross cost in US$ millions by epidemiological sub-region for implementation of selected source-based and household-based interventions to improve water quality at 100%, 80% and 50% coverage***

	Source-Based Interventions			**Household-Based Interventions**											
	Mean Cost of Standpost, Borehole and Dug Well			**Chlorination**			**Ceramic Filtration**			**Solar Disinfection**			**Flocculation Disinfection**		
Coverage	**100%**	**80%**	**50%**	**100%**	**80%**	**50%**	**100%**	**80%**	**50%**	**100%**	**80%**	**50%**	**100%**	**80%**	**50%**
Afr-D	200.8	160.6	100.4	180.5	144.4	90.3	828.7	663.0	414.4	175.0	140.0	87.5	1353.8	1083.0	676.9
Afr-E	256.8	205.4	128.4	209.3	167.4	104.7	961.0	768.8	480.5	203.0	162.4	101.5	1569.9	1255.9	785.0
Amr-B	140.6	112.5	70.3	258.1	206.5	129.1	1185.1	948.1	592.6	250.3	200.2	125.2	1936.1	1548.9	968.1
Amr-D	37.3	29.8	18.7	42.8	34.2	21.4	196.5	157.2	98.3	41.5	33.2	20.8	321.0	256.8	160.5
Emr-B	32.7	26.2	16.4	82.6	66.1	41.3	379.4	303.5	189.7	80.1	64.1	40.1	619.7	495.8	309.9
Emr-D	157.0	125.6	78.5	208.9	167.1	104.5	959.2	767.4	479.6	202.6	162.1	101.3	1567.0	1253.6	783.5
Eur-B	71.5	57.2	35.8	129.2	103.4	64.6	593.2	474.6	296.6	125.3	100.2	62.7	969.2	775.4	484.6
Eur- C	22.0	17.6	11.0	139.0	111.2	69.5	638.2	510.6	319.1	134.8	107.8	67.4	1042.6	834.1	521.3
Sear-B	143.6	114.9	71.8	172.9	138.3	86.5	794.0	635.2	397.0	167.7	134.2	83.9	1297.1	1037.7	648.6
Sear-D	444.7	355.8	222.4	749.6	599.7	374.8	3441.1	2752.9	1720.6	726.8	581.4	363.4	5621.7	4497.4	2810.9
Wpr-B	824.0	659.2	412.0	905.9	724.7	453.0	4158.7	3327.0	2079.4	878.4	702.7	439.2	6793.9	5435.1	3397.0

6.2 Cost Offsets

As described in Chapter 5, the outcome of a CEA is the cost associated with a certain health outcome (e.g., DALYs averted). Unlike a CBA, it is not intended to capture and reduce to economic valuation all the benefits that might obtain by implementation of a particular intervention. As Hutton & Haller (2004) have demonstrated, most of the economic benefits associated with water and sanitation interventions derive from non-health benefits. There are, however, certain cost offsets that are directly associated with the implementation of a health intervention and thus are properly included in a generalized CEA (Johns 2003). These are (i) savings that accrue to the patient (householder) and the health sector in the form of direct expenditures averted due to reduced levels of disease, and (ii) savings to the household and the public sector from the use of the intervention over another option.[32]

Savings from direct expenses avoided due to reduced illness from diarrhoea have been estimated by the WHO. The nature and sources of estimates are summarized in Table 6.2a.

Table 6.2a: Summary of cost offsets from health cost savings

Costs Averted	Variable	Data Source	Data value (and range)
Health sector expenses averted due to prevention of diarrhoeal disease	Unit cost per treatment	WHO regional unit cost data	$4.30-$9.70 per visit $16.10-$39.70 per day
	Number of cases	WHO BoD data	Variable by region
	Visits or days per case	Expert opinion	1 outpatient visit per case (0.5-1.5) 5 days for hospitalized cases Probably much less than 0.5.
	Hospitalisation rate	WHO Data	91.8% ambulatory
Patient (householder) costs averted due to prevention of diarrhoeal disease	Transport cost per visit	Assumptions	$0.50 per visit
	% patients using transport	Assumptions	50% of patients
	Number of cases	WHO BoD data	Variable by region
	Visits or days per case	Expert opinion	1 outpatient visit per case (0.5-1.5) 5 days for hospitalized cases
	Hospitalization rate	WHO data	91.8% ambulatory

Source: adapted from Hutton & Haller (2004)

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[32] Implementation of household water treatment options may also allow a community to use water from existing surface sources and thus forego the cost of a borehole or gravity system. However, this cost savings is already captured in GCEA by comparing mutually exclusive interventions with the null scenario.

Table 6.2b shows the savings from applying these estimates to household-based water quality interventions by epidemiological sub-region.

Table 6.2b: Cost offsets (in US$ millions) from health cost savings for selected household-based water quality interventions by epidemiological sub-region

	Household-Based Interventions			
	Chlorination	**Ceramic Filtration**	**Solar Disinfection**	**Flocculation Disinfection**
Afr-D	1464	2493	1227	1227
Afr-E	1544	2844	1494	1494
Amr-B	3328	5667	2789	2789
Amr-D	389	662	325	325
Emr-B	831	1415	696	696
Emr-D	1622	2762	1359	1359
Eur-B	570	971	478	478
Eur- C	385	656	323	323
Sear-B	974	1658	816	816
Sear-D	4034	6869	3380	3380
Wpr-B	7585	12914	6355	6355

Subtracting these cost offsets to the costs at the 100% coverage level (from Table 6.1.6) yields the net costs estimates shown in Table 6.2c. In most cases the cost offsets more than cover the cost outlays from the implementation of the intervention, thus resulting in net negative costs (i.e., income). To the extent that these health costs are incurred by the public sector, implementing these interventions would save governments money even if the public sector were to pay the full cost of such implementation. This is emphasized in the discussion below. In keeping with convention, however, the analysis of cost-effectiveness ratios (CERs) and the comparison of such CERs below are made on the basis of the gross rather than net cost of the interventions.

Table 6.2c: Net costs (actual cost minus health cost savings) in US$ millions for selected household-based water quality interventions by epidemiological sub-region

	Household-Based Interventions											
	Chlorination			**Ceramic Filtration**			**Solar Disinfection**			**Flocculation Disinfection**		
	Gross Cost	**Cost Offsets**	**Net Cost**	**Gross Cost**	**Cost Offsets**	**Net Cost**	**Gross Cost**	**Cost Offsets**	**Net Cost**	**Gross Cost**	**Cost Offsets**	**Net Cost**
Afr-D	180.5	1464	-1283.5	828.7	2493	-1664.3	175.0	1227	-1052.0	1353.8	1227	126.8
Afr-E	209.3	1544	-1334.7	961.0	2844	-1883.0	203.0	1494	-1291.0	1569.9	1494	75.9
Amr-B	258.1	3328	-3069.9	1185.1	5667	-4481.9	250.3	2789	-2538.7	1936.1	2789	-852.9
Amr-D	42.8	389	-346.2	196.5	662	-465.5	41.5	325	-283.5	321.0	325	-4.0
Emr-B	82.6	831	-748.4	379.4	1415	-1035.6	80.1	696	-615.9	619.7	696	-76.3
Emr-D	208.9	1622	-1413.1	959.2	2762	-1802.8	202.6	1359	-1156.4	1567.0	1359	208.0
Eur-B	129.2	570	-440.8	593.2	971	-377.8	125.3	478	-352.7	969.2	478	491.2
Eur- C	139.0	385	-246.0	638.2	656	-17.8	134.8	323	-188.2	1042.6	323	719.6
Sear-B	172.9	974	-801.1	794.0	1658	-864.0	167.7	816	-648.3	1297.1	816	481.1
Sear-D	749.6	4034	-3284.4	3441.1	6869	-3427.9	726.8	3380	-2653.2	5621.7	3380	2241.7
Wpr-B	905.9	7585	-6679.1	4158.7	12914	-8755.3	878.4	6355	-5476.6	6793.9	6355	438.9

The foregoing health cost savings are only one of the categories of cost offsets from implementing water quality interventions. There are other direct cost savings that would inure to users of such interventions. For example, to the extent that householders currently boiling their water to make it safe for drinking switch to a disinfection or filtration method, they will likely reduce the amount of fuel consumed and thus the expenditure of time or cash used to procure the same. Despite soliciting information on household cost offsets from each of the programme implementers as part of the cost collection process, no reliable information was provided. However, in a report published in 2003 on their ceramic water filter programme in Cambodia, IDE found that after three months, the percentage of households boiling water for drinking fell from 69% to 0.5% (IDE 2003). They estimated the monthly savings in fuel to be $1.45 per household (or $3.48 per person per year for a household of 5) for the 11% of the study population that purchase the fuel.[33] They also reported that the percentage of households purchasing water for drinking fell from 9% to 0%, resulting in mean savings of $2.11 per household per month ($5.06 per person per year) for such households. In promotional material, Hindustan Lever Limited claims that its household-based water treatment device treats water at half the cost of boiling with gas in India.[34]

These data suggest that there are direct savings at the household level from implementing interventions to improve water quality. These are in addition to the obvious indirect benefits (mainly time savings in collecting water) that accrue from source-based interventions such as new stand posts and wells, as reported in CBAs (e.g., Hutton & Haller 2004). Nevertheless, estimating these cost offsets is problematic. As the IDE data suggest, even estimating the savings from converting from boiling water to another household water treatment option would require assumptions regarding fuel costs, fuel expended exclusively for boiling water, portion of populations currently boiling, etc. These are likely to vary dramatically from one country or region to another. While such information could be collected household in surveys under the JMP, accurate and comprehensive data

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[33] The calculation is based on the a survey of 57 households that showed that 29% of firewood purchased was consumed to boil water twice daily for an average of 18.5 minutes each time. In addition to the out-of-pocket cost, IDE calculated that these householders spend 18.5 person-hours per month boiling water. Households that collect instead of purchase wood spend an additional 20.9 person-hours per month. Netting out the cost of maintaining their filters, this resulted in time savings from using filters to be 15.9 person hours per month for firewood purchasers and 22.0 person hours per month for firewood collectors. However, unlike direct savings from reduced out-of-pocket expenses, these indirect time savings are not included in a CEA.

[34] http://www.hllpureit.com/htmls/protectionprice.htm

are not currently available. Moreover, for many populations, boiling is not practised for reasons of culture, acceptability, affordability, or a lack of understanding of the potential benefits, even if actively promoted (Wellin 1955; White 1972; Gilman 1985). Thus, even estimating the portion of a given population that follows the practice would be difficult. Even less information is available on expenditures on vendor-supplied water, bottled water and tankered water or the extent to which expenditures on such supplies may be reduced as a result of the introduction of one of the subject water quality interventions.[35] Accordingly, while it is important to recognize the likelihood of such non-health cost savings when interpreting the results, no attempt is made to include them in this CEA.

6.3 DALYs Averted

Figure 6.3 shows the estimates of yearly DALYs averted for each of the four household- and the source-based interventions to improve water quality identified in Section 6.1. Once again, for completeness, these data assume 100% coverage of each of the interventions. Table 6.3 shows the actual number of DALYs averted at such 100% coverage, together with the corresponding figures for coverage at more realistic targets (80% and 50%).

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[35] These are critical questions, since in some respects, they define the market for interventions to improve water quality, and thus allow for potential investors to determine the risk-adjusted returns available. For an example of how this information was defined for long-lasting insecticidal nets, see WHO (2004a).

Figure 6.3: Yearly DALYs averted from implementation of certain water quality interventions to prevent diarrhoea at 100% coverage level

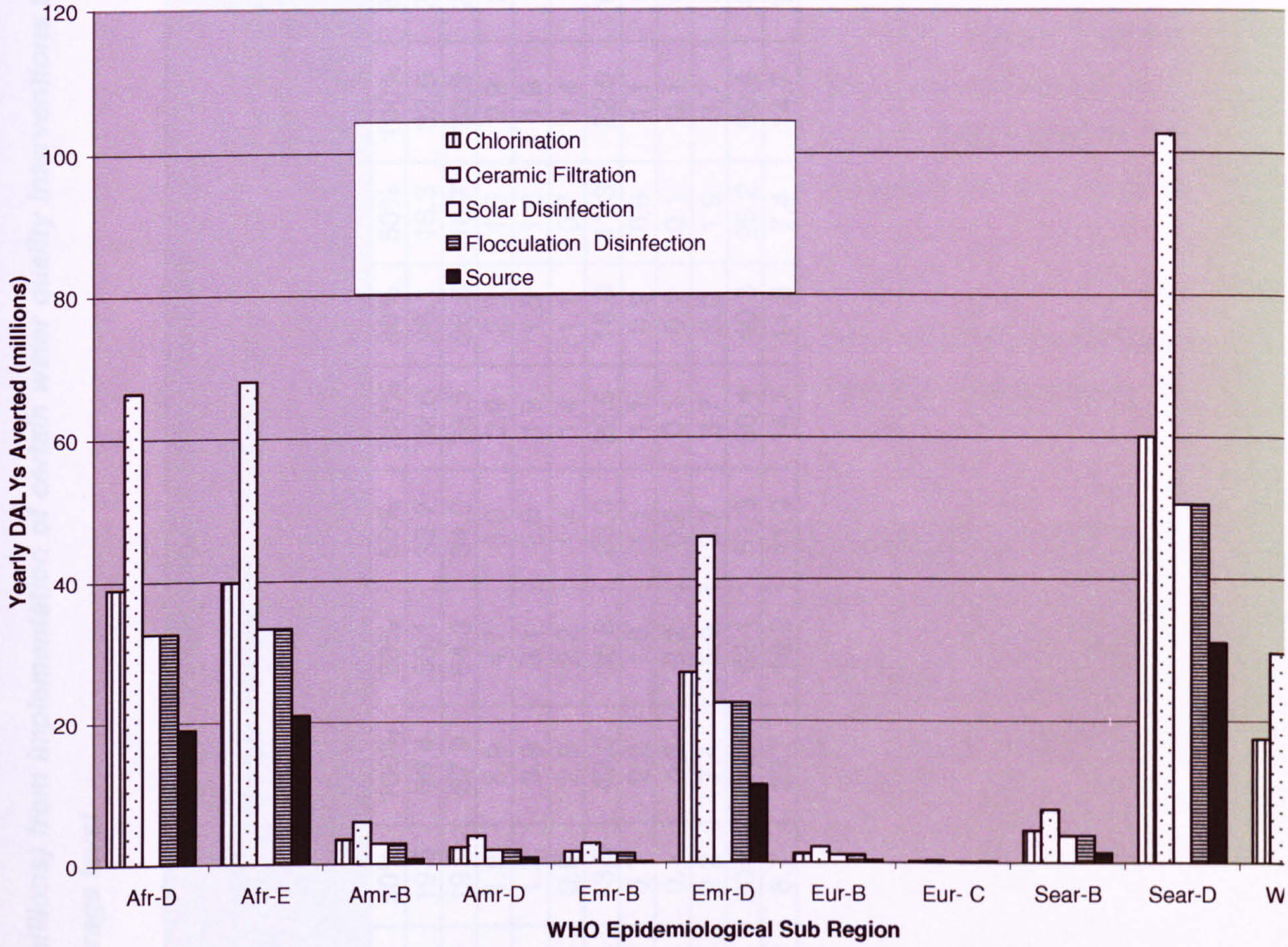


Table 6.3: Yearly DALYs averted (in millions) from implementation of certain water quality interventions to prevent diarrhoea at 100%, 80% and 50% coverage level

	Source-Based Interventions			Household-Based Interventions											
	Mean Cost of Standpost, Borehole and Dug Well			Chlorination			Ceramic Filtration			Solar Disinfection			Flocculation Disinfection		
Coverage	**100%**	**80%**	**50%**	**100%**	**80%**	**50%**	**100%**	**80%**	**50%**	**100%**	**80%**	**50%**	**100%**	**80%**	**50%**
Afr-D	18.9	15.1	9.5	38.9	31.1	19.5	66.4	53.1	33.2	32.6	26.1	16.3	32.6	26.1	16.3
Afr-E	20.9	16.7	10.5	39.8	31.8	19.9	67.9	54.3	34.0	33.3	26.6	16.7	33.3	26.6	16.7
Amr-B	0.7	0.6	0.4	3.5	2.8	1.8	5.9	4.7	3.0	2.9	2.3	1.5	2.9	2.3	1.5
Amr-D	0.8	0.6	0.4	2.3	1.8	1.2	3.9	3.1	2.0	1.9	1.5	1.0	1.9	1.5	1.0
Emr-B	0.2	0.2	0.1	1.6	1.3	0.8	2.8	2.2	1.4	1.4	1.1	0.7	1.4	1.1	0.7
Emr-D	10.8	8.6	5.4	26.9	21.5	13.5	46.0	36.8	23.0	22.5	18.0	11.3	22.5	18.0	11.3
Eur-B	0.3	0.2	0.2	1.3	1.0	0.7	2.2	1.8	1.1	1.1	0.9	0.6	1.1	0.9	0.6
Eur- C	0.1	0.1	0.1	0.2	0.2	0.1	0.3	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1
Sear-B	1.4	1.1	0.7	4.4	3.5	2.2	7.4	5.9	3.7	3.7	3.0	1.9	3.7	3.0	1.9
Sear-D	31.1	24.9	15.6	60.1	48.1	30.1	102.6	82.1	51.3	50.4	40.3	25.2	50.4	40.3	25.2
Wpr-D	7.7	6.2	3.9	17.4	13.9	8.7	23.7	19.0	11.9	14.7	11.8	7.4	14.7	11.8	7.4

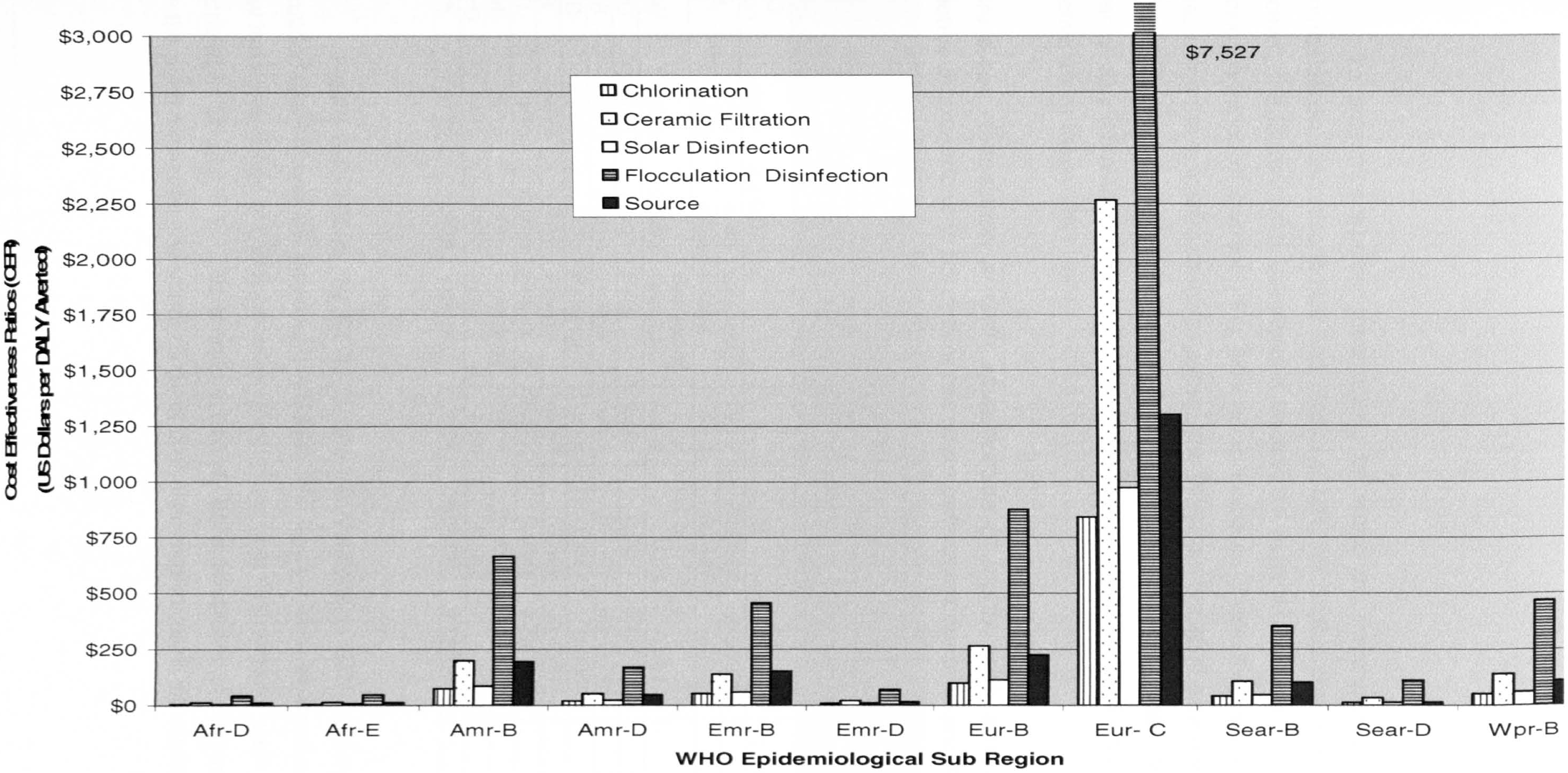
6.4 Cost Effectiveness Ratios (CERs)

Dividing the yearly costs (Section 6.1) by the yearly DALYs averted (Section 6.3) results in the average cost effectiveness ratio (CER) for each intervention. These CERs are shown in Table 6.4a for each intervention by each of the 11 WHO epidemiological sub-regions covered by this analysis. The table also shows the range of CERs based on the range of costs for each intervention as described in Section 6.1. These CERs and range of CERs are also shown graphically in Figure 6.4a.

Table 6.4a: Cost-effectiveness ratios (CERs) and range of CERs in US$ per DALY averted for certain source- and household-based interventions to improve water quality

	Source-Based Interventions		**Household-Based Interventions**							
	Mean Cost of Stand Post, Borehole and Dug Well		**Chlorination**		**Ceramic Filtration**		**Solar Disinfection**		**Flocculation Disinfection**	
	CER	**Range**	**CER**	**Range**	**CER**	**Range**	**CER**	**Range**	**CER**	**Range**
Afr-D	11	4-28	5	5-27	12	8-16	5	4-7	42	8-42
Afr-E	12	5-32	5	5-30	14	9-18	6	5-8	47	9-47
Amr-B	193	76-507	74	74-426	200	134-255	86	65-118	666	133-666
Amr-D	47	18-123	19	19-108	51	34-65	22	16-30	169	34-169
Emr-B	151	60-396	51	51-292	137	92-175	59	44-81	457	91-457
Emr-D	15	6-38	8	8-44	21	14-27	9	7-12	70	14-70
Eur-B	225	89-591	98	98-560	264	176-335	113	85-1338	875	175-875
Eur- C	1300	512-3407	841	841-4815	2267	1511-2880	973	730-1338	7527	1505-7527
Sear-B	102	40-269	40	40-227	107	71-136	46	34-83	355	71-355
Sear-D	14	6-37	12	12-71	34	22-43	14	11-20	112	22-112
Wpr-D	108	42-282	52	52-298	140	94-178	60	45-83	467	93-467

Figure 6.4a: Comparison of CERs for household and source interventions by WHO epidemiological sub-region.



To determine whether these CERs fall within the thresholds prescribed by the Commission on Macroeconomics and Health (CMH) for "highly cost effective" and "cost effective", the I$ thresholds described in Section 5.8 must be converted to US$s using the specific countries of interest. For illustration, however, Table 6.4b shows the threshold values using the indicative countries shown, the PPP from the 2000 estimates developed by the WHO[36] and the commercial exchange rates recently quoted for each indicative country currency. Any intervention whose CER exceeds the threshold for "cost effective" is not-cost effective under these CMH limits.

Table 6.4b: Calculation of CMH classification of highly cost- effective and cost-effective interventions in US dollars based on indicative countries and PPP

	International dollars		**Conversion Calculation**				**US dollars**	
	Highly cost-effective	**Cost-effective**	**Indicative Country**	**2000 PPP**	**Exchange Rate**	**Conver. Factor**	**Highly cost-effective**	**Cost-effective**
WHO region	1 x GDP	3 x GDP		a	b	a x b	1 x GDP	3 x GDP
AfrD	1381	4143	Senegal	273.7	0.00018	0.049266	68	204
AfrE	1576	4728	Kenya	17.1	0.0137	0.23427	369	1108
AmrB	7833	23499	Dominican Republic	6.932	0.03	0.20796	1629	4887
AmrD	3837	11511	Peru	1.465	0.2907	0.4258755	1634	4902
EmrB	7870	23610	Tunisia	0.421	0.7405	0.3117505	2453	7360
EmrD	2393	7179	Pakistan	12.24	0.017	0.20808	498	1494
EurB	5873	17619	Albania	45.93	0.0098	0.450114	2644	7931
EurC	6916	20748	Russia	6.372	0.0349	0.2223828	1538	4614
SearB	3915	11745	Indonesia	1950	0.0001	0.195	763	2290
SearD	1449	4347	India	8.65	0.022	0.1903	276	827
WprB	4186	12558	Vietnam	2312	0.0000628	0.1451936	608	1823

Figure 6.4b shows the CERs for the interventions in each region against these calculated CMH thresholds expressed in US$s. The figure includes narrow vertical bars that show the upper range of CERs based on the highest cost estimates for each intervention as described in Section 6.1. This therefore permits an assessment of cost effectiveness for both the point estimates and upper range of cost estimates for each intervention.

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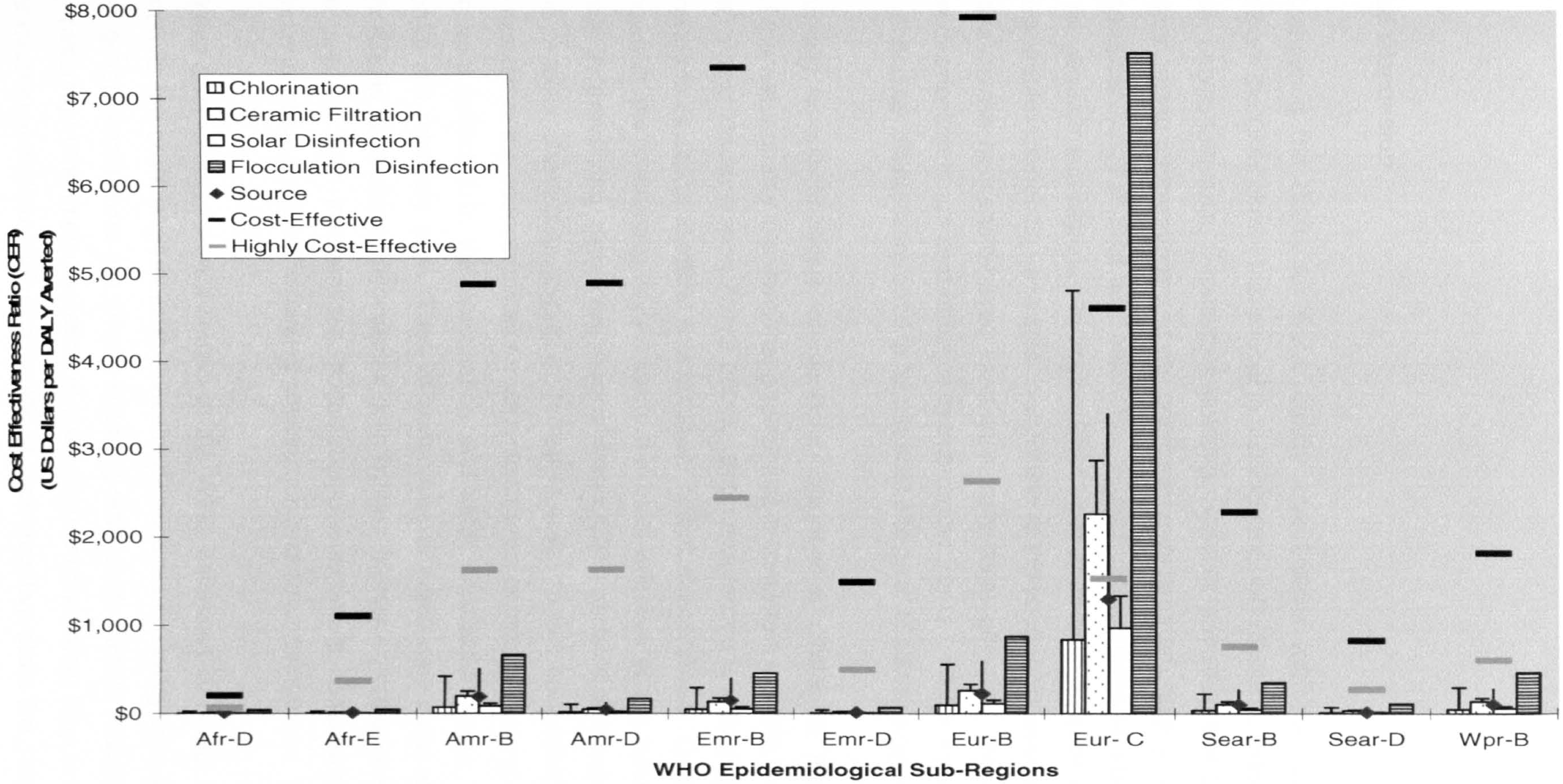
[36] http://www.who.int/choice/costs/ppp/en/index.html

Figure 6.4b: CERs (vertical bars) and upper range of CERs (narrow vertical bars) of household and source interventions and calculated US$ thresholds for highly cost-effective and cost-effective interventions (solid lines)



6.5 Discussion

Comparing the CERs for water quality interventions with the calculated US$ thresholds from the CMH shows that except in sub-region Eur-C (Belarus, Estonia, Hungary, Kazakhstan, Latvia, Lithuania, Republic of Moldova, Russian federation and Ukraine), both the household-based interventions and the source interventions are "highly cost effective". Even at the upper range of their cost estimates, all such interventions remain "highly cost effective" for all such sub-regions. In region Eur-C, the point estimates for source based interventions and for chlorination and solar disinfection at the household level are still "highly cost-effective", while household-based filtration is only "cost effective"; household-based flocculation-disinfection is not cost effective in sub-region Eur-C. At the top range of cost estimates, only solar disinfection remains "highly cost effective" in sub-region Eur-C.

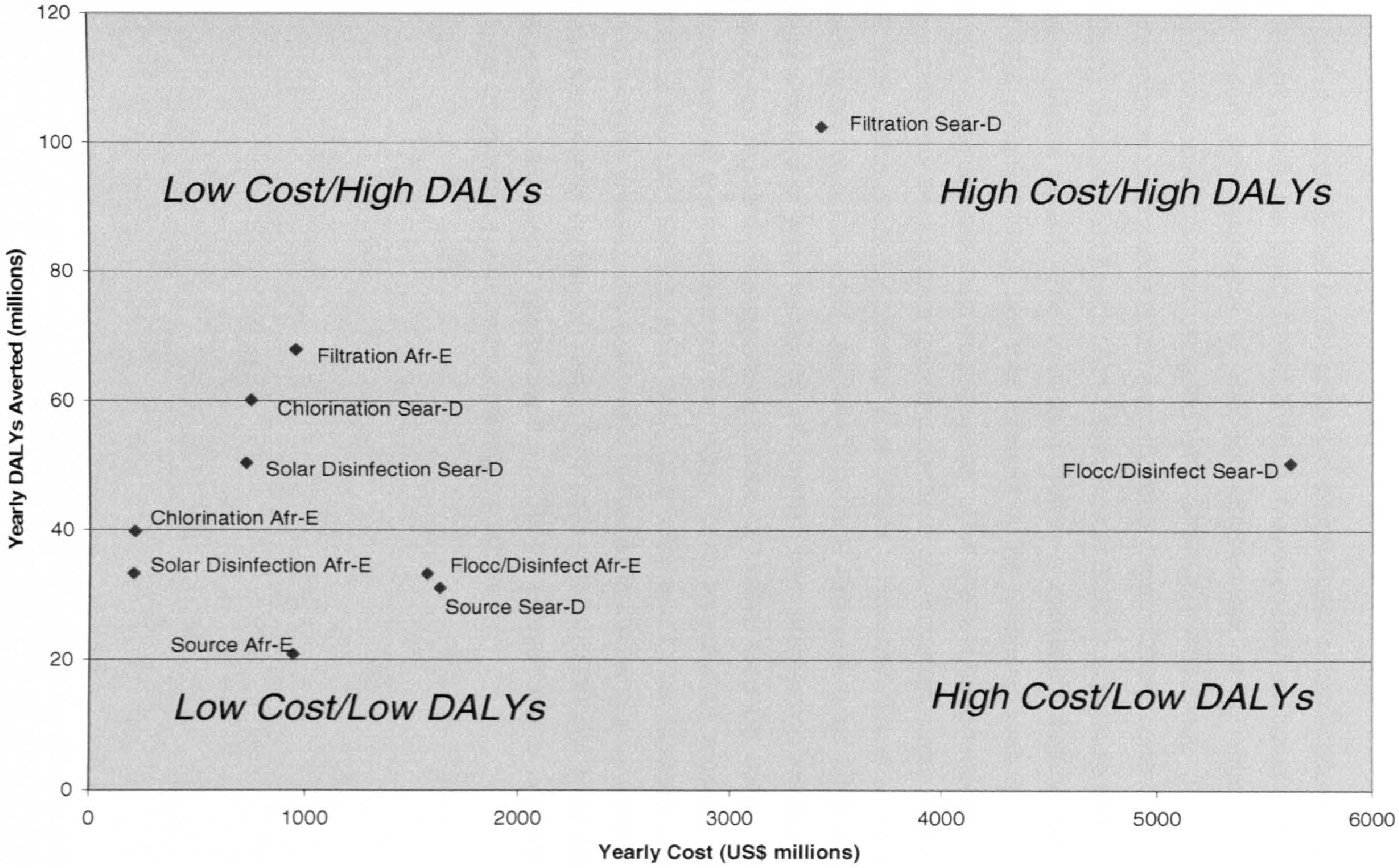
Among household-based interventions, chlorination (SWS) is the most cost-effective of the water quality interventions, a result that is consistent with the finding reported in the WHO World Health Report (WHO 2002). Solar disinfection is only slightly less cost effective, owing to its almost identical cost but lower overall effectiveness. Ceramic filtration, though shown in the systematic review to be the most effective of the household-based interventions in preventing diarrhoea, has a mean CER about 2.5 times higher than chlorination or solar disinfection, owing to its higher cost. In this connection, however, it should be noted that the cost estimates for ceramic filtration do not reflect any economies of scale that were reflected in the chlorination and solar disinfection costs, because the intervention is still relatively new. Lack of economies of scale may have also adversely affected the CERs of combined flocculation/disinfection. Moreover, if the low-end estimate of costs is used for such interventions, flocculation/disinfection is comparable to ceramic filtration and only about 2 times the level of chlorination and solar disinfection.

Direct cost offsets, even if limited to the WHO estimates of health cost savings, more than offset the costs implementing household-based water quality interventions. This means that governments, who are chiefly incurring such costs, would reduce their overall outlays by investing in the implementation of such interventions rather than in the treatment of cases of diarrhoeal disease. While a finding of such negative costs (i.e., income) are not uncommon in CEAs with high DALYs averted for relatively low costs, it should be noted that these estimates include only health costs offsets, and not other savings that are likely to inure to householders as they begin to adopt household water treatments, such as reduced fuel costs.

CERs of source-based interventions (stand posts, boreholes and dug wells) ranged from US$11 in Afr-D to US$1300 in Eur-C. The weighted average CER for all 11 sub-regions is US$109, comparable to the US$93 figure estimated by Cairncross and Valdmanis (2004). This weighted average is about twice the CER of household-based chlorination (US$58) and solar disinfection (US$67), but less than ceramic filtration (US$155) and considerably less than flocculation/disinfection (US$517). As noted above, however, the CERs are not completely comparable since this CEA assumes the implementation of household- but not source-based interventions in exposure scenario IV. Nevertheless, the fact that source-based interventions are generally "highly cost effective", and fall within the range of CERs of the household-based interventions is an important finding. As noted elsewhere, CEA is concerned only with health outcomes and therefore do not measure increases in time, productivity, etc. Given the substantial non-health benefits that Hutton and Haller reported in connection with interventions to improve water supplies, source-based interventions are likely to have a substantial advantage over household water treatment in CBA which does measure and attach economic values to such other benefits.

While CERs provide a consistent way to compare the cost-effectiveness of various interventions, it is also helpful to compare the interventions in terms of their overall cost and health impact. Figure 6.5 presents a scatter plot of the various interventions by yearly cost and yearly DALYs averted in two key sub-regions, Afr-E and Sear-D. This scatter plot can then be divided into quadrants to reflect relative costs and health impact. Where the lines are drawn to separate the quadrants is, of course, subjective, and it is important to note that the comparison here is among the interventions inter se. However, from a policy perspective, interventions in the "Low Cost/High DALYs" quadrant would obviously be most advantageous, while those in the "High Cost/Low DALYs" quadrant would be least attractive. In comparing the various interventions on this scatter plot, most are distributed in the "Low Cost/Low DALYs" quadrant. This analysis suggests that household-based filtration in Afr-E and chlorination in Sear-D should be given priority, for example, over flocculation-disinfection in Sear-D. This comparison also makes clear that despite the possible advantages of source-based interventions in CBA, household water treatment carries a far greater potential for preventing disease due to its higher level of effectiveness.

Figure 6.5: Scatter plot showing household and source interventions in Afr-E and Sear-D by overall cost and DALYs averted



As part of a recent series on the costs and effectiveness of interventions to achieve the MDGs (Evans 2005), the WHO-CHOICE MDG Team recently published a number of papers that report their estimates of the cost-effectiveness of a variety of health interventions in developing countries using the WHO CHOICE methodology. These include strategies to combat malaria (Morel 2005) and HIV/AIDS (Hogan 2005), control tuberculosis (Baltussen 2005), improve child health (Tan-Torres Edejer 2005) and promote maternal and neonatal health (Adam 2005). The evaluations follow a consistent methodology using generalised CEA (Evans 2005b), like that followed in the foregoing evaluation of water quality interventions to prevent diarrhoeal disease. Like the foregoing analysis of water quality interventions, the investigators reporting on these other strategies also chose not to reduce their intervention costs by possible cost offsets. However, whereas the current analysis used reports of actual costs, the WHO-CHOICE estimates used WHO database estimates supplemented in some cases by information from programme managers. In addition, results are reported in International dollars ($I) rather than US dollars (US$).[37] Table 6.5 lists some of the interventions that these CEAs investigated, together with the average CERs of thereof. For this table only, US$ costs and CERs reported above for interventions to improve water quality have been converted to I$s using a conversion factor of 0.20 (about the existing conversion factor for Kenya (Afr-E) (0.22) and India (Sear-D) (0.19). This provides a means of comparing the CERs for interventions to improve water quality with other interventions relevant to achieving the MDGs.

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[37] International dollars (I$) use purchasing power parity (PPP) to account for differences in price levels across countries. The exchange rate for domestic currency into I$s is the amount of domestic currency required to purchase the same quantity of goods and services as US$1 could buy in the United States. In low-income countries, income measured in $Is is generally higher than in US$s, since domestic prices for many goods are lower. To convert I$s into any other currency, multiply them by the PPP (available at http://www.who.int/choice/costs/ppp/en/index.html). By definition, the PPP for US$ is 1.

Table 6.5: ***Yearly costs, yearly DALYs averted and CERs for certain health interventions in Afr-E and Sear-D (I$s)***

Category and Source	Intervention	Coverage	Afr-E			Sear-D		
			Yearly Costs ($I millions)*	Yearly DALYs averted (millions)	CER (Cost/ DALYs)	Yearly Costs ($I millions)*	Yearly DALYs averted (millions)	CER (Cost/ DALYs)
Malaria (Morel 2005)	Case management with artemisinin	80%	73	5.9	12	ND	ND	ND
	Case management with artemisinin	95%	254.7	9.1	28	ND	ND	ND
	ITNs plus above case management	95%	441.2	10.7	41	ND	ND	ND
	Residual spraying plus ITNs plus above case management	95%	442.3	10.7	32	ND	ND	ND
HIV/AIDS (Hogan 2005)	Mass media campaigns	100%	16	4.5	3	33	1.8	18
	Peer education of sex workers	80%	61	14.3	4	115	36.1	3
	Voluntary counseling and testing	95%	406	5.0	82	207	5.2	40
	Prevention of mother to child transmission	ANC**	161	4.7	34	268	0.9	310
	Antiretroviral therapy, no intensive monitoring, first line drugs only	ANC	1350	2.4	556	550	1.0	542
Tuberculosis (Baltussen 2005)	Minimal DOTS	95%	366.3	44.8	9	536.4	76.6	7
	Full DOTS	80%	439.6	39.9	11	731.7	70.2	10
	Minimal DOTS plus first and second line drugs for resistant cases (DOTS Plus)	95%	495.9	45.9	11	932.6	78.4	12
	Full combination (Full DOTS + DOTS Plus)	80%	518.6	40.8	13	1056.7	71.6	15
Childhood Health (Tan-Torres 2005)	Vitamin A and zinc fortification	95%	23	1.2	19	49	1.4	35
	Above plus measles immunization	95%	91	3	28	ND	ND	ND
	All above plus case management of pneumonia (80%)	80%	386	7	55	609	8	75
	All above plus oral rehydration therapy	95%	1167	12	95	ND	ND	ND
Diarrhoeal Disease (Chapter 6 hereof)	Household chlorination	100%	1046	39.8	25	3748	60.1	60
	Household filtration	100%	4804	67.9	70	17205	102.5	170
	Household solar disinfection	100%	875	32.6	30	3634	50.3	70
	Household flocculation/disinfection	100%	7850	33.3	235	28110	50.4	560
	Communal standpost, borehole, dug well	100%	1284	20.9	60	2223	31.1	70

ND= no data provided. *Amounts are in $I. **ANC=Antenatal care coverage level.

As the table shows, all of these interventions meet the definition for "highly cost effective" in the selected regions (i.e., <I$1576 for Afr-E and <I$1449 for Sear-D) (Evans 2005c). Many of the other interventions are more cost-effective than the water quality interventions. However, there are three reasons to consider carefully such cross-disease comparisons. First, as noted in Section 6.6 below, there is considerable uncertainty associated with the calculation of CERs. As a result of this imprecision, variations that are less than an order of magnitude should not be considered to clearly favour one intervention over another. Second, while the studies of the other disease interventions were aimed at capturing the overall health benefits therefrom, the effectiveness data used to calculate the DALYs averted from the water quality interventions were limited to diarrhoea. Thus, they do not include the other health benefits that may be expected from improving microbial water quality.

The third difference is perhaps most important. This relates to the overall health benefits that obtain from water quality interventions. Apart from interventions to treat or prevent tuberculosis, the overall number of DALYs averted as a result of water quality interventions is massive when compared to the other categories of interventions. In region Afr-E, for example, household filters save 68 million DALYs and other water quality interventions 21-40 million. None of the malaria, HIV/AIDS or childhood health interventions delivers more than 14.3 million. The same dominant overall impact is found in region Sear-D. The number of DALYs averted is also larger than certain interventions for promoting maternal and childhood health (Adam 2005). Thus, water quality interventions are not only highly cost effective in most cases, but except for tuberculosis interventions which are comparable, the magnitude of their health impact is substantially larger than other important interventions associated with achieving the MDGs.

6.6 Limitations of CEA and need for additional data

The disciplined application of cost-effectiveness analysis yields results that policy makers can find compelling. Complex choices among sector priorities and individual interventions seem to be magically resolved when plotted on a graph showing cost against health gains or when summarized in stochastic league tables.

Generalized CEA is a powerful tool and can play an important role in formulating policy. By providing a means of comparing a set of interventions, generalized CEA can help set national priorities at both the programme and sectoral level. This should result in improved economic efficiency for the health system overall. Generalized CEA can also help inform decisions about targeting, combining, scaling up and financing interventions. It can also help guide research and development priorities. By drawing on the WHO-CHOICE database, national governments can also obtain access to evidenced-based cost and effectiveness data on emerging interventions and technologies (Tan-Torres Edejer 2003).

At the same time, it is important to understand the limitations of CEA. Chief among these is the uncertainty that underlies the apparent precision of the results. Uncertainty arises in three areas (Tan-Torres Edejer 2003). First, there is parameter uncertainty due to sample variation around the estimates used to develop a CER and the assumptions used in the analysis (e.g., the discount rate). Second, there is model uncertainty, particularly arising from the lack of data on the cost and effectiveness of joint or multiple interventions. Third, there is generalisability uncertainty associated with the need to extrapolate the data from individual programs and trials to target populations as a whole. All of these sources of uncertainty are present in CEAs of household water treatment interventions, but so are others such as imprecise estimates of cost and effectiveness. While sensitivity analysis and probabilistic uncertainty analysis can be used to quantify this uncertainty to some extent, and thus allow analysts to report a range around a CER, policymakers will often fail to appreciate the uncertainty or understand how to interpret results when uncertainty intervals overlap. The WHO-CHOICE MDG Team perhaps puts this uncertainty most clearly in its recent series: "For cross disease analysis, we believe it is not possible to recommend that an intervention shown to cost $45 per DALY averted is more efficient than one costing $60, given the nature of the uncertainties. However, we are much more confident that $45 per DALY is better than $450 per DALY" (Evans 2005b). Analysts have a special duty to present their findings in a manner that does not overstate their precision or conclusiveness.

The uncertainty associated with CEAs can be reduced with more reliable data. In the case of household-based interventions to improve water quality, all three types of uncertainty could be reduced by collecting more complete data at the household level on demographics, water and sanitation facilities, current water treatment and other handling practices, hygiene behaviour, access to household-based intervention technologies, the acceptability and affordability of such technologies, and the prevalence and patterns of diarrhoea and other diseases associated with waterborne pathogens. This information could potentially be solicited as part of the existing international household surveys conducted by the USAID-supported Demographic and Health Surveys (DHS) and the UNICEF-supported Multiple Indicator Cluster Surveys (MICS) (Ezzati 2005). More complete and accurate information on the costs of implementing household-based water treatment interventions, particularly over the long term, can be obtained by providing programme implementers with the tools and means of recording and sharing cost data, and encouraging them to do so, perhaps with support (and pressure) by funders. The WHO-backed International Network to Promote Household Water Treatment and Safe Storage is advancing this effort. Finally, as suggested by the Cochrane review, assumptions used to estimate the effectiveness of water quality interventions to prevent diarrhoea must be enhanced by conducting rigorous, long-term, multi-arm trials in different settings that can help reduce or identify the sources of heterogeneity that characterize current pooled estimates.

The WHO recommends three other means of dealing with the uncertainty associated with CEAs. Uncertainty relating to variables that carry value judgements should be subjected to one-way and, if appropriate, two-way sensitivity analysis. While WHO-CHOICE defaults to a 3% discount rate for both costs and health effects, with age-weighting, analysts are urged to examine the sensitivity of results by using 0% discounting for health effects, 6% for costs, and no age weighting. Uncertainty relating to parameter estimates should be quantified by probabilistic uncertainty analysis using Monte Carlo simulations (repeated random draws from the distribution of each key variable to determine the probability distribution of the CER). Finally, stochastic league tables can be used to provide additional information on how to interpret the results in view of the uncertainty. The WHO has developed a software programme, known as MC League, based on Monte Carlo simulations, to help develop the stochastic league table. Like the Cost-It and PopMod programmes, MC League can be downloaded directly from the WHO-CHOICE website. It is anticipated that these steps will be taken, with assistance from WHO, when the foregoing results are prepared and submitted for publication.

Finally, in interpreting these results, readers are urged to bear in mind the qualifications on cost-effectiveness analysis noted in Section 5.2 above.

PART III

FIELD STUDIES: PILOT STUDY OF CERAMIC DRIP WATER FILTERS AND HOUSEHOLD WATER TREATMENT IN EMERGENCY RESPONSE

Chapter 7: Ceramic Filters in Colombia: Introduction and Methods

7.1 Introduction

Section 1.4 above provided certain background information concerning ceramic water filters. While porous rock and ceramics have been used to treat water since antiquity, their potential value as a public health intervention to improve the microbial quality and prevent diarrhoeal disease among vulnerable populations has not been rigorously investigated (Sobsey 2002). After providing certain background information on such filters, this Part reports on the assessment of their microbiological performance and impact on diarrhoeal disease in a pilot programme by Oxfam GB.

7.1.1 Background

Ceramic water filters were first introduced in 1827 by John Doulton, a British merchant working out of a pottery shop in Vauxhall Walk, Lambeth not far from the River Thames which a pamphlet of the same year described as "offensive to the sight, disgusting to the imagination and destructive to the health" (Doulton, 2005). Initially, only the vessels were ceramic; the actual filter element consisted of powdered carbon. By 1835, when Queen Victoria (whose husband, Prince Albert, died of typhoid) commissioned the company to produce water purifiers for the Royal household, they were fitted with clay filter elements for bacterial removal. The British Army began constructing gravity filters with ceramic elements in the 1850s (Warwick 2002). The hollow cylindrical "candles" of the type still used in Doulton and other commercial filters first appeared in 1904. Silver, first recognized for its antimicrobial activity in 1869 (and, following Crede's recommendations in 1881, widely used until recently to prevent blinding by gonorrhea in newborns), was introduced as a bacteriostatic agent in ceramic water filters by Swiss-based Katadyn (Russell, 1994). An estimated 10 million to 15 million ceramic candles are produced and sold annually throughout the world by the dozen leading producers. Many are still used in gravity-type systems; others are installed in portable pump-style units used mainly by outdoor enthusiasts, or in plastic housings with pipe fittings where they are plumbed into pressure water systems at the point of use.

While the candle-style filter has been driven mainly by commercial companies, alternative designs have begun to emerge in low-income settings mainly with governmental and NGO support. The most widely used alternative is an open, pot-style design, in which the upper ceramic vessel itself serves as the filter element. This first evolved from a comparative study by the InterAmerican Development Bank in 1981 which emphasized the appropriateness of the technology to developing countries (Latange, 2001). While USAID financed the development of a factory in Ecuador to produce the filters, the enterprise was abandoned in 1985, reportedly because of its inability to develop sufficient demand for the product (MAP International, 1985). With assistance from Potters for Peace (PFP), a US-based non-profit organization, and the Massachusetts Institute of Technology (MIT), the design and method of fabrication of the pot-style filter has been refined. Most recently, Industrial Development Enterprises (IDE) has worked with local partners in Cambodia and elsewhere to establish factories for local production of the PFP design and to distribute them to householders either completely free or through social marketing with partial cost recovery (IDE 2003). A disc-shaped filter element which is cemented into the bottom of a vessel has also been developed (Dies 2003, Cheeseman 2003). While this design has a lower cost and fragility, disc-shaped elements have not been widely embraced, mainly because of challenges in sealing the element into the floor of the raw water holding chamber.

The composition, fabrication, properties and means of operation of ceramics used for the treatment of water have been described (Lantange 2001; Dies 2003; Long 2005). Unlike activated carbon filters which remove contaminants chiefly by adsorption, ceramic filters operate mainly by imposing a mechanical barrier against pathogens. The efficiency of the filter element in removing such contaminants thus depends on its pore size. While common waterborne cysts, such a *Giardia* and *Cryptosporidium* are relatively large (> 3 μm), certain bacterial rods such as *E. coli* are as small as 0.7μm in width. This range of filter pore size, known as "microfiltration", is within the technical capabilities of better quality ceramic filters operating at gravity pressures. Waterborne viruses, such as norovirus, range from 20-100 nanometres in size, and require reverse osmosis or "nanofiltration" that can only operate at high pressure.[38] By employing specialized materials (such as diatomaceous earth) and advanced mixing, moulding and firing techniques, higher quality ceramic filters achieve a smaller (e.g., 0.2 to 0.5µm) and more consistent pore structure. This allows them to achieve greater capture of microbial pathogens while minimizing the adverse impact that lower pore size would otherwise have on flow rate (Lantange 2001). More advanced filters also incorporate silver as a bacteriostatic agent to prevent microbial growth within the filter matrix itself, a well-known problem in carbon filters (Chaidez 2004) and a possible problem with poor quality ceramic filters as well (Alabi 1986).

7.1.2 Microbial Performance: Standards and Testing

In 1986, India established its current standard for ceramic water filters (Indian National Standards 1986). The standard, however, only addresses the materials and fabrication of the filters, not their microbiological performance. In fact, by establishing a maximum pore size of 30µm, the Indian standard implicitly acknowledges that most ceramic filters in India and other parts of Asia are not designed or intended to remove microbial pathogens. While very popular in the country, most consumers use them only to remove suspended solids (turbidity), thus improving the appearance and potentially the taste of drinking water. The normal practice by households using such filters is to filter their water before boiling it or treating it with a chemical disinfectant (Warwick 2002).

A year later, the US Environmental Protection Agency adopted the Guide Standard for Testing Microbial Purifiers (EPA 1987). The Protocol established minimum standards for the microbial performance of water treatment devices to be used with water of unknown microbial quality. The Protocol requires microbial water purifiers to achieve minimum log

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[38] Owing to their negative charge, viruses do tend to aggregate and associate with larger participles. This may account for the approximately 1 log reduction in viruses that ceramic filters have been shown to deliver (Brown 2005). Viral reduction can also be achieved by insertion of adsorption medium, such as activated carbon, into the hollow core of ceramic candle. This medium, however, can be quickly exhausted when the adsorption sites are occupied by chemicals and other non-microbial contaminants. A more creative and longer-term approach is currently under investigation. It is based on the finding by Sobsey and Jones (1979) that at neutral pHs, viruses sorb to surfaces carrying a positive charge. By coating ceramics with certain metals, Scott (2002) increased the sorptive capacity of filter media. Using this approach, Brown (2005) has reported >7 log reductions of bacteriophages by ceramics treated with low-cost ferric and aluminum hydrous metal oxides. A field trial of such ceramics is planned in 2006 in Cambodia.

reduction values (LRVs)[39] of 6 for bacteria, 4 for viruses and 3 for protozoan cysts. The Protocol prescribes a specific method for testing ceramic water filters with or without silver and establishes maximum leaching limits for silver for those devices containing the metal. While NSF International also maintains certain standards for water treatment devices, apart from Standard 53 (Drinking Water Treatment Units—Health Effects) which covers protozoon cysts and requires a 3.3 log (99.95%) reduction for certification, the NSF/ANSI standard simply incorporates the EPA Protocol (NSF/ANSI P231). Thus, the EPA Protocol continues to serve as the most widely accepted standard for microbial water treatment devices.

Few studies of ceramic filters have been published in peer-reviewed journals, and all but one were lab-based studies. Two studies report on the microbial performance of commercial pump-style water treatment devices used chiefly by backpackers and outdoor enthusiasts in developed countries. Horman (2004) reported >6 log reductions of *E. coli* from pump-style filters manufactured by Swiss-based Katadyn Products and US-based Marathon Ceramics. The filters were also effective against *C. parvum* oocysts, but not F-RNA phages. Schlosser (2001) found a Katadyn® Mini Ceramic™ filter to reduce viable *E. coli* by >3 logs in clear water and by 2 to 4 logs in turbid (10.4 to 52.3 NTU) water. Ongerth (1989) tested four brands of such filters for removal of *Giardia* cysts, and found generally complete retention. On the other hand, an evaluation of ceramic gravity (drip) filters from Pakistan found them to be capable of reducing bacterial loads by less than 1 log (Jaffar 1990). Chaudhuri (1994) reported that while three brands of Indian ceramic filters (one silver impregnated) initially reduced *E. coli* levels by 1.4 to 3.05 logs, longer term results were under 1 log for all three filters. They attributed the poor performance to high pore diameters (16.0 to 39.2 µm). Only Basu (1982) reported bacteria-free effluent from candles with a pore size of 6-31 microns. However, the candles, which were produced in the laboratory, achieved such performance only after being soaked in silver salts.

In the only field study of ceramic filters published in a journal prior to Clasen (2004c), most filters used on a Nigerian university campus produced water that was highly contaminated (Alabi 1986). The investigators recommended that householders take more care in cleaning and maintaining the candles, even though they found no association between cleaning and maintenance practices and the coliform load from the filters' product

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[39] The efficiency of water treatment methods is often expressed in terms of the log reduction value. LRV= $\log_{10}$ (concentration of influent/concentration in filtrate). Thus, a LRV of 1 (or "1 log") represents 90% removal of the feed contaminant, a 2 log reduction is 99%, a 3 log reduction is 99.9%, etc.

water. It seems more likely that the ceramic quality itself was inferior, though the investigators did not even report the brand, origin or specifications of the tested filters or conduct any testing to determine if they were even capable of producing microbiologically safe water when new.

More recently, much of the testing of ceramic filters, both in the lab and in the field, appears in student dissertations and internal reports. Unfortunately, most of these results are from short-term tests of new filters under controlled conditions. Sagara (2000) showed how the performance of locally-fabricated PFP filters in Nepal could be improved by treating the ceramics with silver, but was unable to achieve consistent reductions in faecal bacteria, thus requiring the use of a supplemental disinfectant after filtration. In her laboratory-based investigation, Lantange (2001) reported a >3 log reduction of faecal coliform from silver-treated, PFP-style filters fabricated in Nicaragua. In the field, however, many of the filters produced water with significant bacterial loads (Lantange 2001a). In 2003, a similar study over 6 months reported that only 80.4% of samples from households in Nicaragua that used locally-produced and silver-treated PFP filters contained less than 2.2 CFU of hydrogen-sulphide producing bacteria, the detection limit for this alternative test for faecal contamination (Hwang 2003). Dies (2003) compared the microbial performance of commercial and locally fabricated filters in the laboratory and found LRVs ranging from 0.7 to 1.75. Cheeseman (2003) also compared microbial performance of commercial and locally fabricated filters under laboratory conditions, achieving high reductions of microsphere proxies for cysts and of bacteria and no reduction of viruses. In a 12-month assessment of a pilot programme in Cambodia producing PFP-style filters, IDE reported that 83% of samples at the household filters were free of faecal coliform (IDE 2003). However, an independent field investigation of such filters found only 5.4% of such samples to conform to the WHO standard of zero coliforms per 100ml and a mean reduction of thermotolerant coliforms (TTC) of only 1.004 logs (Smith 2004). That same investigation reported similar results for untreated candle-style filters from Vietnam, with only 8.3% of samples being TTC-free and a mean reduction of just 1log.

7.2.3 Health Impact Studies

Apart from the Colombia study described below, the health impact of interventions involving the use of ceramic filters has been investigated in only four intervention studies, all involving diarrhoea (URL 1995; Clasen 2004; Clasen 2004a; duPreez 2004). These studies were included in the Cochrane review described in Part I above; the Colombia study was not included since the results were not available until after the December 31, 2004 cut-off date for research covered by the initial review.

The first study was a randomized, controlled trial conducted in Guatemala by the Rafael Landivar University from December 1993 to November 1994 to assess the impact of locally-made filters in a health and nutrition programme conducted by AFAGUATEMALA. The filter was a silver-coated PFP design fabricated in Guatemala at a cost of US$20-22 per unit. Two intervention arms (the filter alone and the filter plus nutrition/hygiene instruction) were compared with controls (using traditional practices) among 680 families in three separate communities representing the country's geographical regions. The mean faecal contamination of source water ranged from 5 to 270 faecal coliforms/100ml; the study did not measure the microbial quality of water at the household level, either for intervention groups or controls. In terms of disease, however, investigators found that the prevalence of diarrhoea among persons in households that received filters was 53% lower than controls (0.47, 95%CI: 0.24 to 0.92); among those who received both filters and nutrition/hygiene instruction, the rate was 65% lower (0.35, 95%CI: 0.13 to 0.92).

Clasen (2004) was the first study of the health impact of filters using commercial ceramic elements. Apart from the Colombia trial described below, it is also the only health impact study of a ceramic filter that has been published to date. The study was designed as a randomized, controlled trial and was conducted in a rural community in central Bolivia whose water was sourced from open irrigation canals. The intervention consisted of a filter fabricated on site from two transparent buckets, a metal tap and two Katadyn® 240mm Ceradyn™ ceramic candles; controls continued to use customary water management practices. The estimated cost of the system was US$25. A pre-intervention survey revealed heavy faecal loads in drinking water (mean TTC of 795 CFU/100ml) and a high period prevalence of diarrhoea (22.2% reported at least one episode in the preceding 7 days). After a baseline survey, 50 households were randomly allocated, half to receive filters and half to serve as controls. Thereafter, they were visited at approximately 6-week intervals from February 2003 to July 2003 to obtain a sample of household drinking water and data regarding prevalence of diarrhoea among household members in the previous week. 100% of the 96 samples from intervention households were free of TTC. Samples from the control group continued to have significant levels of TTC; 65.6%, 34.4% and 11.4% of the samples exceeded 10, 100 and 1000 TTC per 100 ml, respectively. Only 15 of 96 (15.6%) control household samples tested meet the WHO standard of zero coliforms per 100ml. The risk of diarrhoea among members of households using the filters was 70% lower than controls (0.30, 95%CI 0.19 to 0.47); among children under 5, it was 83% lower (0.17, 95% CI: 0.06 to 0.49).

Later the same year, an assessment of a pilot programme by Food for the Hungry, International in another rural community in Bolivia provided additional information on the microbial performance and health impact of a ceramic filter (Clasen 2004a). The assessment consisted of a randomized, controlled trial among 60 households, 20 of which served as controls and 40 of which received a locally-fabricated filter similar to that described above but with 120mm candles (half US$6.00 Katadyn Ceradyns with a design life of 20,000L and half US$2.00 Brazilian-made Stefani™ elements with a design life of 5000L). Pre-investigation water quality was 87TTC/100ml and the prevalence of diarrhoea in the study population was 9.9%. After a baseline survey, the study population was followed for 5 months. The filters significantly reduced, but did not eliminate, faecal coliforms in samples taken from intervention households. The filters were associated with a significant reduction in the risk of diarrhoea, both among all ages (0.47, 95%CI: 0.24 to 0.92) and in children under 5 years of age (0.50, 95%CI: 0.27 to 0.94).

Finally, duPreez and colleagues (2004) investigated the effect of a fully-fabricated commercial filter manufactured by British Berkefeld (Doulton). The study covered both general (non-bloody) diarrhoea and bloody diarrhoea in a randomized, controlled trial among 115 households in two settings in Zimbabwe and South Africa. The filter consisted of a specially-designed stainless steel unit with upper and lower chambers and a tap for accessing water. The Doulton candles are manufactured in the UK and have been shown to reduce bacteria by >5 logs and protozoan cysts by >3 logs. They cost approximately US$50. The investigators reported that intervention households had significantly lower levels of *E. coli* in their drinking water than controls (geometric means of 3.22 versus 15.54, respectively). Over the six-month trial, the intervention was associated with a 79% reduction in all diarrhoea (0.21, 95%CI: 0.07 to 0.61). The reduction was protective both for bloody diarrhoea (0.16, 95% CI: 0.06 to 0.46) and for non-bloody diarrhoea (0.21, 95%CI: 0.10 to 0.47).

7.2 Materials and Methods of Colombia Study

Oxfam GB, a British charity, has been working in Colombia for more than 20 years. Among other things, Oxfam supports vulnerable communities in Uraba and Catatumbo (Santander) affected by the armed conflict with housing, food security and public health initiatives, including water and sanitation. Based on successes in other Andean trials (Clasen 2004; Clasen 2004a), Oxfam elected to pilot the use of ceramic water filters in three remote communities. The intervention was chosen mainly due to its potential for providing safe drinking water to the affected region over longer periods of time with minimal support. Oxfam asked me to conduct this assessment of the microbiological performance and health impact of the filters. I designed the study, trained the field workers (Freddy Vidal and Luz Marina Londono) in water sampling and diarrhoea surveillance, provided them with survey instruments and surveillance sheets, helped analyze the data (with support from Sophie Boisson and Simon Collin) and wrote the report to Oxfam and the subsequent paper (Clasen 2005a). Oxfam GB in Bogota (Gloria Garcia Parra, Luz Marina Londono and Freddy Vidal) selected the study sites and conducted the field work, foreigners being prohibited from working in the region due to security issues.

7.2.1 Study Sites

Three separate communities representing different circumstances and challenges were selected by Oxfam for the pilot programme (Figure 7.2.1). Vigía de Curvaradó, the most remote of the sites, is a fishing village of approximately 350 inhabitants along the Atrato river in the Department of Chocó. Inhabitants suffer from a poor and unbalanced diet, and there is considerable illness, especially among infants and children. Homes are built on stilts over the water, and the river is the source of all water needs, including washing water, human and other waste disposal and, except for periodic rain harvesting, drinking water. Inhabitants spend much of the day on or around the river. When thirsty, many inhabitants, and especially children, consume water directly from the river. Dabeiba is a town of approximately 30,000 located in a mountainous region of the Department of Antioquia. Most inhabitants raise crops and livestock. Water used for drinking and all other purposes is supplied by a gravity-fed pipeline. There is an antiquated and poorly maintained pipe distribution system to yard taps, but because of poor service, inhabitants collect and store water in open vessels also used for watering livestock and other purposes. The municipality has a water treatment facility but uses only alum as a flocculant and does not disinfect the water. Cartagenita is coffee-growing community of about 105 families in the Department of Norte de Santander who have recently returned after having been displaced due to the conflict. Water is supplied from a mountain stream through a series of channels and storage ponds and finally into a piped distribution network to taps on most household plots. The water is not treated, either by sedimentation or disinfection.

Figure 7.2.1: Location of study sites for Oxfam pilot of ceramic filters in Colombia

All three sites are in areas affected by the armed conflict in Colombia. Security problems make it impossible for Oxfam to establish and maintain consistent programmatic activities around water, sanitation and hygiene. Owing both to the conflict and to their remoteness, Vigía de Curvaradó and Dabeiba receive less regular follow up and programmatic support than Cartagenita. Only in Cartagenita has Oxfam been able to establish a network of health promoters who reside locally and therefore visit the area regularly, monitoring health and providing support.

After meeting with community representatives and performing an initial analysis of water samples, a total of 140 households were recruited to participate in the study, 49 from Vigía de Curvaradó, 51 from Dabeiba and 40 from Cartagenita. An investigator then collected baseline information from the head of each participating household by means of a standard questionnaire, and obtained a sample of the pre-intervention drinking water for baseline data purposes. Thereafter, a lottery was conducted at each study site to allocate households randomly to an intervention group.

7.2.2 Intervention

Intervention group households received a gravity water filter system. It consisted of two locally-produced 15L covered clear plastic buckets, two Katadyn® 120mm porous ceramic filter elements (Katadyn Produkte AG, Zurich, Switzerland) and a metal valve for dispensing the product water (Figure 7.2.2). While best known for its pump-style filters for expeditions, Katadyn also produces candle-style filter elements for pressure and gravity water treatment devices. Independent testing sponsored by the manufacturer has shown its Ceradyn™ filters elements to achieve LRVs of >6 for bacteria and >3 for cysts (Spectrum Laboratories 1997). While the manufacturer makes no claims concerning the capacity of the filters to reduce viruses, independent testing has shown LRVs for MS2 and other coliphages of approximately 1 (Brown 2005).[40] The decision to use Katadyn elements was based on the effectiveness of the filters in the Bolivian trials. Although the 120cm have a shorter life than the 240mm candles (20,000L versus 50,000L), experience in Bolivia demonstrated that the shorter candles were less susceptible to breakage when the filter was accidentally tipped over. The landed cost of the complete unit was approximately US$20.00

Members of the intervention group attended a meeting during which they assembled their filter systems and received instructions on filling, using and cleaning the system. They were encouraged to place the filter on a flat, stable surface that was accessible even to

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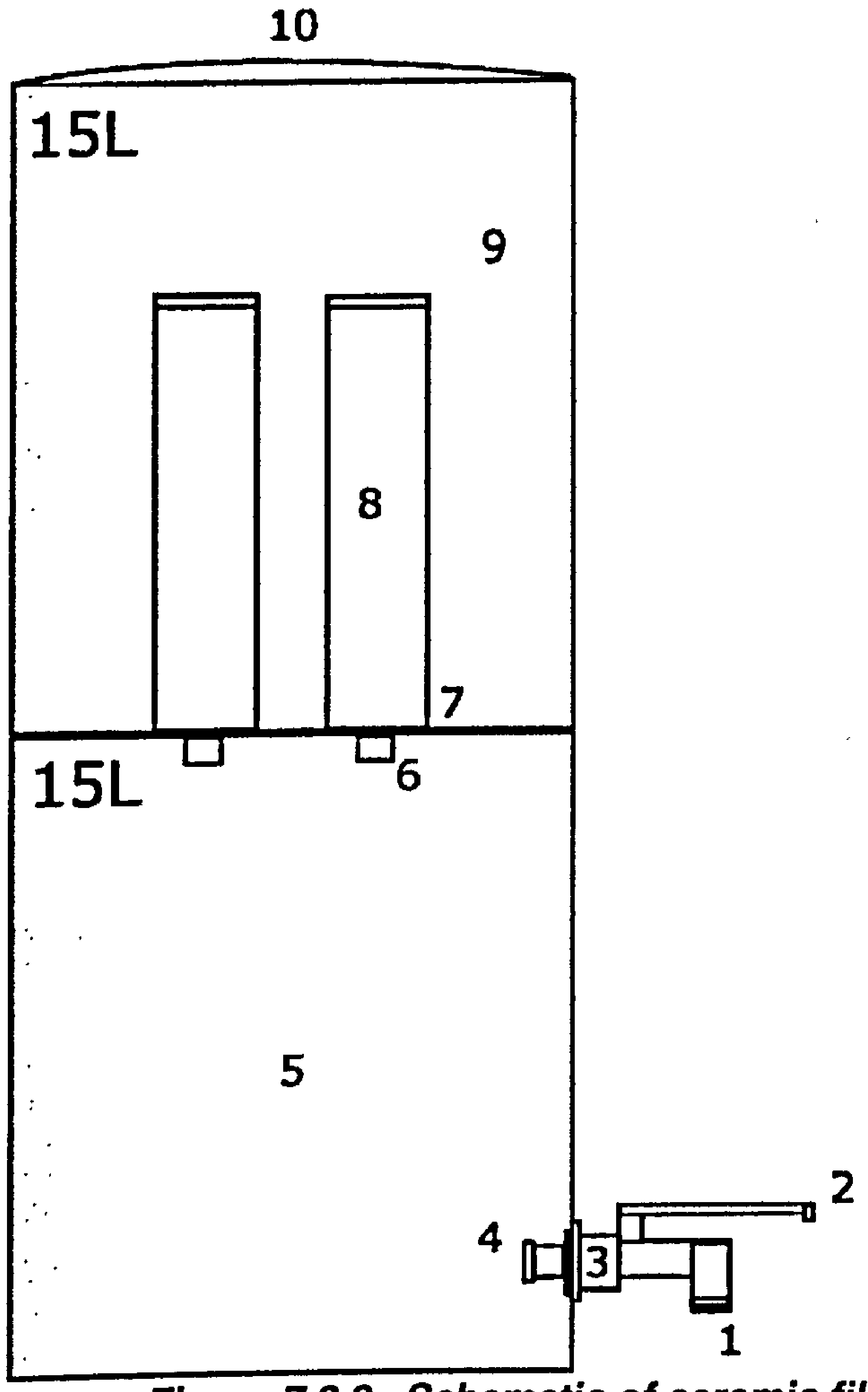
[40] MS2 is a male specific RNA virus that can replicate only in its bacterial host, *E. coli.* Such bacteriophages are useful surrogates for modelling the behaviour of enteric viruses in water treatment processes (Grabow 2001) and have been used to model virus retention in other membrane processes (e.g., van Voorthuizen 2001).

small children; to fill the unit as frequently as necessary using the same water that they previously used for drinking; to encourage all household members to use the filter for drinking, cooking and cleaning eating utensils; and to clean the candles with a coarse sponge (also provided) whenever they noticed that the flow rate was reduced. They were also instructed to refrain from opening the lower vessel for any reason, and to access the filtered water solely from a cup or other utensil filled from the tap. Spare candles, buckets and taps were left with the community leader. Two filter systems were also provided to the school master in each community, one for each classroom. Apart from answering questions upon distribution of the system or in subsequent visits for sampling and diarrhoea surveillance, no hygiene or other instructions, further training nor other explanations were provided as part of the intervention. Control households continued to use their customary practices and vessels for collecting, storing and drawing drinking water.



1	Heavy-duty metal spigot
2	Lever to operate ball-type valve
3	Plastic collar (PVC)
4	PVC nut and rubber gasket securing fitting to receiving/storage container
5	Transparent plastic receiving/storage container
6	Plastic nut securing candle in place
7	Barrier between containers, with a rubber gasket below candle and between containers
8	Katadyn® Ceradyn™ ceramic filter candle
9	Transparent plastic top container
10	Hinged top container lid

Figure 7.2.2. Schematic of ceramic filtration unit used in field trial in Colombia. Schematic of filtration unit (not to scale) (J. Brown).

7.2.3 Sampling and Surveillance

Following the distribution of the filter systems, investigators went to each of the study sites at approximately six-week intervals to record diarrhoea prevalence during the previous 7 days and to obtain a sample of drinking water. It was necessary to collect and use such period prevalence data rather than incidence due to the inability to ensure constant access to the study areas. Diarrhoea was defined as three or more loose stools within a period of 24 hours. For the intervention group, water was sampled directly from the filter taps without flaming the tap so that the sample would reflect normal collection procedure and include any contamination associated with normal use. Water from the control group was collected from the vessel or reservoir used to fill a drinking cup. All samples were preserved between 4° and 10° C and analyzed within four hours using the membrane filter technique (Standard Methods 1998). Sample water was passed through a 0.45 micron membrane filter (Millipore Corporation, Bedford, Massachusetts, USA) and incubated on membrane lauryl sulphate media (Oxoid Limited, Basingstoke, Hampshire, England) at 44°C±0.5°C for 18 hours in an Oxfam Delagua portable incubator (Robens Institute, University of Surrey, Guildford, Surrey, UK). When a volume of 100ml produced a number of colony forming units (CFU) that were too numerous to count (TNTC), the count was recorded as TNTC and assigned a value for purposes of statistical analysis of 300 FC colonies per 100ml as prescribed by the DelAgua manual.

7.2.4 Data collection and analysis

Data was recorded on spreadsheets and analyzed using Stata 8.1 and certain meta-analysis supplements (StataCorp. 2003. *Stata Statistical Software: Release 8.1.* College Station, TX: Stata Corporation). Data from the control and intervention groups were compared by two-sample t-test and by Fisher's exact test. Generalized estimating equations (GEE's) were used for the analysis of repeated observations of diarrhoea in individuals over time and episodes of diarrhoea in families controlling for clustering within households (Zeger & Liang, 1986).

7.2.5 Ethics

The assessment of the pilot programme was initiated by Oxfam GB and was within the scope of its governmental authority and reporting obligations for operating in Colombia. Written informed consent was obtained from the head of each participating household at the beginning of the programme. The expectations and obligations of both the participants and investigators were explained and any questions answered. It is not believed that the participants were subjected to any additional risks as a result of the project. At the conclusion of the trial, all control group households were offered the same filters without charge. Oxfam is continuing to work in each of the communities and thus able to assist with replacement ceramic elements and other components as well as additional filters.

APPENDIX 7.1

INVESTIGACION DEL FILTRO CERAMICO DE AGUA

CUESTIONARIO

1. El código de identificación: ___ ___ ___ y ubicación de GPS

____

2. La fecha de entrevista:___/___/___

3. El entrevistador: ________________________________

4. El nombre de persona entrevistada: ______________ ______________

Apellido *Nombre (s)*

Ahora apreciaría preguntarlo acerca de su casa y la gente que viven en su casa.

5. ¿El tipo predominante de la construcción?

_____ ***Barro Reforzado*** ____ ***Adobe*** _______***Ladrillo*** _____ ***Cemento***

6. ¿Cuántas habitaciones están en la casa? _____***Total***______ ***Dormitorios***

7. ¿Cuántas personas vive en su casa (inclusive usted mismo)? _______ ***Personas***

8. Yo lo preguntaré varias preguntas acerca de cada persona que vive en su casa. El comienzo con la persona mayor y entonces nosotros hablaremos acerca de cada dos personas en cambio.

#	***Nombre***	***Relación***	***Edad***	***Sexo***	***Educación****	***Diarrea pasada 7d***
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						

**Ninguno (0); Alguna escuela primaria (1); Alguna escuela secundaria (2); Más que escuela secundaria (3)*

Ahora yo lo preguntare algunos preguntas acerca de la mano que lava y los hábitos del saneamiento.

9. ¿Ha tenido usted cualquier instrucción de la higiene durante los últimos seis meses? ***Sí No***

10. ¿Durante el día, en qué tiempo lo hace lava típicamente las manos?

_____ ***Después de defecación*** _____ ***Después de limpiar el niño***
_____ ***Antes preparar o comer alimento***

11. ¿Qué usa usted cuándo lavar manos? ____***Agua sólo*** __***el Jabón*** ***Otro***______
12. ¿Tiene usted el jabón aquí hoy (pide verlo)? ***Sí*** ***No***
13. ¿Dónde va normalmente usted al lavabo? _____ ***Sanatorio o Letrina*** ____***El campo***
14. ¿Si en un sanatorio o letrina, qué tipo?.

______***Letrina Pit*** _____***Pour Flush*** ______***Cisterna tanque***
______***Sanatorio conectado***

Ahora yo lo preguntare acerca del agua que usted usa actualmente para beber.

15. ¿Dónde obtuvo usted el agua que usted beben aquí hoy?

________***Canal de riego*** ________***Pozo excavado***______***Rio/Lago***
_______***Bomba*** _______***Pila (tipo*** ____________________***)***

16. ¿Me podría mostrar usted cómo usted obtendría una bebida para usted mismo o para un niño ahora mismo? (Registre el tipo de nave de que el agua se toma como el "Almacenada de Agua")

Balde	***Sí***	***No***	***Cubrió***
Olla de Cocina o cacerola que lava	***Sí***	***No***	***Cubrió***
Jerry Can	***Sí***	***No***	***Cubrió***
Barril	***Sí***	***No***	***Cubrió***
Jara de Barro	***Sí***	***No***	***Cubrió***
Otro__________________	***Sí***	***No***	***Cubrió***

17. REGISTRE LA MANERA EN QUE FUE CONSEGUIR ACCESO A EL AGUA PARA UNA BEBIDA:

______***Moja (Dip) una copa/tazón/cántaro en la nave***
______***Echa (Pour) de la nave en la copa/tazón/cántaro o manos***
______***Use grifo para dibujar agua en la copa/tazón/cántaro***
______***Otra manera*** ______________________________

18. ¿Podría dar me usted una muestra pequeña de agua? LA MUESTRA DEL AGUA SE DEBE VERTIR EN LA BOTELLA DE MUESTREO DE LA MISMA COPA, EL CANTARO O LA PALA DE QUE EL ENTREVISTADO LO ASEGURO.

19. ¿Almacena usted su es agua que bebe en un contenedor diferente en su casa que el uno en que se reúne? ***Sí*** ***No***

20. ¿Si ése es el caso, usted me podría mostrar qué contenedor usted usa principalmente para reunir agua? Registre el tipo de nave en que rega es reunido como

Balde		***Sí***	***No***	***Cubrió***
Olla de cocina o cacerola que lava	***Sí***	***No***	***Cubrió***	
Jerry Can		***Sí***	***No***	***Cubrió***
Barril		***Sí***	***No***	***Cubrió***
Olla de Barro		***Sí***	***No***	***Cubrió***
Otro ______________		***Sí***	***No***	***Cubrió***

21. ¿Se queda la recipiente inmediata de la agua que bebe con una espita (grifo)? ***Sí*** ***No***

22. ¿Trata usted esta agua para beber? Sí no

(Si) Cómo lo hace trata su agua [la marca todo que aplica]

________***Hervir el agua*** ______***Tratamiento con cloro*** _____***Permita sedimentarse***
________***Floculación*** ______***Otra (especificar)***____________________

Chapter 8: Ceramic Filters in Colombia: Results and Discussion

8.1 Baseline

Baseline demographic and other characteristics for each study site and for the aggregate control and intervention groups are shown in Table 8.1. Baseline data did not reveal statistically significant differences between intervention and control households in any area measured, including demographics, hygiene practices, sanitation facilities or water handling practices. Between study sites, on the other hand, there were potentially important differences. Study participants in Cartagenita were younger (mean age 16.6, 95% CI 14.5-18.6) than Curvaradó (21.6, 95% CI 19.0-24.2). Average household size in Dabeiba (4.1 persons/household) was larger than in the other two communities. In Curvaradó, homes were more likely to be constructed of wood than in Dabeiba and Cartagenita, a difference that reflects their typical construction on stilts over the river. The mean number of rooms for homes in Dabeiba (1.8, 95% CI = 1.5, 2.2) was less than that of Curvaradó (2.5, 95% CI = 2.2, 2.9) or Cartagenita (3.1, 95% CI = 2.5, 3.6). In terms of hygiene practices, fewer study participants used soap in Dabeiba compared to Curvaradó ($P = 0.002$) and Cartagenita ($P < 0.001$). Only 29.5% of participants from Dabeiba reported having received hygiene education in the 6 months prior to the study compared to 76.2% in Curvaradó and 65.7% in Cartagenita. Unlike Dabeiba and Cartagenita, the population from Curvaradó did not have connected toilets. Finally, only 45.7% of study participants in Cartagenita reported treating water against 77.3% in Curvaradó ($P = 0.004$) and 83.7% in Dabeiba ($P < 0.001$).

Table 8.1. Baseline data for each study site and for combined intervention and control groups

Characteristic	**Curvaradó**	**Dabeiba**	**Cartagenita**	**Combined**			
				Total	Intervention	Control	Difference
Demographics							
Total Persons	172 (25.3%)	309 (45.4%)	199 (29.3%)	680 (100%)	415 (61.0%)	265 (39.0%)	-
<5 years	28 (16.3%)	64 (20.7%)	50 (25.1%)	142 (20.9%)	88 (21.2%)	54 (20.4%)	NS
5-15 years	50 (29.0%)	113 (36.6%)	68 (34.2%)	231 (34.0%)	146 (35.2%)	85 (32.1%)	NS
>15 years	94 (54.7%)	132 (42.7%)	81(40.7%)	307 (45.1%)	181 (43.6%)	126 (47.5%)	NS
Total Households	49 (35.0%)	51 (36.4%)	40 (28.6%)	140 (100%)	76 (54.3%)	64 (45.7%)	-
Wood construction	42 (91.3%)	24 (49.0%)	3 (8.3%)	69 (52.7%)	41 (56.2%)	28 (43.3%)	NS
Brick construction	4 (8.7%)	25 (51.0%)	33 (91.7%)	62 (47.3%)	32 (43.8%)	30 (51.7%)	NS
Mean number of rooms/household	2.5	1.8	3.1	2.4	2.6	2.2	NS
Mean Occupants/household	4.1	6.2	4.9	5.1	5.5	4.6	NS
Mean Occupants/room	1.9	4.1	2.0	2.7	2.9	2.5	NS
Hygiene and Sanitation							
Attribute diarrhoea mostly to							
Water	39 (88.6%)	42 (85.7%)	27 (69.2%)	108 (81.8%)	64 (86.5%)	44 (75.9%)	NS
Food	28 (63.6%)	21 (42.9%0	29 (74.4%)	78 (59.1%)	46 (62.2%)	32 (55.2%)	NS
Hygiene	32 (59.1%)	13 (36.7%)	23 (41.0%)	68 (45.4%)	38 (50.0%)	30 (39.7%)	NS
Hand washing events							
After defecating	28 (63.6%)	30 (61.2%)	33 (86.8%)	91 (69.5%)	52 (70.3%)	39 (68.4%)	NS
Before eating	40 (90.9%)	43 (87.8%)	35 (94.6%)	118 (90.8%)	67 (91.8%)	51 (89.5%)	NS
After cleaning child	19 (43.2%)	6 (12.2%)	23 (60.5%)	48 (36.6%)	26 (35.1%)	22 (38.6%)	NS
Use soap for hand washing	39 (90.7%)	31 (63.3%)	33 (97.1%)	103 (81.7%)	55 (78.6%)	48 (85.7%)	NS
Have soap in home today	39 (92.9%)	34 (70.8%0	34 (94.4%)	107 (81.7%)	59 (81.9%0	48 (88.9%)	NS
Had hygiene instruction last 6 mos.	32 (76.2%)	13 (29.5%0	23 (65.7%)	68 (56.2%)	38 (55.9%)	30 (56.6%)	NS
Use sanitation facilities	39 (88.6%)	44 (89.8%)	33 (89.2%0	116 (89.2%)	65 (89.0%)	51 (89.5%)	NS
Type of sanitation facilities	10 (20.4%)	6 (11.8%	5 (12.5%)				
Directly into river	39 (100%)	0	0	39 (32.8%)	25 (36.8%)	(32.8%)	NS
Sewerage or septic tank	0	45 (100%)	35 (100%)	80 (67.2%)	43 (63.2%)	37 (72.5%)	NS
Water Handling Practices							
Type of water source							
River	39 (86.7%)	0	0	39 (29.8%)	23 (31.5%)	16 (27.6%)	NS
Rainwater harvesting	13 (28.9%)	0	1 (2.7%)	14 (10.7%)	7 (9.6%)	7 (12.1%)	NS
Yard tap	0%	49 (100%)	36 (97.3%)	84 (64.1%)	45 (61.6%)	39 (67.2%)	NS
Claim to treat water	34 (77.3%)	41 (83.7%)	16 (45.7%)	91 (71.1%)	50 (71.4%)	41 (70.7%)	NS
By boiling	9 (27.3%)	41 (100%)	12 (92.3%)	62 (71.3%)	32 (65.3%)	30 (78.9%)	NS
With bleach	10 (30.3%)	0	0	10 (11.6%)	7 (14.6%)	3 (7.9%)	NS
By settling	14 (42.4%)	0	0	14 (6.3%)	9 (18.7%)	5 (13.2%)	NS
Access water by							
Pouring	0	2 (4.5%)	4 (25.0%)	6 (5.9%)	3 (5.7%)	3 (6.1%)	NS
Dipping in utensil	30 (71.4%)	34 (77.3%)	4 (25.0%)	68 (66.7%)	38 (71.7%)	30 (61.2%)	NS
Tap on storage vessel	12 (28.6%)	8 (18.2%)	8 (50.0%)	28 (27.4%)	12 (22.6%)	16 (32.6%)	NS

Demographic data is by individual; remaining data is by household. N varies due to missing data. % >100 indicate multiple responses. NS=not significant.)

8.2 Water quality

The distribution of TTC counts among water samples was found to be heavily skewed; accordingly results are presented as geometric means (mean of log10 transformed TTC counts) to minimize skewness and allow for proper computation of t-tests for statistical significance. Table 8.2a sets forth the geometric mean TTC levels for control and intervention households by study community and overall. There was no statistically-significant difference in baseline levels of TTC between intervention and control groups overall or for any of the study sites. In four rounds of sampling following the introduction of the filters, product water from intervention households was associated with a significantly lower TTC. In Cartagenita, samples from the filters were completely free of TTC compared to an geometric mean TTC count of 50.8 (95% CI = 40.4, 3.9) from the control group. The reduction in geometric mean TTC was 64.4% in Curvaradó and 79.1% in Dabeiba. Overall, the geometric mean TTC among intervention group households was 4.2 (95% CI = 3.3, 5.3) compared to 82.7 (95% CI = 69.5, 98.4) for the control households, a reduction of 75.2% (P < 0.0001).

Table 8.2a: Geometric mean TTC levels (and 95% confidence intervals) for each study community and overall

Site	Control (N= 256)	Intervention (N=234)	P-value (t-test)
Curvarado	78.9 (56.0, 111.1)	8.0 (5.4, 11.9)	<0.0001
Dabeida	135.9 (100.7, 181.9)	5.0 (3.4, 7.6)	<0.0001
Cartagenita	50.8 (40.4, 63.9)	1*	<0.0001
Overall	82.7 (69.5, 98.4)	4.2 (3.30, 5.3)	<0.0001

*No TTC was detected in any samples from intervention households in this community. However, consistent with convention, 0 was assigned a value of 1 in order to calculate the geometric means.

The microbiological performance of the filters is also demonstrated by their capacity to reduce the portion of water samples presenting higher levels of faecal contamination. Table 8.2b sets forth the percentage of samples examined that fall into the various WHO risk categories for faecal contamination: 0 TTC/100 ml (in compliance), 1--10 TTC/100 ml (low risk), 11--100 TTC/100 ml (intermediate risk), and 101--1000 TTC/100 ml (high risk) (WHO 1993). At each study community, the filters were associated with a statistically significant improvement in the percentage of samples meeting lower risk categories. Overall, 47.7% of samples from the intervention households met WHO guidelines for zero

TTC/100 ml compared to just 0.9% for control households ($P < 0.001$). Conversely, 54.5% of samples from control households had 101--1000 TTC/100 ml compared to 10.6% of samples from intervention households ($P < 0.001$). While 71.9% of intervention group samples were in compliance or presented low risk, 91.9% of samples from control group households presented intermediate or high risk.

Table 8.2b: Percentage of samples from control and intervention households by WHO risk category for each study community and overall

Site	**Percentage of Samples by WHO Risk Category (WHO, 1997)**				
	0 TTC/100 ml (N=103)	1-10 TTC/100 ml (N=78)	11-100 TTC/100 ml (N=131)	101-1000 TC/100 ml (N=154)	P-value (chi^{2})
Curvarado					<0.001
Control	0%	9.86%	39.44%	50.70%	
Intervention	23.47	33.67%	29.56%	13.27%	
Dabeida					<0.001
Control	0%	10.7%	16.7%	72.6%	
Intervention	41.58%	28.71%	15.84%	13.86%	
Cartagenita					<0.001
Control	2.56%	1.28%	57.69%	38.46%	
Intervention	100%	0%	0%	0%	
Overall					<0.001
Control	0.86%	7.30%	37.34%	54.51%	
Intervention	47.66%	24.22%	17.58%	10.55%	

8.3 Diarrhoea

Data on diarrhoea was collected from all but 7 households (5%) who were lost to follow up. Table 8.3a sets forth the ratios of diarrhoea prevalence by study site and overall, adjusted for age and visit[41]. Overall, persons living in households with filters had 60% lower prevalence of diarrhoea than their counterparts in control households. Adjusting for age and visit and controlling for clustering at the household, the prevalence ratio was 0.40 (95% CI: 0.25 to 0.63, $P < 0.001$) for all persons participating in the study and 0.40 (95% CI: 0.21 to 0.76, $P = 0.005$) for children under 5 years. Among individual study sites, however, results were statistically significant only in Cartagenita where the filter was protective for all ages (0.21, 95% CI: 0.08 to 0.41, $P < 0.001$) and for children under 5 (0.19, 95% CI: 0.06 to 0.58, $P = 0.004$). In Dabeiba, the filters showed some evidence of protection against diarrhoea, but the difference did not achieve conventional levels of statistical significance. In

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[41] The visits to each household were numbered consecutively from 1 to n so that the visit number corresponded to time since the beginning of the study.

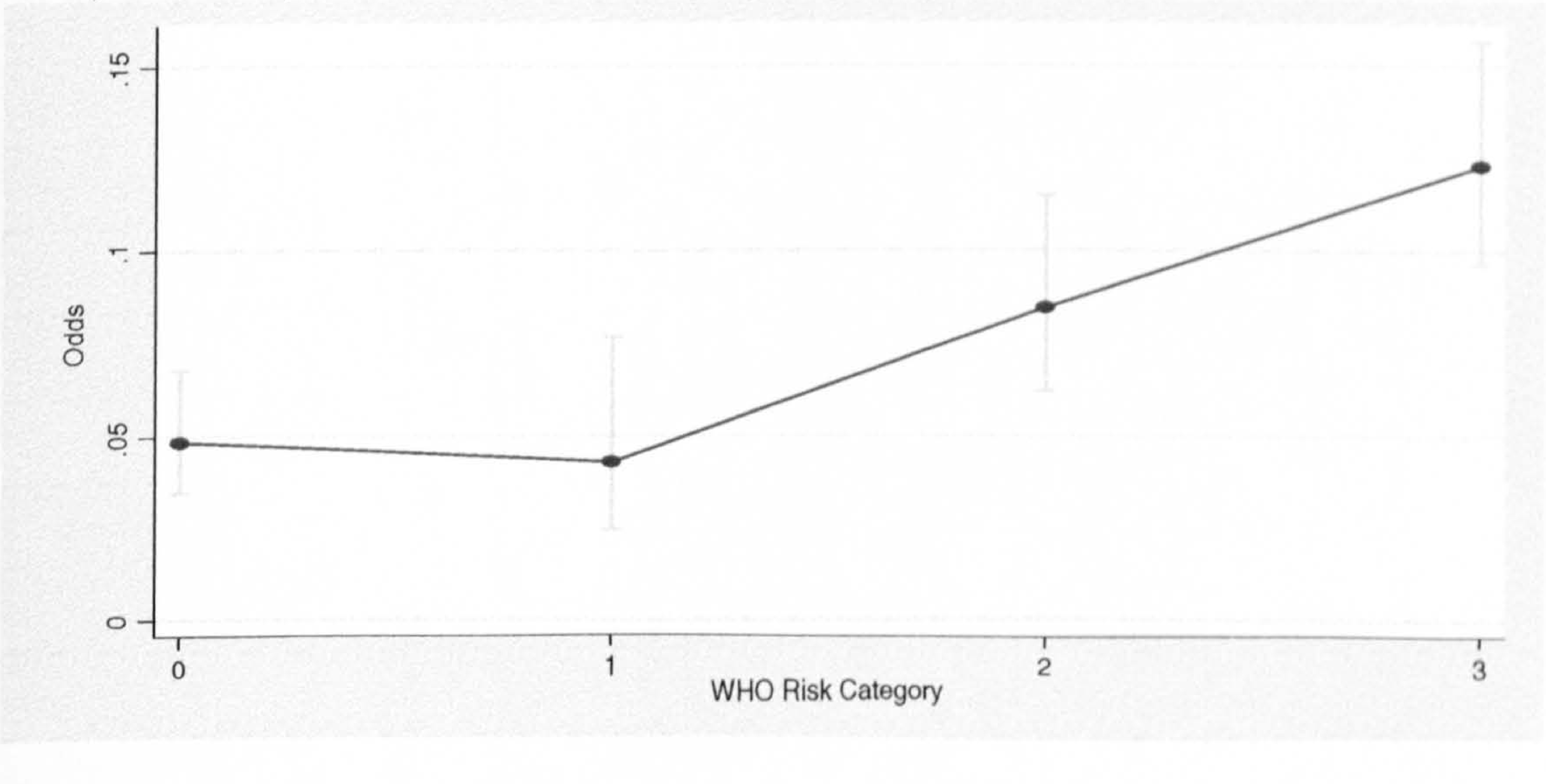
Curvaradó, the prevalence of diarrhoea reported by members of the intervention group was not statistically different than for the control group.

Table 8.3: Prevalence ratios of diarrhoea among all participants and for children <5 years of age by study site and overall, adjusted for age and visit and controlling for clustering by household

	All ages			**Children < 5 years of age**		
Site	**Ratio**	**95% CI**	**P-value**	**Ratio**	**95% CI**	**P-value**
Curvarado	0.87	0.31, 2.39	0.781	1.37	0.21, 8.87	0.743
Dabeida	0.49	0.21, 1.13	0.095	0.60	0.24, 1.56	0.297
Cartagenita	0.21	0.10, 0.41	<0.001	0.19	0.06, 0.58	0.004
Overall	0.40	0.25, 0.63	<0.001	0.40	0.21, 0.76	0.005

Finally, in order to explore the apparent association between the faecal contamination of drinking water and diarrhoea prevalence, prevalence ratios were computed against log TTC counts, controlling once again for household clustering and for age and visit. The risk of diarrhoea increased with log TTC counts both for all ages (OR = 1.48, 95%CI:1.12 to 1.95, P = 0.006) and for children under 5 years (OR = 1.47, 95% CI: 1.01 to 2.15, P = 0.046). Figure 8.3, which plots the crude odds of diarrhoea against log TTC counts (i.e., WHO risk category), shows the trend for increased risk with worsening microbial water quality. The increased risk of diarrhoea with increased levels of TTC suggests a dose-response relationship between faecal contamination of water and diarrhoeal disease.

Figure 8.3: Crude odds of diarrhoea by WHO Risk Category based on TTC Count (0=0, 1=1-10, 2=11-100, 3=101-1,000 TTC/100mL)

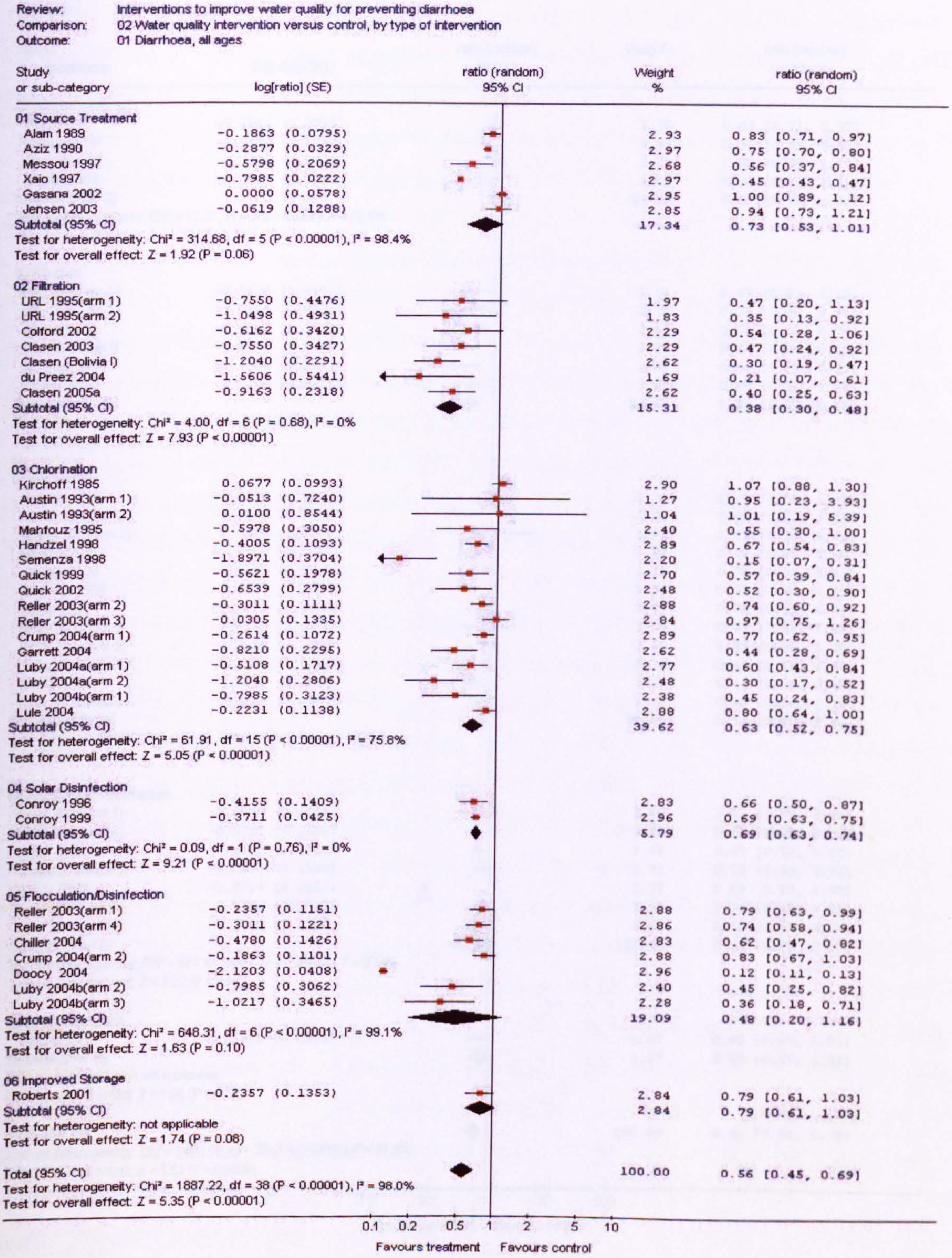


8.4 Discussion

This study was undertaken to assess a pilot intervention by Oxfam GB using household-based ceramic filters to prevent diarrhoeal disease in Colombia. Overall, the filters demonstrated a capacity to reduce faecal bacteria in source water, and thus improve drinking water quality. The filters were also associated with a significant reduction in the prevalence of diarrhoea.

These findings are consistent with the microbiological performance and health impact of the only other intervention trials involving ceramic water filters used at the household level (URL 1995, Clasen 2004; Clasen 2004a, du Preez 2004). In time, these results will be added to the Cochrane review described in Part I. Figure 8.4a shows how adding the results from Colombia (designated as "Clasen 2005a") would affect the Cochrane review results by type of intervention for all age results. In comparing this to Figure 4.1.3a above, it can be seen that including the results from Colombia moves the overall point estimate of effect for filtration only slightly, from 0.36 to 0.37, while a minor tightening the 95% CI (from 0.28-0.49 to 0.30-0.48). Adding these results also increases homogeneity slightly; the test for heterogeneity shows a slightly more homogeneous result. The same effect obtains when the Colombia results for children <5 years are added to the those currently in the Cochrane review. Comparing Figure 8.4b with Figure 4.1.3b, the point estimate of effect for filtration moves from 0.36 to 0.37 with a similar tightening of the confidence interval and improved homogeneity.

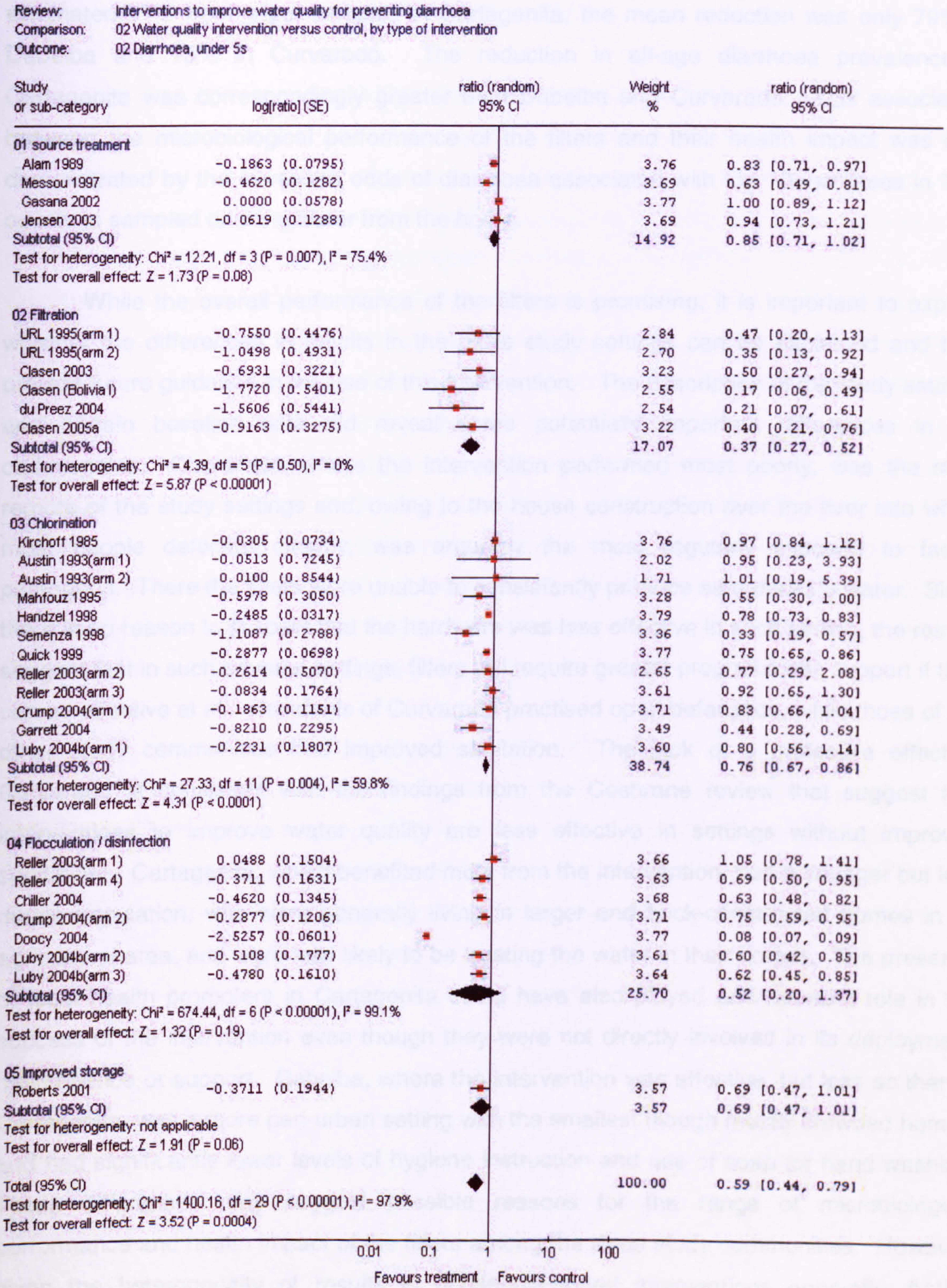
Figure 8.4a: Comparison from Cochrane review showing effect of including data from Colombia trial (Clasen 2005a) for all age results



Review: Interventions to improve water quality for preventing diarrhoea
Comparison: 02 Water quality intervention versus control, by type of intervention
Outcome: 01 Diarrhoea, all ages

Study or sub-category	log[ratio] (SE)	Weight %	ratio (random) 95% CI
01 Source Treatment			
Alam 1989	-0.1863 (0.0795)	2.93	0.83 [0.71, 0.97]
Aziz 1990	-0.2877 (0.0329)	2.97	0.75 [0.70, 0.80]
Messou 1997	-0.5798 (0.2069)	2.68	0.56 [0.37, 0.84]
Xaio 1997	-0.7985 (0.0222)	2.97	0.45 [0.43, 0.47]
Gasana 2002	0.0000 (0.0578)	2.95	1.00 [0.89, 1.12]
Jensen 2003	-0.0619 (0.1288)	2.85	0.94 [0.73, 1.21]
Subtotal (95% CI)		17.34	0.73 [0.53, 1.01]
Test for heterogeneity: Chi² = 314.68, df = 5 (P < 0.00001), I² = 98.4%			
Test for overall effect: Z = 1.92 (P = 0.06)			
02 Filtration			
URL 1995(arm 1)	-0.7550 (0.4476)	1.97	0.47 [0.20, 1.13]
URL 1995(arm 2)	-1.0498 (0.4931)	1.83	0.35 [0.13, 0.92]
Colford 2002	-0.6162 (0.3420)	2.29	0.54 [0.28, 1.06]
Clasen 2003	-0.7550 (0.3427)	2.29	0.47 [0.24, 0.92]
Clasen (Bolivia I)	-1.2040 (0.2291)	2.62	0.30 [0.19, 0.47]
du Preez 2004	-1.5606 (0.5441)	1.69	0.21 [0.07, 0.61]
Clasen 2005a	-0.9163 (0.2318)	2.62	0.40 [0.25, 0.63]
Subtotal (95% CI)		15.31	0.38 [0.30, 0.48]
Test for heterogeneity: Chi² = 4.00, df = 6 (P = 0.68), I² = 0%			
Test for overall effect: Z = 7.93 (P < 0.00001)			
03 Chlorination			
Kirchoff 1985	0.0677 (0.0993)	2.90	1.07 [0.88, 1.30]
Austin 1993(arm 1)	-0.0513 (0.7240)	1.27	0.95 [0.23, 3.93]
Austin 1993(arm 2)	0.0100 (0.8544)	1.04	1.01 [0.19, 5.39]
Mahfouz 1995	-0.5978 (0.3050)	2.40	0.55 [0.30, 1.00]
Handzel 1998	-0.4005 (0.1093)	2.89	0.67 [0.54, 0.83]
Semenza 1998	-1.8971 (0.3704)	2.20	0.15 [0.07, 0.31]
Quick 1999	-0.5621 (0.1978)	2.70	0.57 [0.39, 0.84]
Quick 2002	-0.6539 (0.2799)	2.48	0.52 [0.30, 0.90]
Reller 2003(arm 2)	-0.3011 (0.1111)	2.88	0.74 [0.60, 0.92]
Reller 2003(arm 3)	-0.0305 (0.1335)	2.84	0.97 [0.75, 1.26]
Crump 2004(arm 1)	-0.2614 (0.1072)	2.89	0.77 [0.62, 0.95]
Garrett 2004	-0.8210 (0.2295)	2.62	0.44 [0.28, 0.69]
Luby 2004a(arm 1)	-0.5108 (0.1717)	2.77	0.60 [0.43, 0.84]
Luby 2004a(arm 2)	-1.2040 (0.2806)	2.48	0.30 [0.17, 0.52]
Luby 2004b(arm 1)	-0.7985 (0.3123)	2.38	0.45 [0.24, 0.83]
Lule 2004	-0.2231 (0.1138)	2.88	0.80 [0.64, 1.00]
Subtotal (95% CI)		39.62	0.63 [0.52, 0.75]
Test for heterogeneity: Chi² = 61.91, df = 15 (P < 0.00001), I² = 75.8%			
Test for overall effect: Z = 5.05 (P < 0.00001)			
04 Solar Disinfection			
Conroy 1996	-0.4155 (0.1409)	2.83	0.66 [0.50, 0.87]
Conroy 1999	-0.3711 (0.0425)	2.96	0.69 [0.63, 0.75]
Subtotal (95% CI)		5.79	0.69 [0.63, 0.74]
Test for heterogeneity: Chi² = 0.09, df = 1 (P = 0.76), I² = 0%			
Test for overall effect: Z = 9.21 (P < 0.00001)			
05 Flocculation/Disinfection			
Reller 2003(arm 1)	-0.2357 (0.1151)	2.88	0.79 [0.63, 0.99]
Reller 2003(arm 4)	-0.3011 (0.1221)	2.86	0.74 [0.58, 0.94]
Chiller 2004	-0.4780 (0.1426)	2.83	0.62 [0.47, 0.82]
Crump 2004(arm 2)	-0.1863 (0.1101)	2.88	0.83 [0.67, 1.03]
Doocy 2004	-2.1203 (0.0408)	2.96	0.12 [0.11, 0.13]
Luby 2004b(arm 2)	-0.7985 (0.3062)	2.40	0.45 [0.25, 0.82]
Luby 2004b(arm 3)	-1.0217 (0.3465)	2.28	0.36 [0.18, 0.71]
Subtotal (95% CI)		19.09	0.48 [0.20, 1.16]
Test for heterogeneity: Chi² = 648.31, df = 6 (P < 0.00001), I² = 99.1%			
Test for overall effect: Z = 1.63 (P = 0.10)			
06 Improved Storage			
Roberts 2001	-0.2357 (0.1353)	2.84	0.79 [0.61, 1.03]
Subtotal (95% CI)		2.84	0.79 [0.61, 1.03]
Test for heterogeneity: not applicable			
Test for overall effect: Z = 1.74 (P = 0.08)			
Total (95% CI)		100.00	0.56 [0.45, 0.69]
Test for heterogeneity: Chi² = 1887.22, df = 38 (P < 0.00001), I² = 98.0%			
Test for overall effect: Z = 5.35 (P < 0.00001)			

Figure 8.4b: Comparison from Cochrane review showing effect of including data from Colombia trial (Clasen 2005a) for all children <5 years of age



Review: Interventions to improve water quality for preventing diarrhoea
Comparison: 02 Water quality intervention versus control, by type of intervention
Outcome: 02 Diarrhoea, under 5s

Study or sub-category	log[ratio] (SE)	Weight %	ratio (random) 95% CI
01 source treatment			
Alam 1989	-0.1863 (0.0795)	3.76	0.83 [0.71, 0.97]
Messou 1997	-0.4620 (0.1282)	3.69	0.63 [0.49, 0.81]
Gasana 2002	0.0000 (0.0578)	3.77	1.00 [0.89, 1.12]
Jensen 2003	-0.0619 (0.1288)	3.69	0.94 [0.73, 1.21]
Subtotal (95% CI)		14.92	0.85 [0.71, 1.02]
Test for heterogeneity: Chi² = 12.21, df = 3 (P = 0.007), I² = 75.4%			
Test for overall effect: Z = 1.73 (P = 0.08)			
02 Filtration			
URL 1995(arm 1)	-0.7550 (0.4476)	2.84	0.47 [0.20, 1.13]
URL 1995(arm 2)	-1.0498 (0.4931)	2.70	0.35 [0.13, 0.92]
Clasen 2003	-0.6931 (0.3221)	3.23	0.50 [0.27, 0.94]
Clasen (Bolivia I)	-1.7720 (0.5401)	2.55	0.17 [0.06, 0.49]
du Preez 2004	-1.5606 (0.5441)	2.54	0.21 [0.07, 0.61]
Clasen 2005a	-0.9163 (0.3275)	3.22	0.40 [0.21, 0.76]
Subtotal (95% CI)		17.07	0.37 [0.27, 0.52]
Test for heterogeneity: Chi² = 4.39, df = 5 (P = 0.50), I² = 0%			
Test for overall effect: Z = 5.87 (P < 0.00001)			
03 Chlorination			
Kirchoff 1985	-0.0305 (0.0734)	3.76	0.97 [0.84, 1.12]
Austin 1993(arm 1)	-0.0513 (0.7245)	2.02	0.95 [0.23, 3.93]
Austin 1993(arm 2)	0.0100 (0.8544)	1.71	1.01 [0.19, 5.39]
Mahfouz 1995	-0.5978 (0.3050)	3.28	0.55 [0.30, 1.00]
Handzel 1998	-0.2485 (0.0317)	3.79	0.78 [0.73, 0.83]
Semenza 1998	-1.1087 (0.2788)	3.36	0.33 [0.19, 0.57]
Quick 1999	-0.2877 (0.0698)	3.77	0.75 [0.65, 0.86]
Reller 2003(arm 2)	-0.2614 (0.5070)	2.65	0.77 [0.29, 2.08]
Reller 2003(arm 3)	-0.0834 (0.1764)	3.61	0.92 [0.65, 1.30]
Crump 2004(arm 1)	-0.1863 (0.1151)	3.71	0.83 [0.66, 1.04]
Garrett 2004	-0.8210 (0.2295)	3.49	0.44 [0.28, 0.69]
Luby 2004b(arm 1)	-0.2231 (0.1807)	3.60	0.80 [0.56, 1.14]
Subtotal (95% CI)		38.74	0.76 [0.67, 0.86]
Test for heterogeneity: Chi² = 27.33, df = 11 (P = 0.004), I² = 59.8%			
Test for overall effect: Z = 4.31 (P < 0.0001)			
04 Flocculation / disinfection			
Reller 2003(arm 1)	0.0488 (0.1504)	3.66	1.05 [0.78, 1.41]
Reller 2003(arm 4)	-0.3711 (0.1631)	3.63	0.69 [0.50, 0.95]
Chiller 2004	-0.4620 (0.1345)	3.68	0.63 [0.48, 0.82]
Crump 2004(arm 2)	-0.2877 (0.1206)	3.71	0.75 [0.59, 0.95]
Doocy 2004	-2.5257 (0.0601)	3.77	0.08 [0.07, 0.09]
Luby 2004b(arm 2)	-0.5108 (0.1777)	3.61	0.60 [0.42, 0.85]
Luby 2004b(arm 3)	-0.4780 (0.1610)	3.64	0.62 [0.45, 0.85]
Subtotal (95% CI)		25.70	0.52 [0.20, 1.37]
Test for heterogeneity: Chi² = 674.44, df = 6 (P < 0.00001), I² = 99.1%			
Test for overall effect: Z = 1.32 (P = 0.19)			
05 Improved storage			
Roberts 2001	-0.3711 (0.1944)	3.57	0.69 [0.47, 1.01]
Subtotal (95% CI)		3.57	0.69 [0.47, 1.01]
Test for heterogeneity: not applicable			
Test for overall effect: Z = 1.91 (P = 0.06)			
Total (95% CI)		100.00	0.59 [0.44, 0.79]
Test for heterogeneity: Chi² = 1400.16, df = 29 (P < 0.00001), I² = 97.9%			
Test for overall effect: Z = 3.52 (P = 0.0004)			

While the filters were protective overall, there was a substantial range in the results among the three settings comprising the overall study. While the filters completely eliminated TTC from water samples in Cartagenita, the mean reduction was only 79% in Dabeiba and 75% in Curvaradó. The reduction in all-age diarrhoea prevalence in Cartagenita was correspondingly greater than Dabeiba and Curvaradó. This association between the microbiological performance of the filters and their health impact was also demonstrated by the increased odds of diarrhoea associated with log 10 increases in TTC counts in sampled drinking water from the home.

While the overall performance of the filters is promising, it is important to explore whether the differences in results in the three study settings can be explained and thus provide future guidance in the use of this intervention. The description of the study settings and certain baseline data did reveal some potentially important differences in the communities. Curvaradó, where the intervention performed most poorly, was the most remote of the study settings and, owing to the house construction over the river into which most people defecate directly, was arguably the most regularly exposed to faecal pathogens. There the filters were unable to consistently produce safe drinking water. Since there is no reason to suspect that the hardware was less effective in such setting, the results suggest that in such adverse settings, filters will require greater programmatic support if they can be effective at all. Residents of Curvaradó practised open defecation, while those of the other study communities had improved sanitation. The lack of a protective effect in Curvaradó is consistent with the findings from the Cochrane review that suggest that interventions to improve water quality are less effective in settings without improved sanitation. Cartagenita, which benefited most from the intervention, had a younger but less dense population, who were generally living in larger and brick-constructed homes in an agricultural area, and were less likely to be treating the water in their homes. The presence of local health promoters in Cartagenita could have also played an important role in the success of the intervention even though they were not directly involved in its deployment, maintenance or support. Dabeiba, where the intervention was effective, but less so than in Cartagenita, was a more peri-urban setting with the smallest though mostly crowded homes, and had significantly lower levels of hygiene instruction and use of soap for hand washing. These differences may suggest possible reasons for the range of microbiological performance and health impact of the filters among the three study communities. However, given the heterogeneity of results in household-based interventions generally, further research should be undertaken before the results from these communities are used to guide decisions about the appropriateness of the intervention in particular settings, or the need to supplement the hardware in certain cases with additional programmatic support.

The design of this study had certain shortcomings, owing in part to its having been undertaken in the context of a pilot intervention, First, this study was not blinded, either at the level of the intervention or the assessor. Certain studies of household-based water treatment interventions that have employed a placebo-controlled, double blind design found no statistically significant difference between intervention and control groups (Colford 2002, Kirchhoff 1985, Austin 1992). Second, this study assessed diarrhoea using a 7-day recall. Research has suggested that recall periods in excess of 48 hours tend to understate the actual frequency of the disease (Boerma 1991). Third, as a result of the remoteness of the study sites and the lack of on-site investigators, there was no rigorous means of assessing compliance with the intervention, particularly compliance by young children, the age group most affected by diarrhoea in the study population. Finally, while the intervention was randomly allocated within each study setting following a method that ensured an appropriate generation of the allocation sequence and concealment of such sequence, the selection of the study communities was not random but made by Oxfam in an attempt to obtain a representation of the types of settings in which it operates in Colombia.

Notwithstanding these shortcomings, this assessment does provide additional evidence of the potential value of household water treatment in the prevention of diarrhoeal disease among a vulnerable population. At the same time, it demonstrates the range of effectiveness of such interventions and thus the need to consider carefully the circumstances prevailing in a target community when choosing among possible options.

Chapter 9: Household Water Treatment in Emergencies

9.1 Introduction

When normal supplies of drinking water are interrupted or compromised by an emergency, affected populations have long been encouraged to boil or chlorinate their drinking water in order to ensure its microbiological integrity (CDC 1993). Such household water treatment is suitable in settings where the volume and access to water is not affected by the emergency event and where fuel or disinfectant is widely available. In many developing countries, however, where natural disasters and conflicts affect the greatest numbers of vulnerable people, such an approach is rarely practical. Floods, earthquakes and war more often force populations to flee, at least temporarily, to settings that often lack adequate access to water supplies, or cause the available water sources to become contaminated. Both the displaced and those who stay behind frequently lack the resources to treat their own water. International relief organizations, NGOs and government emergency management agencies have thus developed alternative solutions for providing drinking water to populations affected by emergencies that focus on the bulk treatment and delivery of safe water to communal tanks and tap stands (Davis 2003).

Nevertheless, the success of household water treatment in development settings has led certain emergency responders to consider and in some cases implement point-of-use approaches as part of an emergency response. Oxfam GB, for example, has recently distributed ceramic water filters to populations affected by floods in Cambodia, Haiti and the Dominican Republic (Smith 2004; Caens 2005). UNICEF distributes millions of NaDCC tablets each year in emergency response, both directly and through partner NGOs, increasingly for longer-term use (P. Edmondson, personal communication). PSI, Samaritan's Purse, World Vision and others have distributed Procter & Gamble PUR® sachets in response to floods and earthquakes in Haiti and India, and earthquakes in Pakistan, and AmericCares has used the same product with conflict-affected refugees in the Sudan and Liberia (P&G 2005).[42] CARE and PSI have used the CDC safe water system in response to

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[42] In order to overcome some of the issues associated with the PUR product, Procter & Gamble has recently released a "Standard Operation Procedure for the Use of Procter & Gamble's PUR Purifier of Water in Emergency Response Settings". http://www.pghsi.com/safewater/pdf/aquaya_SOP_draft_4_Oct_05.pdf

typhoons in West Timor and Indonesia (CDC 2005) and cyclones in Madagascar (Dunston 2001; Mong 2001). Guidelines on the use of household water treatment in emergency settings issued by the International Network to Promote Household Water Treatment also include solar disinfection and home-based biosand filters.[43]

Research on the emergency use of household water treatment is limited. A few studies have assessed the microbiological performance or use of various products and technologies. Mong (2001) found that jerry cans distributed with dilute sodium hypochlorite as part of a Safe Water System (SWS) intervention in cyclone-affected Madagascar were free of *E. coli* compared to a median of 13 CFU/100ml among those not receiving the intervention (P=0.005). In a randomised controlled trial (RCT) described in Part I above, Roberts (2001) introduced an "improved bucket" (consisting of a 20L container with spout for pouring and a barrier to discourage entry of hands or utensils) into a refugee camp in Malawi; controls continued to use traditional open buckets provided by camp organizers. The mean concentration of faecal coliforms at 6 sampling times over 10 weeks was 53.3% lower (geometric mean 69% lower) in the improved buckets than in the ration buckets. Doocy (2004), also discussed in Part I, was an RCT to assess the PUR flocculant-disinfectant among displaced persons in two Liberian camps. Investigators did not measure microbial indicators, but did find that 95.4% of samples from the intervention group had detectable chlorine (80.0% with minimum free chlorine level of 0.5mg/L prescribed by Sphere Project standards) over the 12-week intervention period.

A number of studies have assessed the use of household-based ceramic filters in emergency settings by Oxfam GB. These studies, which consist of student dissertations and internal reports, are summarized in Table 9.1. In many cases, the filters did produce safe drinking water. In general, however, they did not do so uniformly or to levels that match the 3-6 log reduction capacity which the same filters were shown to achieve in laboratory testing. Moreover, a significant percentage of the samples did not meet Sphere Project standards for disaster response (Sphere Project 2004). There is some evidence from the studies that the deficiencies in microbiological performance were attributable to a poor programmatic support on behalf of the implementer.

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[43] http://www.who.int/household_water/resources/emergencies.pdf

Table 9.1: Microbiological Performance of Ceramic Filters in Emergency Settings

Location (reference)	Filter Type	Test Method	Results
Cambodia (Smith 2004)	Vietnamese commercial candle-style	Paired samples of pre-and post-filtered water from household filters analyzed for thermotolerant coliform (TTC)	1.03 log reduction in TTC; 8.3% and 4.1% of filter samples had <1TTC or 1-10 TTC/100ml, respectively.
	PFP design locally-fabricated by IDE		1.00 log reduction in TTC; 5.4% and 8.1% of filter samples had <1TTC or 1-10 TTC/100ml, respectively.
Haiti (Caens 2005)	Candle filters using Brazilian filter elements	Paired samples of pre-and post-filtered water from household analyzed for TTC	During the 22 weeks following initial distribution of the filters, 85% of samples from 148 filters were TTC-free; thereafter, water quality diminished as filters reached end of design life
Dominican Republic (Boisson 2005)	Candle filters using Brazilian filter elements	Six-month randomized, controlled trial of 80 households, half with filters and half serving as controls	70.6% and 12.3% of filter samples had <1 TTC or 1-10 TTC/100ml, respectively, compared to 31.8% and 11.3% from control samples

Research on the diarrhoeal disease impact of household-based interventions in emergency settings is also limited. Roberts (2001) and Doocy (2004) are the only RCTs of such interventions conducted in emergency settings. These studies are described more fully in Part I of this thesis. The improved bucket used by Roberts and colleagues in the Malawi refugee camp reduced the rate of episodes of diarrhoea among children under 5 years by 31% (P=0.06); an 8.4% reduction recorded among all study participants, however, was not statistically significant (P=0.26) (Roberts 2001). The combined flocculant-disinfectant used by Doocy and Burhnam in the Liberian camps, on the other hand, was associated with the largest reduction in diarrhoea among both all ages (longitudinal prevalence ratio of 0.12, 95% CI: 0.11 to 0.13) and under 5s (0.08, 95% CI: 0.07 to 0.09) of all trials included in the systematic review. At least two other observational studies have shown POU water treatment in the home to be effective in preventing diarrhoea in emergency settings. Submicron filters used in Milwaukee following the massive outbreak of cryptosporidiosis were associated with a reduced rate of watery diarrhoea (Addiss 1996).

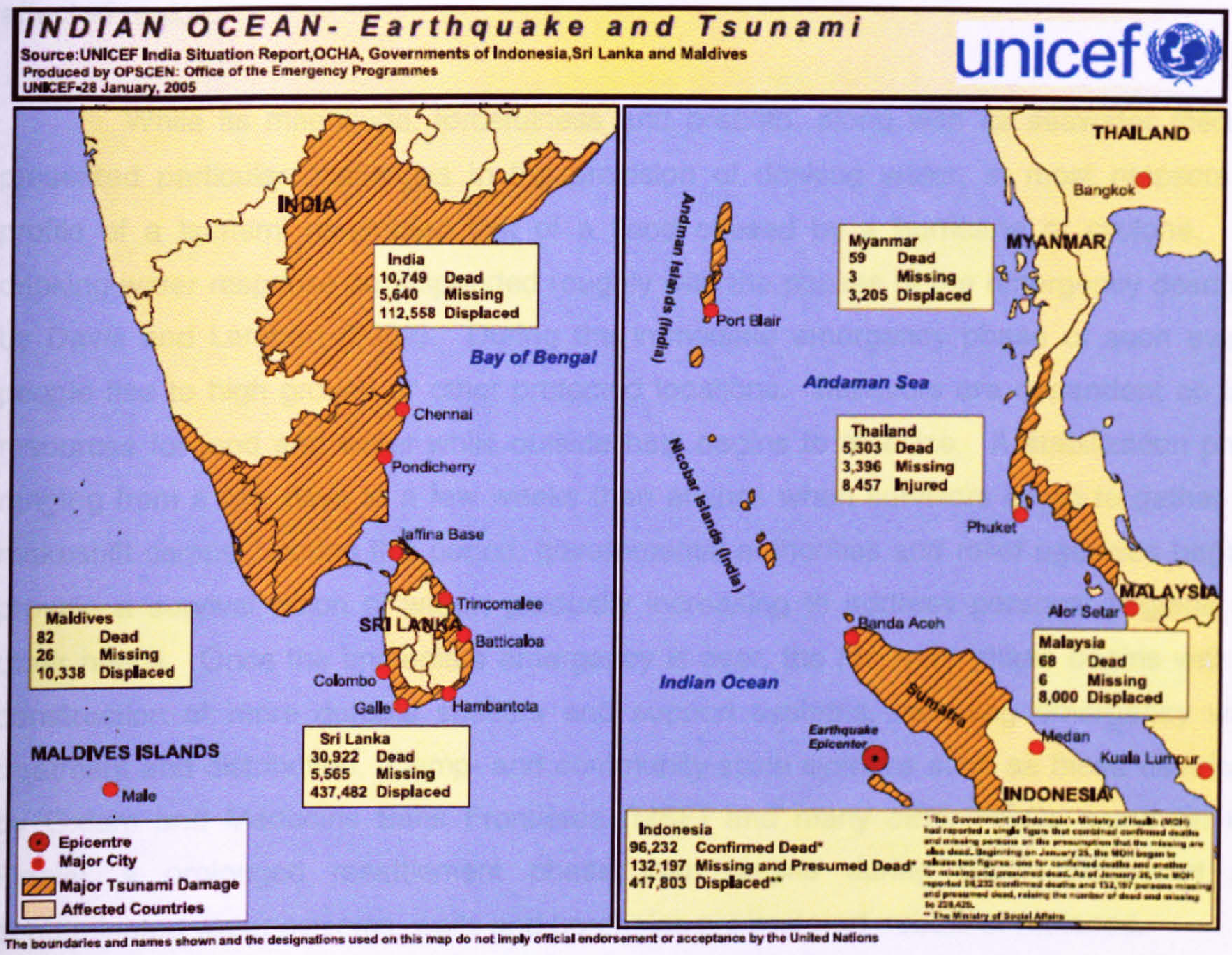
Persons who reported boiling or chlorinating their water at home following the 1998 floods in Bangladesh also experienced lower rates of diarrhoea (Kunii 2002).

The 2004 Indian Ocean tsunami provided an opportunity to investigate the role of household water treatment as part of the emergency response. With the assistance of the WHO, and funding from Hindustan Lever Ltd., a study was undertaken to investigate and document the drinking water response in the immediate aftermath of the tsunami. T. Clasen conceived of and designed the study, conducted the interviews and field work in India and Sri Lanka, and drafted the corresponding reports; L. Smith, a research assistant at the London School of Hygiene & Tropical Medicine, conducted the interviews and field work in Indonesia and contributed to the reports. The full report on the study has been published by the WHO (Clasen 2005). This chapter summarizes the main findings from the study, particularly with respect to household water treatment.

9.2 Background and Methods

On 26 December 2004, an earthquake off the Indonesian island of Sumatra measuring 9.0 on the Richter scale triggered a number of massive tsunamis. The leading wave raced through the deep water at a speed of more than 800 km per hour. As it neared land, its enormous energy unleashed at least three waves of up to 25 m, killing and devastating coastal regions of eleven countries around the Indian Ocean. At least five million people were affected in Indonesia, Sri Lanka, India, Thailand, Malaysia, the Maldives, the Seychelles, Myanmar and Somalia. The death toll exceeded 250 000 people, and more than one million persons were displaced as a result of the destruction. Figure 9.2 shows the administrative areas affected by the disaster.

Figure 9.2: Map showing areas affected by the Indian Ocean tsunami



The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations

(Source: UNICEF)

Governments, UN agencies and NGOs, citing the threat of outbreaks from waterborne diseases such as diarrhoea, cholera, typhoid and hepatitis, urgently appealed for assistance to provide safe drinking water to affected populations. A WHO release two days after the event was typical: "Poor quality and quantity of water and insufficient sanitation, overcrowding and poor hygiene in temporary camps will bring forward the risk for outbreaks of different diarrhoeal diseases. Thorough and sustained water purification is an absolute priority." (WHO 2004b) Rapid assessments and statements stressed the urgency of the drinking water response: "Access to potable water is essential to avoid the propagation of waterborne disease. " (IFRC, 29 December 2004). Calls for the provision of safe water—a need with which all humans can readily identify—became a central theme in the campaigns of many organizations as they themselves became inundated with unprecedented levels of contributions from around the world. Many organizations even accepted in-kind donations of filters, chlorine and other water treatment products. Regular situation reports from the field monitored the drinking water response throughout the affected region.

While its magnitude, forcefulness and breadth, along with its seawater medium, presented particular challenges in the provision of drinking water, in most respects the profile of a tsunami resembled that of a flood caused by a hurricane or cyclone. The drinking water response corresponded roughly with the phases of the emergency described by Davis and Lambert (2002). During the immediate emergency phase of such events, people flee to high ground or other protected locations. Survivors are dependent on local resources for food and water while outside help begins to mobilize. A stabilization phase ranging from a few days to a few weeks then ensues when survivors begin to gather into makeshift camps. During this period, governmental authorities and relief agencies begin to provide a survival ration of water, gradually increasing to address personal hygiene and other needs. Once the immediate emergency is over, the recovery phase begins with the construction of more durable shelters and support systems, including emergency water treatment and distribution. Camp- and community-scale systems such as those developed by Oxfam and Médecins Sans Frontières (MSF) and many other NGOs come on line. Finally, a prolonged resettlement phase then begins during which destroyed and contaminated water systems, wells and boreholes are restored, rebuilt or replaced.

This study of the drinking water response followed a cross-sectional design. Shortly after the tsunami, broadcast, web and print media were monitored to obtain information relevant to the drinking water response and to identify organizations that were involved therein. Commencing four weeks after the event, the identified organizations, including governmental ministries and authorities, UN agencies, NGOs and private-sector companies, were contacted. The scope and objective of the study were explained, and organizations were encouraged to provide any relevant information, including copies of any reports or accounts that addressed drinking water issues, and to supply investigators with the names and contact details of their representatives in the field. Such representatives were contacted by phone and email, and asked to provide any further relevant information and reports.

Commencing approximately eight weeks following the event, the investigators began two-week field assessments in India, Sri Lanka and Indonesia. These countries were selected because they collectively represent a significant majority of the human casualties (known dead or missing) and perhaps a similar portion of internally displaced persons (IDP) living in camps or temporary shelters. We interviewed national, regional and local representatives of organizations involved in addressing drinking water issues, obtained copies of reports, and accompanied them on visits to affected areas. During our field work, we interviewed on-site relief personnel working on water, sanitation and hygiene projects, including local personnel involved in providing water. We also met with health workers, mainly in temporary clinics. Finally, we interviewed victims of the disaster and solicited their input on the drinking water response from the immediate aftermath through the first four months. A list of the organizations that provided information for this study appears in Table 9.2.

Table 9.2: List of organizations that provided information for the study

Action for Food Production (AFPRO)
AmeriCares
Apollo Hospitals
Aquaya/Brown University
Bless
BushProof
CARE
Catholic Relief Services (CSR)
CAWST
Centers for Disease Control and Prevention
Community and Water Environment Forum
DHAN Foundation
EAWAG
Evangelical Church of India
Helvetas Sri Lanka
Hindustan Lever Ltd.
Indian Ministry of Health and Family Welfare
International Committee for the Red Cross
International Federation of Red Cross & Red Crescent Societies (IFRC)
International Network to Promote Household Water Treatment and Safe Storage
International Rescue Committee (IRC)
Johns Hopkins University
LEAD
London School of Hygiene & Tropical Medicine
Lutheran World Service
Katadyn Products AG
Medentech Ltd.
Médicins Sans Frontières
National Water Supply & Drainage Board (Sri Lanka)
Oxfam GB
Procter & Gamble Company
Project Hope
PSI
Red Cross Sri Lanka
RedR
Tamil Nadu Water and Drainage Board (TWAD)
Samaritan's Purse
Sri Lanka Ministry of Health
UNICEF
Yayasan Dian Desa
WaterAid
World Health Organization
World Vision

Although steps were taken to collect as much relevant information as possible, circumstances limited the investigation. First, while the field portion of the investigation was intentionally delayed so as to minimize interference with the response itself, the continued priorities of attending to the emergency limited our access to key personnel. Second, logistical issues and costs permitted field assessments to be conducted only in selected countries and locations. Third, in soliciting information for this study, investigators agreed to respect the confidentiality of sources, where necessary, in order to encourage candid disclosure, respect privacy and protect proprietary information. While these factors may bias the results, they are the limitations that typically attend emergencies of this kind and thus may be unavoidable in order to obtain potentially useful data from which to distil useful guidance for the future.

9.3 The Drinking Water Response Generally

9.3.1 Pre-Existing Water Supplies and the Impact of the Tsunami

With the notable exception of Aceh, the areas most affected by the tsunami consisted of a relatively narrow strip of land (a few metres to up to 5 km) along the sea coast. Depending on the location, this area varied in population density from isolated rural areas where no one resided to medium-sized cities. As a result, the water supplies serving the affected area came from a wide range of sources, including surface water (ponds, rivers and streams), hand-dug wells, springs, boreholes, piped-in water systems and tanker-supplied water. Shallow wells (usually <10 metres deep), unprotected wells, some fitted with hand pumps, represented the most common source of drinking water, though these frequently produce water with a high level of saline and faecal contamination and often produce no water whatsoever during the long dry seasons between monsoons that extend to most of the region. Rainwater harvesting is practiced in some areas, but does not play a major role due to limited and seasonal rainfall. Although portions of the affected population had household connections to conventional treatment and distribution systems, most drew water from household or communal sources that were untreated and unprotected. Regardless of the source, many stored water in the home due to inadequate and unpredictable supplies.

The tsunami affected existing water supplies in at least five ways. In those areas hit hardest by the impact of breaking waves, many of the supply and distribution systems, regardless of their type, were completely destroyed or otherwise rendered inoperable. In other areas, where the impact was less forceful, rising waters inundated surface sources and unprotected wells with seawater, sand, debris and, in many cases, faecal matter from coastal areas where open defecation was common and sanitation facilities were largely unimproved (Figure 9.3.1). Third, even protected sources such as shallow wells, many of which had high levels of salinity before the tsunami, underwent subsurface saline water intrusion, raising the saline level to a point that rendered them unfit for human consumption. Fourth, wells and other sources of supply that did survive the tsunami itself were often used at rates beyond safe recharge. In some cases, excess use may have increased saline water intrusion, resulting in water that was no longer potable. Finally, in some regions, there were dramatic shifts in the coast line, thus completely eliminating former home sites and complete communities. As a result of all of these factors, many sources of drinking water in the affected areas were unavailable or unusable following the tsunami. Groundwater experts have also expressed concerns that the inundation introduced chemical and microbiological contaminants as well as increased salinity into the aquifers that may affect water quality for years to come (IGRAC 2005).

Figure 9.3.1: Open wells in Tamil Nadu, India filled with debris from inundation

(Photographs: T. Clasen)

9.3.2 The Drinking Water Response

The evidence from the first three months from those countries from which information was available suggests that the drinking water response to the tsunami disaster was timely, effective and comprehensive. Though the area has never experienced a disaster on the scale of the 26 December 2004 tsunami, the countries involved are regularly affected by heavy monsoons and flooding, perhaps explaining why governmental bodies were quick to mobilize. UN agencies and NGOs, some of which already worked in the region with populations affected by conflict, provided invaluable experience and expertise, and were able to assume complete responsibility for specific areas. Defence forces played an important role in the immediate aftermath of the disaster, and continued to help reach remote areas. Commercial companies, organizations and individual volunteers all made important contributions. Their collective efforts with respect to drinking water can perhaps best be summarized with reference to the phases of the emergency response.

(a) Immediate Emergency Phase. During the immediate emergency, when those who survived the impact of the tsunami began assembling onto high ground or other unaffected areas, reliance was chiefly on local water supplies that had not been damaged by the force of the waves or by the rising seawater. Mosques, temples, churches, schools, hospitals and public buildings and grounds offered the first refuge for reuniting families and creating some minimum space for collecting a few possessions. In those areas in which the damage was more sporadic, survivors gathered at the homes of family, friends and neighbours. In the 24-48 hours immediately following the disaster, the affected population relied largely on serviceable groundwater sources in these locations. The quantity of water supplied during this period was extremely limited; many survivors had no vessels in which to store water, and many of these basic sources were quickly exhausted by the rapidly increasing demand.

(b) Stabilization Phase. As the magnitude of the disaster was being realized, governments (including defence forces), UN agencies, NGOs, private-sector companies and committed individuals began to mobilize the relief effort. Rapid needs assessments were undertaken and disease surveillance and control teams were dispatched. A decision was taken not to institute mass immunization campaigns for vaccine-preventable waterborne diseases such as cholera and typhoid, relying instead on environmental interventions and comprehensive disease surveillance. The water response during this period consisted of various initiatives:

- Packaged water (in 200ml polybags and PET bottles) was distributed to some squatter camps, though some organizations expressed concern about the microbial quality of this water. These were also being distributed to thousands of individual volunteers who were conducting search and rescue operations as well as recovery of bodies, road clearing and utility restoration efforts. One clearly visible downside to this response was the high levels of solid waste which persisted around camps due to packaging materials. However, other accounts report that the bottles were often re-used as water collection and storage vessels.

- As roads became serviceable, large plastic 500L to 2500L tanks were set up at the squatter camp sites. These tanks are commonly used by householders for storing larger volumes of water to make up for intermittent supplies from conventional sources. As a result, they were quite readily available in many affected areas. The tanks were typically filled by public and privately operated tanker trucks which are also common in many of the areas. While NGOs frequently hired and paid for the tanker deliveries, water supply was typically provided by the governmental water boards. Because of the focal nature of the damage caused by the tsunami, the tankers were normally able to procure water from unaffected sources within relatively close proximity to the affected areas. While the tankered water was normally believed to be chlorinated at or before the loading point or on the truck, as discussed more fully below, there are questions about such treatment. Figure 9.3.2 shows a typical tank while being filled by a tanker truck.

Figure 9.3.2a: Tank and tanker in camp, Galagama, Sri Lanka

(Photograph: T. Clasen)

- In a limited number of areas, mobile water treatment purification plants (including desalination plants) and portable coagulation/disinfection systems were brought in and began producing large volumes of potable water. In most cases, these were used to fill tanker trucks, though in other cases, they were positioned near camps and supplied them directly, storing water in bulk in corrugated steel "Oxfam" tanks and collapsible bladder and onion tanks, and distributing the water using rigid and layflat (fire) hose to communal tap stands.

- In a few areas, relief organizations began to encourage the affected population to treat their own water, mainly by boiling. In other areas, bleach (sodium hypochlorite), bleaching powder (calcium hypochlorite), chlorine tablets (NaDCC, halazone), PUR sachets (combined flocculant and disinfectant), and alum (flocculant) were distributed with the intent that they be used for treating water at the distribution points or at the household level. These household-based approaches are discussed below. During this period, relief organizations also began distributing vessels and utensils for collecting, storing and consuming water. Nutritional drinks, milk and other available liquids were also distributed as safe though limited means of hydrating survivors.

In most cases, governmental authorities, including state and local water boards took the lead in supplying water. They were also typically responsible for ensuring the microbiological quality of the water they supplied, chiefly by using some form of chlorine alone. In some cases, health authorities monitored water quality, usually only by checking levels of residual chlorine. In those areas where governments could not respond, defence forces and international relief agencies took responsibility for water supplies. Water and sanitation coordination committees, consisting of key actors in this sector, began to form and allocate responsibility, usually by region or camp; these watsan meetings also provided a forum to raise and discuss challenges that were unique to the particular emergency, such as saline water intrusion.

(c) Recovery Phase. As more relief supplies were being delivered to the affected areas, especially tents and supplies for establishing more durable shelters, some survivors were moved to semi-permanent 'temporary living centres' with water supply systems and sanitation facilities (Figure 9.3.2b). Others remained in transitional camps, while relief agencies continued to implement improved water supplies and latrines, cooking facilities, etc. In many cases, however, survivors were already returning to the sites of their former homes, setting up tents or living in makeshift shelters so that they could protect their holdings and begin to rebuild. Some maintained a nominal residence in camps or settlements (thus potentially misleading the official statistics) so as not to jeopardize their eligibility for assistance.

Figure 9.3.2b: Temporary living centre (shown with previous taps and pumps and new storage tanks) in Tamil Nadu, India

(Photograph: T. Clasen)

- For the most part, populations continued to rely during this period on tankered water delivered to the large plastic storage tanks, some of which were moved with the population to the temporary settlements. In fact, these two simple and low-technology pieces of equipment probably played the most important role among all hardware involved in the drinking water response. Nevertheless, there were problems with their use. First, despite being deployed in great numbers, the combination of tanks and tankers was often insufficient to meet the demand for water quantity. Water boards often controlled deliveries, making it difficult at times for NGOs to service camps for which they were responsible. Tanks were often empty, a problem that could be aggravated as summer approached and the need for water increased. When the trucks did arrive to fill the tanks, usually no more than once or twice per day, householders rushed out with anything that could hold water and filled them directly from the truck to maximize their water supply (Figure 9.3.2c), concomitantly increasing the risk of contaminating their stored drinking water prior to use in the home. A lack of coordination, understandable under the circumstances, also meant some locations had more water than they could use. Second, there was often confusion about who was responsible for ensuring that the water was appropriately chlorinated. This led to a lack of treatment in some cases, and excess levels of residual free chlorine (up to 6 ppm, or 15 times the residual level required) in others. Neither the truck drivers nor, in many cases, anyone in the camps had the tools or know-how to chlorinate or check residual chlorine levels in supplied water. While the trucks were usually filled from deep boreholes, treated municipal systems or NGO water plants, reports also emerged of tanker operators refilling from irrigation points or other surface sources to reach their daily target volumes more quickly. Third, while fitted with taps, the tanks had loose fitting, non-secured covers over large diameter openings. As a result, some users found it more expedient to fill their household containers by directly dipping them into the tanks, creating a serious recontamination hazard. Finally, in certain locations, the delivered water had a distinct colour and odour (suggesting the possibility of chemical contaminants) and a floating layer of particulate on the surface in the tank, providing further evidence of refilling from untreated surface sources as well as suggesting insufficient cleaning of tankers.

Figure 9.3.2c: Filling water containers from tanker truck, Pamadura, Sri Lanka

(Photograph: T. Clasen)

- In certain areas, such as Tamil Nadu in southeast India, the state water board, municipalities and Gram panchayats restored piped water supplies to many of the affected areas, and in fact established hundreds of new public water points to make up for the loss of wells due mainly to saline water intrusion.

- In some areas, relief organizations were operating desalination plants (reverse osmosis and electro-dialysis). There was concern, however, about the ability to continue using such plants due to their high operating costs (in India, for example, the estimated cost was Rs 0.60 (US$ 0.014) per litre. Some water treatment plants used in the initial phase had already been shut down and were no longer in use. During this period, many of the defence forces, who had brought their own mobile water treatment plants, packed up and moved out; most took all their equipment with them. Those who were operating donated equipment coordinated with civilian relief agencies to assume responsibility after their departure.
- By this phase, household water storage vessels were usually in adequate supply. Still, most of these were procured locally and were not fitted with taps or narrow mouths to minimize recontamination (Figure 9.2.3c). Broken taps were common. In some instances, the hygiene programs that responders began to introduce during this period included instructions on safe water handling and storage.
- Wells that were able to provide drinking water with acceptable levels of salinity were identified as sources of drinking water. In some cases, relief agencies chlorinated and cleaned wells (Figure 9.3.2d) and marked them as safe for drinking. Other wells were used for purposes other than drinking and cooking, though salinity levels were often so high that people did not even use them for personal or household hygiene. In certain areas, people were digging new wells. Here the main concern was to avoid locating them too close to latrines or other sources of contamination. There was also a focus on digging both new and existing wells sufficiently deep to accommodate the drop in water table levels that occurs during the dry season.
- An additional concern was that when the monsoon season began, people might begin to use surface water and other untreated sources, thus increasing the risk of waterborne disease.

(d) Resettlement Phase. Three months after the event, most new initiatives focused on the resettlement of the affected populations. In some instances, survivors were relocating in new settlements, either because of fear of another tsunami or because of government mandates designed to reduce vulnerability. In such cases, water was supplied centrally, usually via municipal treatment and distribution systems, or else settlers relied on household or communal groundwater or surface sources. In most instances, however, displaced populations were returning and rebuilding on their previous home sites. Both scenarios presented certain implications:

- Government-drafted recovery plans contemplated the expenditure of significant amounts of tsunami aid on upgrading water and sanitation facilities, particularly in the most populous areas. The unprecedented amount of money raised and committed has created an opportunity to implement suitable, appropriate and sustainable solutions that reflect best practices based on experience in environmental engineering and public health. It also creates the risk that funds will be allocated based on political, commercial and other priorities.

- Restoring wells presented a particular challenge. While this normally consisted of removing silt and debris and chlorinating the well to deal with microbiological contamination, saline water intrusion has rendered many, perhaps even most, wells unusable even after several months. Pumping the wells to encourage freshwater recharge (Figure 9.3.2d) proved ineffective in many cases. While many of those interviewed expressed optimism that groundwater sources would recharge with freshwater after the commencement of the monsoon, hydrologists explained that many of the groundwater aquifers servicing such wells have themselves become contaminated, thus raising questions about the near-term restoration of the wells and the futility of digging wells or drilling boreholes that tap the same aquifer.

Figure 9.3.2d: Well refurbishing, Meulaboh, Indonesia

(Photograph: L. Smith)

- In addition to assisting with redevelopment and restoration, relief organizations are involved with other initiatives relating to drinking water. As described below, household-based water treatment, and water handling and management practices generally, were being introduced over the previous twenty years as part of integrated water-sanitation-hygiene programs. Water quality testing and surveillance can also be implemented on a more systematic basis.

9.4 The Role of Household Water Treatment

In the Indian Ocean tsunami response, boiling was the most common approach to treating water at the household level. This was particularly true in Aceh, Indonesia, where UNICEF and the Ministry of Health had promoted boiling for years. Issues arose concerning the introduction of chlorination as an alternative to boiling, particularly when investigators for NGOs found evidence of unsafe water at the household level. In one study, 47.5% of water sampled from 400 households (78% of which reported boiling, the others not treating their water at all) were positive for *E. coli*, and a significant majority found it often (25.7%) or sometimes (42.6%) difficult to practice boiling, mainly due to the unavailability (65.5%) or cost (62.8%) of fuel or lack of a stove (20.8%) (Handzel 2005). Nevertheless, due to the scale of demand on those involved in the emergency response, most NGOs promoted boiling as the only practical means of treating water at the household level during the initial phases of the emergency. They observed that because boiling was well known and widely accepted, it did not require programmatic support for its promotion, thus allowing them to focus on providing basic watsan needs. They also reported that they believed boiling was the obvious alternative for those householders who were consuming water from unsafe wells or surface sources because they did not like the taste of chlorinated water being delivered to the camps.

Some relief organizations promoted chlorinating water at the household level, but only to a limited extent. They noted that householders showed greater willingness to chlorinate their water during the initial phases of the disaster, mainly using liquid bleach (sodium hypochlorite), bleaching powder (calcium hypochlorite) or a variety of chlorine tablets that were widely distributed during the first two weeks of the response. Health officials explained that when faced early on with dead bodies and other obvious sources of perceived contagion, survivors seemed more willing to treat their water and accept the uncustomary taste of chlorine. As the recovery effort continued, however, many discontinued this practice, perhaps because their assessment of vulnerability declined but also because other bulk supplies of water were more readily available. How extensive or important such household chlorination actually was is difficult to assess. What is clear, however, is that in the absence of programmatic support, chlorination in the home was not generally accepted, particularly when the risk of waterborne disease was not readily apparent and alternatives became available.

The limited role of household water treatment was not a result of unavailability of the technology. In fact, the quantity of products sent to the region for the purpose of treating water at the point-of-use was remarkable, particularly in view of the small quantities that can be shown to have actually been used by the affected population.

- Chlorine and SWS. Common sources of chlorine (liquid bleach, bleaching powder, household disinfectants) were widely available in most areas, but this was used mainly for cleaning and disinfecting surfaces rather than for treating water. An estimated 140,000 bottles of sodium hypochlorite specifically designed for water treatment were shipped to Aceh province from an already established SWS programme in Jakarta for use by CARE, an NGO experienced in promoting the SWS. Only 70,000 bottles were actually reported to have been distributed to affected communities by the end of March. Bottles were initially left with camp coordinators for distribution; however it was soon found that this was not resulting in proper use and distribution was suspended until training could also be provided. Promotional material (Figure 9.4a) and a training session of 30-60 minutes significantly increased uptake and the portion of households with sufficient residual chlorine levels (R. Quick, personal communication).

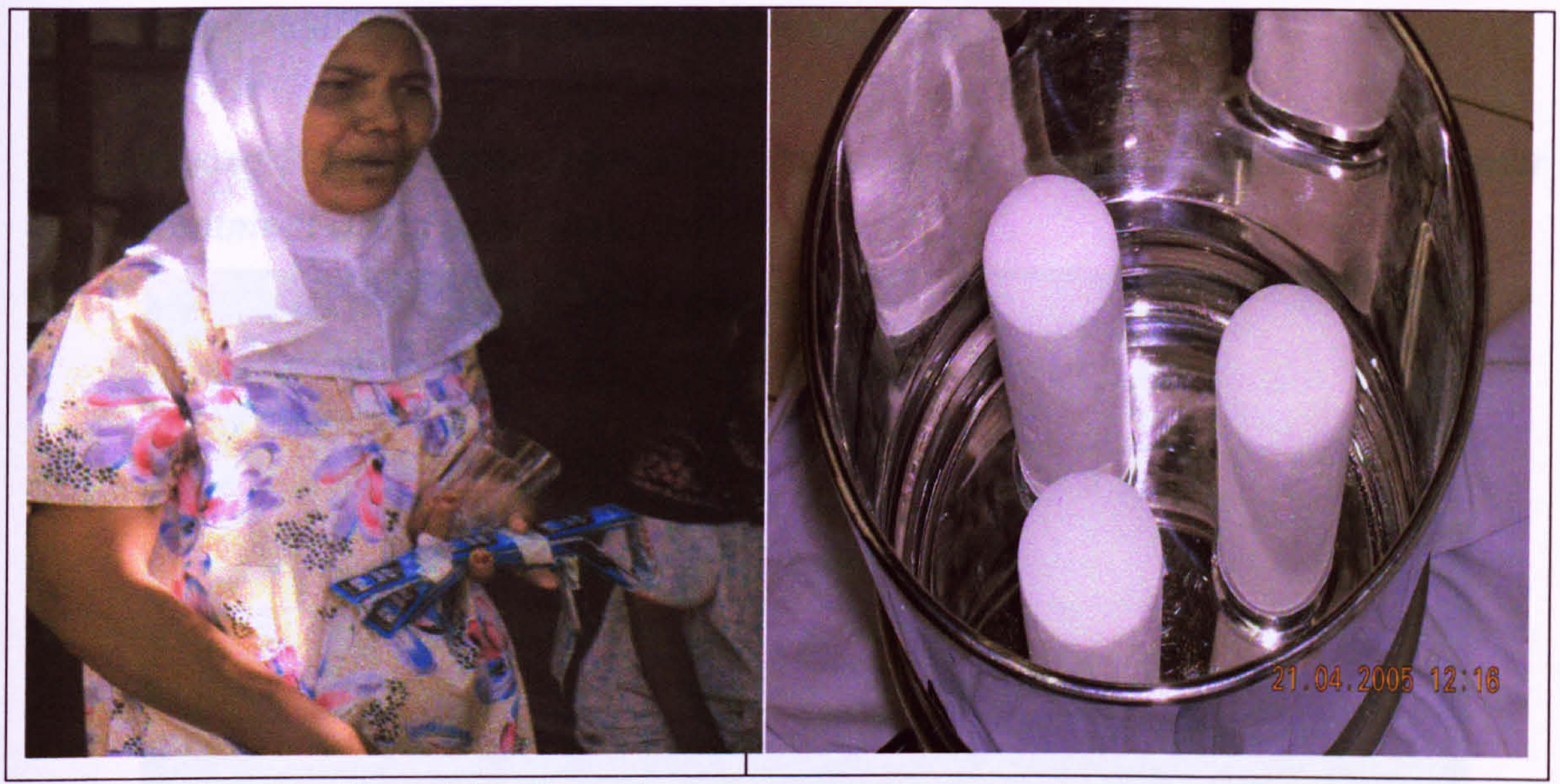
Figure 9.4a: Poster from Lamborah, Indonesia promoting SWS for household chlorination of water

(Photograph: L. Smith)

- Chlorine Tablets. Millions of locally-produced chlorine tablets (mainly chloramine/hydroclonazone, halazone and calcium hypochlorite/HTS) were shipped to affected areas. While these were widely available in the early phases of the emergency, we found few of these tablets in the camps after several months, and it was difficult to find shops that stocked them or knew that they could be used for treating water. One foreign manufacturer reported shipping a total of 50 million dichloroisocyanurate (NaDCC) tablets to the region in a succession of orders, mainly from NGOs and UN agencies (P. Edmondson, personal communication). While chlorine tablets were used to treat water in bulk and in certain settings immediately following the tsunami, only limited use of these tablets at the household level could be confirmed.

- Combined Flocculation/Disinfection. Within two weeks of the disaster, the Procter & Gamble Company shipped over 15 million sachets of combined flocculant/disinfectant to Sri Lanka and Indonesia (Figure 9.4b); a month later, another 1 million sachets went to the Maldives (G Allgood, personal communication). After three months, however, much of the product had not been used and the company began to re-ship the product to other disasters. In Aceh, two NGOs suspended distribution after giving out roughly 1.6 million sachets due to questions about its suitability and acceptability, as well as lack of human resources to provide necessary programmatic support. Certain NGOs expressed enthusiasm for the product, noting its potential especially when turbid surface water (e.g. from a river) is the only available option. In the majority of locations around Aceh, however, water was largely sourced from wells or tanker supplies and was of acceptable clarity. In such cases, recipients reported that the treatment process was too complex and the resultant taste was unpleasant. In Sri Lanka, except for some initial use in limited numbers, NGOs were waiting to use the product at later stages, especially after the monsoon commenced, when the risk of contaminated (and turbid) water would be greater and the product could be deployed with necessary training and follow-up.

Figure 9.4b: Sachets containing combined flocculant-disinfectant, Aceh, Indonesia (left), and commercial ceramic filters, Batticaloa, Sri Lanka



(Photographs: G. Allgood, T. Clasen)

- Ceramic Filters: India and other countries throughout south Asia are among the largest producers and users of ceramic drip water filters. Several brands could be purchased in shops near the areas affected by the tsunami (at prices from Rs700-1100 (US$16-25), and local WHO officials reported that some householders were purchasing and using them. Nevertheless, the evidence suggests that filters were used only sporadically in the four months following the disaster. In one camp in Tamil Nadu, RedR India reported that 40% of the population had been given such filters and that the positive results should lead to wider use in villages and urban camps. UNICEF distributed 550 donated filters to families in five locations in Aceh, and though follow-up confirmed the filters were well received and in use, they had no plans to expand the programme, preferring instead to focus on hygiene messages and promotion of boiling. Oxfam, which has previously used filters in post-flooding responses and other settings, procured 20,000 filters within two weeks of the tsunami (Figure 9.4b), but decided to deploy them only in the resettlement phase when people began to re-establish their households more permanently (Palmer 2005).

- Solar Disinfection. Local NGOs (Helvetas and LEAD) introduced the Sodis solar disinfection programme in 5 camps in Sri Lanka and 22 villages in Tamil Nadu, India (Figure 9.4c). While local partners were also implementing the Sodis programme in other parts of Indonesia, NGOs elected not to implement the intervention in the tsunami-affected areas there due to the availability of treated water under camp- or community-wide systems.

Figure 9.4c: Poster from Tamil Nadu, India, promoting household water treatment using solar disinfection

(Photograph: T. Clasen)

- Biosand Filters. Two NGOs (Dhan Foundation and Samaritan's Purse) with experience in biosand filter programs reported plans to introduce the filters during the resettlement phase of the emergency response. In the early phases of the emergency, however, biosand filters did not play a major role.

- Improved Storage. A few NGOs imported and distributed improved water storage devices (with small necks to prevent introduction of hands, and taps for safely accessing water). In general, however, householders used locally-produced open-mouth vessels, buckets, pots and tubs to collect and store water and use it in their tents, shelters or homes (Figure 9.3.2c). Local inhabitants who were not directly affected by the disaster often procured and provided such vessels to survivors, together with food and other utensils. While improved storage vessels may have been readily embraced by the affected population, they simply were not available in large numbers in the immediate aftermath of the disaster, and once conventional water containers were provided, relief organizations did not regard them as a priority.

9.5 Water Quantity and Quality

The common dichotomy between water quantity and water quality was evident in the drinking water response to the tsunami. In part, this was due to the similarly common separation of responsibility: supplying minimum amounts of water was often the responsibility of one branch of government (e.g., Public Works, Water Board, etc.) while ensuring the quality of the water fell to another branch (e.g., Ministry of Health, Health Board, etc.). More likely, however, this reflects the actual differences in the demands of the affected population, the natural response of the first responders, and the basic fact that providing water does not require unusual training or technology.

Initially, most responders emphasized water quantity, access and availability. For the most part, the evidence suggests that these efforts were largely successful. As can be expected in the early phases of a disaster response, there were camps and other settings with inadequate water. This was particularly true in those locations in which the wells or other sources were completely inoperable or in communities that traditionally had been water stressed. Those populations that could still obtain water from shallow wells, even though too saline to drink, were able to meet certain water needs from these sources. The almost immediate availability of tanks and tanker trucks was a key factor in satisfying water demand. Moreover, the government response in restoring, and in many cases, installing piped water and distribution points, also contributed significantly to the provision of adequate supplies of water.

Efforts to ensure the quality of the delivered water, on the other hand, were less successful. While some international NGOs brought and used portable water testing kits that assessed water for faecal contamination, most governmental and other agencies involved in the provision of drinking water were not regularly testing the microbial quality of the water whatsoever. In some instances, there was no clear allocation of responsibility for chlorinating the water. In most cases, however, it seems that authorities were too overwhelmed with the supply of water to focus much attention on its quality. While the WHO and others provided chloroscopes and pool testers to measure the levels of residual free chlorine in supplied water, those with access to these devices often did not know how or when to use them (Figure 9.5). Excessive levels of chlorine in supplied water encouraged some people to revert to more risky alternative sources due to the unacceptable taste and smell. For the reasons discussed below, the fact that no serious outbreaks of waterborne diseases were reported from the affected areas should not lead to an inference that the drinking water quality was consistently safe.

Figure 9.5: Chloroscope shown to an investigator, Tiranagama, Sri Lanka

(Photograph: T. Clasen)

It is possible that organizations emphasized water quantity over water quality. In fact, this is recommended under Sphere Project standards and other guidelines (Sphere Project 2004; Davis 2002). In the present case, however, it is not clear that surveillance of water quality needed to be compromised to concentrate on water quantity. Governments often allocated this responsibility to different branches, and NGOs experienced in watsan are organized to do both.

If water quantity and water quality is a zero-sum game in an emergency such as this, however, the need to emphasize quantity may have important implications for household water treatment. First, as noted, the evidence clearly supports the position that the overall health risks are reduced by ensuring an adequate supply of water, even if that supply is microbially compromised (Adams 1999; House 2000; MSF 1997). Second, the systematic review described in Part I above suggested that in the absence of sufficient quantities of water, interventions to improve water quality may not be effective in reducing the risk of diarrhoeal disease. Third, most approaches to household water treatment require some, and for certain technologies, considerable, programmatic support. This simply may not be practical in the initial phases of a disaster response when other higher priorities out-compete in the demand for time and resources.

9.6 Surveillance

9.6.1 Disease Surveillance

Disease surveillance was an important priority immediately following the disaster. In most regions, this was led by national ministries of health, with assistance from the WHO South-East Asia Region and certain relief agencies. Most countries had a reasonably well-established disease surveillance system in place which formed the basis for special measures in response to the tsunami. Medical and public health teams were dispatched to the camps to undertake disease surveillance. As the response developed, outbreak early warning systems were implemented in certain areas, and laboratories were organized and equipped to diagnose epidemic-prone diseases. In India, teams recruited from the hundreds of MoH personnel throughout the country were assembled and each assigned to cover six or seven camps (Chatterjee 2005). In Sri Lanka, disease surveillance was primarily handled by medical personnel working in camps and settlements. In Indonesia, on top of high losses of health staff and facilities the task was made more difficult due to lack of sufficient pre-tsunami capacity; no system for centralised data collection at the district or provincial level was previously in place meaning that only limited health statistics were available.

While these efforts appeared to be adequate, there are some uncertainties about the adequacy of the disease surveillance and the lack of reported outbreaks. In Thailand, where one of the most well-developed public health infrastructures is in place, officials from the Ministry of Public Health reported significantly more cases of acute diarrhoeal disease following December 26 in the six provinces affected by the disaster than in the same period in previous years (CDC 2005). By mid January, the annualized rate was 1.7 times that of the previous year. No similar increase in respiratory or febrile illness or wound infection was observed. A survey of 400 households in IDP settlements in Aceh found 25.3% (54 of 214) of children under 5 years of age reported having diarrhoea during the two weeks prior to the interview, with 2.4% reporting an episode of bloody diarrhoea during this period (Handzel 2005). In some instances however, health workers from outside the area could not say with certainty what number of cases represented normal endemic levels of common diseases such as diarrhoea.

Three months after the disaster, status reports and end-of-mission summaries from emergency responders in the region agreed that no serious outbreaks of infectious disease ever materialized. While cases of malaria, measles, watery diarrhoea and hepatitis were reported, the WHO and others concluded that there was no evidence that these were above normal background levels in countries in which these diseases are endemic. In respect of waterborne diseases such as cholera, shigellosis and dysentery, no serious outbreaks were reported (WHO 2005b). In its 90-day report, the WHO observed that "millions (sic) of Tsunami survivors throughout South Asia and East Africa have escaped the horrors of major epidemics of communicable diseases in the immediate aftermath of the disaster", and credited this to "the resilience of the public health systems and response capabilities of the affected countries, the hard work by local communities as well as national and international support" (WHO 2005c). According to Dr. David Nabarro, then head of the WHO's Crisis Management Team, an important lesson was learned about averting epidemics: "It's very important that people realise that it could have been amazingly terrible - it's just that this time we actually got it right" (BBC 2005).

In fact, the risk of outbreaks of infectious diseases following natural disasters may be exaggerated. More than twenty years ago, Seaman and colleagues (1984) questioned this widespread belief, noting that it probably evolved from the historical association of war, famine and social upheavals with epidemics of smallpox, typhus, plague and dysentery. In a comprehensive review, Blake (1989) concluded that during the previous 40 years, outbreaks of communicable diseases following natural disaster had been unusual. In a more recent review of 38 natural disasters (including at least 10 floods) around the world between 1970 and 1992, only six were accompanied by outbreaks, and only two of those (typhoid fever in Mauritius in 1980 following a cyclone, and diarrhoeal disease in the Sudan in 1988 following a flood) involved a potentially waterborne agent (Toole 1997; Morgan 2005). The inevitability of epidemics following natural disasters is a myth.

These reviews notwithstanding, it is nevertheless important to continue efforts to minimise the risk of infectious diseases in the aftermath of a tsunami and to maintain good disease surveillance. First, while perhaps not meeting Blake's definition of an outbreak, there is evidence of increased transmission of faecal-oral transmission of infectious diseases following a flood (WHO 1998; Cairncross 2005). Published studies have reported post-flood increases in cholera, cryptosporidiosis, non-specific diarrhoea, poliomyelitis, rotavirus, typhoid and paratyphoid, and a variety of vector-borne diseases (Ahern 2005). Second, as noted above, there was evidence of increased levels of diarrhoeal disease in certain areas affected by the tsunami even though most reports concluded there was no outbreak. This may, in fact, be attributable to less than optimal surveillance or perhaps to the willingness of local health officials to tolerate some increase in incidence of disease without characterizing it officially as an outbreak. Finally, even if epidemics following floods have been largely averted in the past, it cannot be ruled out that this was in fact the result of active steps in disease prevention such as the provision of safe drinking water.

9.6.2 Water Quality Surveillance

Water quality surveillance did not reach the same level of coverage as disease surveillance. As noted above, government agencies responsible for water supply focused primarily on providing sufficient quantities of water, and only secondarily on water quality. NGOs reported that water quality surveillance was in fact a problem before the tsunami. Ministries of Health in certain countries were able to mobilize surveillance teams to monitor water quality in some cases. Public Health Inspectors (PHIs) were sometimes used for this purpose, as were volunteers, including women's and youth groups. However, even when there were personnel to test water quality, they often depended on WHO or NGOs to provide them with even basic tools to assess residual chlorine levels; few had apparatus or know-how for testing physical parameters to ensure proper disinfection or microbial and chemical contaminants that could present immediate or longer-term health hazards. For example, local water personnel in Tiranagama, Sri Lanka knew that the chloroscope and diethyl-p-phenylenediamine (DPD) tablets pictured in Figure 9.5 were used to test water, but could not demonstrate to the investigator how to use them and could not identify anyone who could.

As a result of the limited surveillance, there is little data on the safety of the water provided to and consumed by the affected population. In Aceh, CARE coordinated a pilot survey of 48 households four weeks after the tsunami (Albert 2005). Of these, 77% were using shallow wells as their primary source of drinking water, the others using tanks (10%), boreholes (8%) and streams (4%). Eighty-five percent considered their water to be unsafe, and all reported boiling to make it safe for drinking, though not in every instance. Forty-three samples of source and stored water were collected in 100ml whirlpacks containing sodium thiosulfate for the inactivation of residual chlorine and analysed for *E. coli* using the IDEXX defined substrate method. Except for 2 of 3 tanks maintained by relief organizations, sources were all positive for *E. coli*, including shallow wells (median 450 CFU/100ml), boreholes (15 CFU/100ml) and streams (>2500 CFU/100ml). More troubling, however, was the finding that 67% of the 43 samples from water stored at the household were positive for *E. coli*, with 15% having counts >101 CFU/100ml (the WHO "high risk" level) and 22% between 11 and 100 ("intermediate risk"). The findings raised questions about the adequacy of the boiling approach being promoted in the region as an alternative to household chlorination, especially since the only samples free of the faecal indicator at source or household were those found to contain residual chlorine.

In February 2005, CARE and the Provincial Health Office conducted a more extensive survey of 400 households from 51 IDP settlements in Aceh (Handzel 2005). In these camps, most people relied on tankered water (61%), shallow wells (12.1%), boreholes (8.8%) or treatment units directly serving the camps (5.8%). Only 11.9% considered the quantity of water supplied to be inadequate. Water supplies under camp management were generally, though not universally, positive for residual chlorine (11 of 14 tanks, 3/5 piped supplies, 2/2 tanker trucks, 3/3 treatment plants). While only 1 of 11 tankers was positive for *E. coli*, boreholes (7/10) and especially hand dug wells were highly contaminated (10/10, with geometric mean of 216.8 CFU/100ml). The survey found that 97.7% of the householders reported collecting water from the camp-managed tanks and 99% reported using this water for drinking. Interestingly, of those who use the chlorinated water for drinking, 78% said they boil it first, perhaps due to lack of experience and/or trust of chlorinated water which was not the norm pre-tsunami. Despite these generally encouraging findings, however, 47.5% of the 400 water samples taken from water stored in the home for drinking were positive for *E. coli*, with 13.3% at the "high risk" level (101-1000 CFU/100ml) and 18.0% at "intermediate risk" (11-100 CFU/100ml). In other areas, NGOs confirmed cases of significant under-dosing (no detectible residual chlorine) and over-dosing (free residual up to 6 ppm) of chlorine. While inadequate disinfection of supplied water presents an obvious health risk, over-dosing is also problematic since it encourages people to consume water from untreated sources and form strong opinions against chlorinated water which may be difficult to reverse.

Under the co-ordination of UNICEF and with technical support from CDC, plans were under way in Aceh to involve more NGOs in an extension of the CARE surveys. This was to involve water quality monitoring (at source and household level) and active diarrhoeal disease surveillance through household surveys in around fifty sentinel camps and temporary living centres (TLCs) around Banda Aceh and Aceh Basar. Such a monitoring system would seem to be vital to gain a more accurate picture of living conditions and highlight areas for improvement in the response as it moved into the rehabilitation phase. These findings also suggest, perhaps, the need for a wider environmental health monitoring programme generally, and not only as part of the emergency response.

9.7 Conclusions regarding Household Water Treatment

In general, household water treatment did not play a significant role in the immediate aftermath of the tsunami response. The main reasons for not using household water treatment fall into five main categories:

- Emphasis on Water Quantity over Quality. As recommended by Sphere Project and other guidelines, and the priorities demonstrated in the early needs assessments, the initial emphasis in the drinking water response was on quantity rather than quality. Physiological needs (hydration) are the first priority, and outweigh microbial concerns. As discussed more fully below, this will have important implications in the priority that should be attached to household water treatment during the early phases of a disaster response.
- Unnecessary Given Bulk Supply of Water. Because the population affected by the tsunami was either displaced or had otherwise lost access to their customary sources of fresh water, they were dependent on water supplied in bulk, the quality of which was easier to ensure at the source than at home. In fact, it is possible that the saline water intrusion that rendered so many surface and shallow groundwater sources unusable actually helped minimize waterborne disease since affected populations were not even tempted to consume water from such sources that were also likely to be contaminated by microbial pathogens

- Need for Programmatic Support. All of the common means for treating water and maintaining its microbiological quality at the household level require some level of programmatic support. While some approaches, such as certain gravity filters that are easy to use and make noticeable improvements in water aesthetics, may require less of a behaviour change campaign than chlorination or solar disinfection, all household-based approaches require a commitment of both human and financial resources for their introduction that may be impractical in the early phases of a disaster. Moreover, while emergencies are often viewed as an opportunity to expose and introduce an affected population to new health and other initiatives, this is not typically true until the situation has become stabilized and recovery begins. As noted above with respect to parts of Aceh, the introduction of chlorination as an alternative to boiling was resisted. Among other things, this was due to awareness among public health workers, given their own long-standing campaign to promote boiling, of the significant effort required to obtain high levels of adoption of such interventions even without having to deal with a massive disaster.
- Concern about Mixed Messages. In Aceh where the practice of boiling drinking water is widely reported and genuinely appears to be a well-established behaviour, there was concern (particularly from the Ministry of Health and UNICEF) that new messages about alternative water treatment methods may confuse matters and result in a decrease in normal practice, thus leaving individuals exposed to increased risk of waterborne diseases. With so many agencies working on water, sanitation and hygiene promotion issues, the early stand made by UNICEF and the Government of Indonesia on the water boiling issue was an attempt to avoid proliferation of conflicting messages being given to the affected populations which would only serve to dilute their effectiveness.
- Concerns about Sustainability. In addition to the preference for existing practice, concerns about the sustainability of new household-based water treatment methods also led to resistance to their introduction. For example, the Indonesian Government made it clear that they would not commit to the chlorination of all public water supplies once the relief agencies left and so it was important to maintain the high pre-tsunami levels of boiling. Although the circumstances and raised risk perceptions which result from a natural disaster may be sufficient to trigger initial or short-term behaviour change, as has been discussed, these do not seem to be sustained and people may no longer feel the need to treat their water if there are no continuing visual or sensory cues to suggest that it is unsafe

or unpalatable. Such short-term behaviour change without sustained promotion could be detrimental to health if it means the abandonment of previous safe drinking water practices. It will also be essential to maintain a supply of the hardware (e.g. sodium hypochlorite or flocculent/disinfectant sachets) which may become difficult in the unstable regions of Sri Lanka and Aceh.

Except for the concerns about sustainability, these reasons mainly argue against the premature introduction of household water treatment, rather than against its use altogether. In fact, many of the relief organizations which had procured products with a view toward introducing household water treatment reported that they still planned to do so but were waiting for more appropriate circumstances. Some organizations expressed the view that point-of-use water treatment at the household level was an ideal solution for certain members of the affected populations once they began to return to their home sites and no longer had access to bulk supplies of treated water. Others also reported that they planned to take advantage of the presence of large numbers of people in the camps and temporary settlements to introduce household water treatment as part of an overall water/sanitation/hygiene programme and ensure its proper use before people vacated these settings.

For these reasons, conclusions about the role of household-based water treatment and safe storage in the tsunami response may be premature if based solely on the first three months following the emergency event. Such interventions have demonstrated their effectiveness in development settings, and it is possible that they will be an important part of the overall drinking water response in the medium- and long-term. There is now at least some evidence that household water treatment did play a role at later stages of the disaster response. A six-month follow-up of commercial and locally fabricated ceramic water filters deployed by Oxfam and the American Red Cross, respectively, in eastern Sri Lanka showed widespread use of the units in communities where the distribution was accompanied by programmatic support (Palmer 2005). There is also limited, though promising, water quality data suggesting that such filters are eliminating faecal bacteria from source water. In August 2005, 88 samples from various sources were tested for TTC. Ninety-five percent of samples from household filters were free of TTC, compared to 13% from dug wells, 41% from distribution tanks, and 0% from stand posts (Oxfam 2005).

9.8 Recommendations Regarding Household Water Treatment

Although household-based approaches to water treatment have proven to be effective in development programmes and certain refugee settings, their utility in emergencies has not yet been widely demonstrated. The evidence from the first three months following the Indian Ocean tsunami suggests that household water treatment may not be appropriate during the immediate phases of a disaster of this kind. Because of the scale of damage and numbers affected, other priorities such as ensuring access to a sufficient quantity of water, took precedence. Thus, despite large shipments of various household water treatment technologies, the evidence suggests that much was not actually distributed. While some relief organizations initially tried introducing such products, most concluded that they would be of more use once the displaced population began to settle permanently, either in their original community locations or the governmental temporary living centres (designed to last between 1-2 years) i.e. when people actually have 'households'.

It is important to note that household water treatment, like all other hardware, also requires appropriate software (i.e. promotion and training support) to be fully effective (Quick 2003). In the case of the sachets of combined flocculant-disinfectant, this is now stressed in the standard operating procedures developed by Procter & Gamble to guide the deployment of PUR® in emergencies. Experience has shown that victims of a disaster may not be open to any new intervention offered to them with a promise of health improvement; they will still have preferences as under normal circumstances and if drinking water treatment is to be sustained into the future then methods must appeal to these preferences. If there are insufficient field staff in the initial emergency stages to carry out such training, it is perhaps preferable to delay the introduction of new point-of-use methods until it can be done more thoroughly with plans for sustainability, rather than risk detrimental effects (such as a decrease in established boiling practices).

When conditions and staffing are suitable for a household-based intervention, implementers should consider carefully the context and choose from among proven technologies. Among the factors to be considered are the following: (i) the extent and precise composition of the microbial threat (e.g., most filters are not effective against viruses, and some encysted protozoa are resistant to chemical disinfection); (ii) physical water parameters (temperature, pH, turbidity, etc., that may affect performance); (iii) anticipated period during which the population will be using the intervention; (iv) extent and nature of the programmatic support necessary to introduce and ensure adoption of the intervention; (v) portability and transferability of the intervention to permanent location; and (vi) mechanisms for sustaining the intervention following the departure of the implementing organization (e.g., local availability of consumables, affordability, acceptability, etc.).

Finally, as noted above, there is evidence to suggest that household-based water treatment and safe storage may play a more important role in the affected area over the medium- and long-term. It is therefore recommended that this issue be revisited, perhaps 12-18 months following the tsunami, to better understand the actual significance of these interventions in the overall response.

EPILOGUE

Chapter 10: The Challenge of Implementation and the Need for Further Research

10.1 Implementation

Parts I and II of this thesis suggest that household water treatment may be a promising option to improve water supplies, both in terms of effectiveness and cost, in order to achieve health gains among a population suffering from burden of diarrhoeal diseases. However, the field studies described in Part III, while not challenging this potential, do suggest that even a cost-effective intervention will not automatically be successful in practice.

In the only assessment of a longer-term programme to implement household water treatment, Olembo and colleagues (2004) revealed a number of sobering findings that should give pause to those who may believe that the promising results from research and pilot studies can readily be transferred to populations at large. They evaluated a 5-year programme in Zambia by the local affiliate of PSI that used social marketing for the national promotion of the SWS (dilute sodium hypochlorite under the PSI brand "Clorin", plus vessel and hygiene message). While they found 42% of the 1319 households surveyed currently reporting use of Clorin, they sampled only from geographical areas with comparatively high sales of the product; nationally, the 1996 Demographic Health Survey (DHS) placed the figure at 13.5% (Zambia Central Statistical Office, 1997) despite five years of country-wide media campaigns (radio, television, newspapers, posters, etc.) and active promotion at the community and household level by pharmacists, staff and volunteers. Regular users were more likely to be from urban and peri-urban settings, better educated, with better houses and generally of higher socio-economic class—hardly the most vulnerable to diarrhoea. Fully 22% from the sample reported that they tried the product but discontinued use, mainly because of cost, poor taste and the belief that their water was already safe. And of the 546 households who in the DHS reported using Clorin, residual chlorine was found in the stored water of only 36.1% of those reporting use for more than one year, 27.3% for users from 6-12 months, and 20.0% for users for less than 6 months. This contrasts with 72%-90% compliance reported in the field trial in Zambia described in Part I (Quick 2002). Given the association that the systematic review found between compliance and effectiveness (Section 4.1.9 above), this finding might raise questions about whether the intervention, as implemented, was effective in preventing diarrhoea. In fact, the cross-sectional survey found no association between the prevalence of diarrhoea in household members under 5 years of age during the two weeks prior to the survey and the reported use of Clorin (Olembo 2004).[44]

Unlike vaccines, POU water treatment in the home requires householders to embrace and routinely employ the intervention. It also requires promoters to reach the target population and meet their needs for effective, appropriate and affordable products. Thus, the real potential for household water treatment to make an important contribution in public health will depend on two important questions relating to their implementation: (i) how can the target population be encouraged to adopt the intervention (uptake), and (ii) how can the interventions be scaled up on a sustainable basis for delivery to that population?

10.1.1 Increasing Uptake

Although numerous approaches have been used for centuries to treat water in the home, few of these have been widely adopted (Sobsey 2002). Affordability is certainly one important issue (Olembo 2004). However, it is clearly not determinative. Certain trials reported in Part I provided the intervention at no cost and yet reported compliance well below 50% (Reller 2003; Garrett 2004). Moreover, solar disinfection, the method found in Part II to offer the lowest annual cost per person covered, has experienced some of the lowest levels of continued utilization in the absence of continued programmatic support. Fully one third of the persons receiving the intervention do not practice it; after two years, coverage in certain areas falls to 13% (A. Mercado Guzmán, personal communication). Other factors that have been hypothesized as possibly influencing uptake are the population's awareness of water as a health hazard, programmatic support, and a visible improvement in water quality (Quick 2003).

Perhaps the best case study for illustrating the challenges associated with the increasing the uptake of household water treatment is also one of the oldest. Wellin (1955) described the diligent efforts of community-based health promoters in rural Peru

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[44] Households reporting that they boiled their drinking water also did not have a lower prevalence of diarrhoea. The study did find two factors that were protective against diarrhoea: older (>20 years) caretakers (OR 0.49, 95%CI: 0.29 to 0.85) for the children and the presence of soap in the hand washing area (OR 0.25, 95%CI: 0.10 to 0.60).

to convince their neighbours to boil their drinking water as part of a national initiative to reduce water-borne disease. After an intensive two-year campaign directed at 200 families in the community, only 11 (5.5%) actually adopted the practice. The case is still ubiquitously cited in consumer research, and is believed to offer important lessons in promoting a wide variety of new products and services—especially the need to understand and leverage existing communication networks, to focus early on opinion leaders to help achieve a critical mass, to recruit and use influential insiders as change agents, and in general to be "client-oriented" rather than "innovation oriented". Unfortunately, the study is rarely mentioned by those promoting household water treatment where its lessons are most directly applicable.

Parker and colleagues (2006) reported greater success in the adoption of the SWS as a result of promotion by nurses in Kenya in an area in which PSI had been promoting diluted sodium hypochlorite under the "WaterGuard®" brand. Eleven nurses underwent a four-hour training session on how to incorporate the SWS and hand washing instruction into their regular clinical practice. They were also given instructional material and pocket guides to leave with their clients. The nurses then trained their assigned clients in five-minute one-on-one encounters or thirty-minute group sessions (varying from 8 to 50 individuals), covering all 220 persons that typically visited the MCH clinic each day. Water sampling from follow-up visits to clients who had visited the clinic two weeks previously showed that 68% had detectable free chlorine residuals in their stored water; after one year, the figure was 71%. Unfortunately, this study failed to measure use at baseline prior to the promotion, so the extent to which the outcome can actually be attributed to the intervention is unknown.

The WHO and others have observed that a principal problem in the uptake of household-based water treatment technologies is "acceptability" (WHO 2002; Sobsey 2002; Quick 1999). While there has been some attempt to assess acceptability of household-based water treatment interventions (McLennan, 2000; Cartagena, 2001; Lantange, 2001; Tabbal, 2002; Brown, 2003), the tools used in such analyses are not comprehensive. Moreover, these assessments seem unlikely to yield information that would be very useful in predicting or enhancing the uptake of such interventions. There are at least four reasons for this. First, most studies define acceptability in terms of continued use after a period of time. This notion, though important, does not provide key information on the reasons for and against adoption or clues about when and why use was discontinued. Second, existing approaches are limited to examining only a few parameters, mainly comparing and contrasting the characteristics of the households based on utilization. They do not focus on the particular aspect of the technology that seems to impact adoption and continued use. Third, none of the studies to date involve a comparison of the acceptability or adoption of different technologies. Thus, researchers can only speculate on whether a different technology may or may not have been more acceptable in the same community. Finally, acceptability, important as it is, does not ultimately determine uptake. This is also a function of a variety of social and economic factors, including the dynamics of the household and the community, affordability, other priorities, etc. The end of the analysis must be "uptake", not just acceptability. A more comprehensive framework for understanding the process and issues relevant to adoption is necessary.

Diffusion research may offer such a framework. While diffusion research has its roots in European social science more than a century ago, the field is most closely associated with Everett Rogers who has contributed substantially to its methodology and carefully documented its development (Rogers 2003). Rogers defines diffusion as a process in which an innovation is communicated through certain channels among members of a social system. Among the key factors in determining the rate of diffusion are the perceived attributes of the innovation: (1) its "relative advantage" or degree to which it is perceived as better than the idea it superseded, (2) its compatibility with existing values, past experiences and needs, (3) its simplicity, both to use and understand, (4) its "trialability" or the degree to which potential adopters may experiment with it on a limited basis without foregoing their traditional approaches, and (5) its "observability" or the degree to which the results of the innovation are visible to others.

Diffusion research has been widely adopted and used not only in the social sciences but also in public health (Orlandi 1990; Haider 2004; Moseley, 2004). This includes strategies to combat HIV/AIDS (Svenkerud 1998; Singhal 2001; Bertrand 2004), cancer screening interventions (Glasgow 2004); contraceptive behaviour (Kincaid 2000); smoking cessation programs (Korhonen 1999); and family planning programs (Murphey 2004). In the area of water, diffusion research has been used to examine the adoption of community water systems (Belasco 1989); communicating the risk of lead in tap water (Griffin & Dunwoody, 2000); and fluoridation of water (Haugegorden 1988).

As noted above, diffusion research involves more than an analysis of the innovation. It also focuses on the characteristics of individuals that make them likely to adopt an innovation, the communication channels used in the adoption process and the decision-making process that occurs when individuals consider adopting the innovation. It also addresses other factors, including the innovation-decision process, communication, the role of diffusion networks and change agents and the consequences of innovations in a population. All of these are potentially useful areas of inquiry in understanding how to enhance the uptake of household-based water treatment interventions.

A few studies have investigated some of these issues. DuBois and colleagues (2003) followed up on 117 purchasers of PUR® sachets in Kenya, administering a questionnaire to help identify factors that motivated the decision to buy and use the product. They administered the same questionnaire to 193 matched non-users in the same area. Logistic regression revealed that users were more likely than non-users to obtain their drinking water from a highly turbid source (OR=16.2, 95%CI 2.1-126). Users also had higher economic status (using housing characteristics as a proxy) (OR=1.7, 95%CI 1.3 to 2.3). Interestingly, users were less likely to believe that diarrhea was a serious problem in their community (OR=0.46, 95%CI: 0.27 to 0.76). As noted above, Olembo and colleagues (2004) also found use of household water treatment (SWS) to be positively correlated with economic status. However, they found that householders who believed high turbidity was a sign of contamination were much less likely to use the Clorin product to treat their water—perhaps because, unlike PUR, the product did not reduce turbidity. Use was associated with perceptions of water quality, with those who believed their water quality was consistently good less likely to use Clorin (OR 0.71, 95%CI: 0.54 to 0.92).

While diffusion research presents a useful framework from which to conduct an assessment of the potential uptake and adoption of household-based water treatment technologies, the specific tools for applying the methodology to such interventions must be developed. DuBois (2003) and Olembo (2004) developed tools for their studies; Freeman (2005) has also developed a comprehensive questionnaire for assessing factors associated with product adoption and use. Following the Rogers framework, and based on these and other field studies, Table 10.1.1a sets forth some of the possible indicators which may be relevant for assessing the likely take-up of household water treatment.

Table 10.1.1a: Possible indicators of likely take-up, based on attributes of the innovation

Attributes of Innovation	Indicators
Relative advantage over existing approach	• Physical characteristics (taste, smell, temperature, color, turbidity), and the perception of the extent to which the innovation affects such characteristics • Microbiological characteristics (removal of pathogenic bacteria, protozoa and viruses), and the perception of the extent to which the innovation affects such characteristics • Convenience (time spent acquiring, assembling, learning how to use, using and cleaning systems; who performs these tasks; how frequently) • Sufficiency of water quantity produced (system capacity, system throughput) • System operation (batching versus continuous flow) • System failure (failure rate; ability to repair or replace components; cost) • Affordability, and the relative importance of various measures of affordability (investment cost, operating cost, cost per unit--e.g., household, family member, year or water treated; importance of instalment or pay-as-you-use options to minimize cash outlays) • Value (perceived worth in relation to actual cost) • Social prestige perceived to be associated with the acquisition and use of the system
Compatibility	• Existing values associated with water (physical characteristics, quantities used or required, convenience, preferred sources) • Possible obstacles (addition of chemicals, adverse changes in temperature or taste, time required, interference with other priorities, cultural incompatibility) • Compatibility with previously introduced ideas (perceptions about chemical treatment, experience with prior failed systems) • Compatibility with perceived need (awareness of hazard, priority attached to need, key aspects of perceived need, extent to which innovation is perceived to meet need)
Complexity	• Relative difficulty in understanding and using the innovation (place on a continuum against other comparable in the community) • Ease of acquisition, use, maintenance and repair/replacement (time spent, frequency, level of expertise, need for assistance)
Trialabilty	• Opportunity to adopt without completely abandoning existing practices (system characteristics; perception that innovation requires abandonment) • Opportunity to try before purchase decision is made (demonstrations, in-home trials) • Ease of terminating use of the intervention (sunk cost, potential for cost recovery) • Opportunity to purchase on an instalment basis (availability of instalment option, effective rate of interest, importance attached)
Observability	• Perceptible improvement in water characteristics (taste, smell, temperature, color, turbidity), and the relative importance of same • Perceptible change in household and/or community health (perception of a change in morbidity associated with diarrhoeal disease)

As noted above, in attempting to understand and enhance the adoption of a new product or technology, diffusion research requires an analysis not only of the innovation itself, but also of the target population. It also considers the process that underlies the adoption decision. In the context of household water treatment, some of the indicators that may be relevant to these issues are summarized in Table 10.1.1b.

Table 10.1.1b: Possible indicators of likely take-up based on characteristics of population and adoption decision process

Attribute	Indicators
Characteristics of Population Affecting Adoption	• Income level (actual income or proxy measures for non-monetized population) • Wealth (proxies such as house size or construction, number of animals owned, etc.) • Family composition (ages, numbers, genders) • Sanitation and hygiene practices (relative level) • Availability, accessibility and quantise of source water • Amount of water used in the home for hydration, preparing and serving food, and personal hygiene • Storage practices relating to water • Responsibility for water-related matters • Knowledge of water quality at home (physical and microbial characteristics) • Perception of health hazard from drinking water • Morbidity and mortality associated with diarrhoea • Availability of other options in water treatment • Importance of prestige associated with system use • Openness to innovations (adoption rates of comparable innovations; rejection of previous innovations) • Access to change agents (early adopters, influential role models such as teachers, doctors, etc.)
Decision Process Leading to Adoption Decision	• Allocation of responsibility for product-purchasing decisions • Exposure to adoption-associated messages (number of times message communicated and/or observed; type of message) • Role of change agents • Key timing and events associated with decision

These and other factors should be evaluated as potentially relevant indicators of uptake. Once this preliminary list is developed, it should be shared with researchers and programme implementers involved in household water treatment to obtain their input on omissions and priority. Following this process, the list of key indicators could be used in a process of formative research to develop a set of assessment techniques designed to measure the indicators and assess their relative importance in the adoption of household-based water treatment. These might include (i) field assessments of indicators such as physical and microbiological water quality and the improvements in such characteristics resulting from such water treatment systems, flow rates, failure rates, etc.; (ii) structured observation to obtain field data on such factors as amounts of water consumed, quantities of water produced, amounts of time required to use and maintain systems, etc.; and (iii) surveys, focus groups, semi-structured interviews and other techniques for obtaining qualitative data (Steckler 1992). Where possible, such studies should be undertaken in settings where different household water treatment products are being employed in order to better understand how these indicators differ among the types of interventions.

10.1.2 Scaling Up Household-Based Water Treatment

Diffusion research, including the innovation-decision process, communication, the role of diffusion networks and change agents and the consequences of innovations in a population, also has much to contribute to the other major challenge facing the implementation of household water treatment—scaling it up on a sustainable basis. However, unlike uptake, where the focus is on the beneficiary of the intervention, scaling up is concerned mainly with the programme implementer or other agent who is attempting to promote the adoption of the intervention. This includes its strategy, objectives and capacity as well as the context in which it must deliver the product or technology intended to help householders treat their own water.

The challenge is awesome. An estimated 1.1 billion are without access to improved water supplies (WHO/UNICEF 2000). An unknown yet undoubtedly significant portion of these lack access to sufficient quantities of water, and thus may not benefit from household-based water treatment. At the same time, many of those with improved supplies have only limited or intermittent access, or access only to unsafe water, and could benefit from POU water treatment in the home. For purposes of this analysis, figure of a 1 billion beneficiaries of household water treatment is assumed. Table 10.1.2 summarizes the current level of coverage for the four major types of household-based interventions for which there is data as well as continuous use slow sand filters (biosand filters). These figures ignore boiling—undoubtedly the largest segment of users—since there is no reliable estimate of the numbers of boilers and since the health impact and sustainability of boiling has not been established. Based on this quick analysis, as a result of more than a decade's progress, current programmatic efforts to promote household water treatment among vulnerable populations are reaching about 7 to 8 million people, or less than 0.08 percent of the need. And as noted above, the limited demographic information available on the populations that these programs serve suggests that current users are more likely to be urban and peri-urban residents with comparatively higher resources, not the remote and destitute who are most vulnerable to diarrhoeal diseases (Olembo 2004; DuBois 2003).

Table 10.1.2: Recent coverage of certain household water treatment interventions

Intervention	**Year targeted programs commenced**	**Number of countries in which programs are underway**	**Estimated number of products sold or users**
Safe Water System	1990	21	5 million bottles sold
Ceramic Filters	1987	19	<1 million users*
Solar Disinfection	1999	20	<1 million users
Combined Flocculant/Disinfectant	2002	7	Unknown (13 million sachets mainly for emergencies)
Biosand Filters	2001	36	500,000

*Excludes higher-quality commercial filters sold primarily in developed countries for use by outdoor enthusiasts, international travellers and owners of country cottages without access to conventional water treatment. Also excludes lower-quality ceramics used mainly to reduce turbidity but not remove microbial contaminants.

(Sources: Allgood 2005; EAWAG/SANDEC 2002; http://www.cawst.org/)

Household-based water treatment technologies may be introduced to a population by four categories of implementers: (i) the public sector, (ii) NGOs, (iii) a NGO/private sector hybrid (social marketers or social entrepreneurs, or (iv) the private sector. These actors, in turn, may pursue one of three basic approaches to the dissemination of the intervention: (i) providing it free of charge (or for nominal consideration) as a public good, (ii) providing support or subsidies for sales or donations by NGOs or others; (iii) selling it directly, but with only partial cost recovery; and (iv) selling it on a commercial basis at a price designed to cover its full manufacturing and sales cost, together with a profit. Figure 10.1.2a shows examples of some these combinations of implementers and basic strategies.

Figure 10.1.2a: Examples of household water treatment implementers and implementation strategies.

Implementer	**Strategy**			
	Government- or donor-supported, with no charge or nominal charge to beneficiary	**Government- or donor-subsidized**	**Commercial sales with partial cost recovery**	**Commercial sales with full cost recovery**
Public sector	Emergency response by UNICEF and national governments	USAID support for PSI, AED programs for POU; CDC support for SWS	X	Medentech sales of NaDCC tablets to UNICEF for distribution in emergency response
NGO	EAWAG/SANDEC promotion of Sodis solar water disinfection; Samaritan's Purse, CARE, ICRC, ARC and others distribution of SWS and PUR® in emergency response; Oxfam distribution of ceramic filters	PSI promotion of SWS; CARE promotion of SWS;	IDE and EPHNO promotion of ceramic filters; CAWST and BushProof promotion of biosand filters	NetWas promotion of ceramic filters in Kenya; Sumaj Huasi sales of ceramic water filters in Bolivia
Private sector	X	X	Procter & Gamble promotion of PUR®;	Unilever/Hindustan Lever promotion of Pureit®; Katadyn, First Water and Stefani promotion of ceramic water filters
Social marketer	X	PSI promotion of SWS and PUR; IDE promotion of ceramic filters	AED collaboration with First Water and Stefani filters	X

Note: X = unlikely/no example known

Using different implementers and implementation strategies to scale up the delivery of household water treatment is an acknowledgement of important differences in the target population (buying power, priorities, geographical location) and in the products and technologies used to treat water in the home (cost, portability, length of life). Solar disinfection in plastic bottles, for example, involves a relatively minor hardware component and considerably more programmatic support. Accordingly, its profit potential for a private sector provider may be limited, even though a creative entrepreneur could potentially sell communities the service of introducing the intervention or sell consumers solar-disinfected bottled water. Filters carry higher costs, especially at the front end. These may limit the market in some countries; at the same, they may almost certainly offer the highest unit profit, thus making them more attractive to private sector purveyors. This is almost certainly why there are dozens of manufacturers of ceramic filters producing tens of millions of candle filters annually. Disinfection products (sodium hypochlorite, chlorinated isocyanurates, iodine) and combined flocculation/disinfection products (PUR® , Watermaker®, Chlorofloc®) are produced by the private sector, but are distributed by all four types of actors (government, NGOs, private sector and social marketers), suggesting their potential at least for scaling up following multiple strategies.

The most progress in scaling up household water treatment has been achieved by the SWS. Figure 10.1.2 shows annual sales of the product from 1996. In many ways, the growth in sales after a tepid start is comparable to other demand-driven environmental health interventions, such as squatting slabs for latrines (Cairncross 1993). However, the five-fold growth since 2000 is mainly attributable to PSI taking on the product and launching it in an increasing number of countries using its social marketing strategy. Employing a variety of promotional techniques, including national media campaigns, group training sessions, and one-on-one appeals, most of which are subsidized by donors such as USAID, PSI seeks to create demand which it then meets through national or regional manufacturing, usually on a contract basis. Sales channels include local women's groups (Haiti and India), restaurants in urban neighbourhoods (Madagascar), community-based agents on bicycles and on foot who carry the product to local markets (Kenya), and co-marketing with commercial soap companies (Tanzania) (PSI 2005). Spurred by cholera outbreaks, coverage has reached an estimated 18% of households in Madagascar (WHO/UNICEF JMP 2005). In Zambia, where cholera has also helped drive demand, sales have grown from 187,000 bottles in 1999 to 1.7 million in 2003 (Banerjee 2005). Still, according to the authors, even at this level, full cost recovery is not possible.

Figure 10.1.2: Estimated global sales of SWS, 1996-2004

(Source: http://ww.dcd/gov/safewater)

Perhaps the biggest disappointment in the prospect for scaling up household water treatment is the recent decision by Procter & Gamble Company (P&G) in late 2004 to discontinue its commercial marketing of PUR® (Ellison 2005) A global consumer-products giant, P&G spent more than US$10 million developing and testing its PUR® sachets to demonstrate their efficacy in the laboratory and effectiveness in the field; it spent an equivalent amount establishing manufacturing capability and donating samples to governments and NGOs for pilot projects (G. Allgood, personal communication). While it is a major producer of household bleach (sodium hypochlorite) and pour-through and faucet-mounted household water filters used widely in developed countries, it settled on the combined flocculant-disinfectant technology due to its efficacy against the full range of microbial pathogens and the belief that consumers would need a visual clue—the elimination of turbidity—to adopt a product (Carpenter 2003). Analysts who follow the public company's stock noted that P&G discontinued pursuing the product as a commercial activity since the business was too small, was not core and was not profitable (Ellison 2005; Harris 2005). P&G now promotes the product as a corporate social responsibility initiative, and P&G's former chairman has recently joined the board of PSI. Others have blamed the commercial failure on the cost of the product compared to other alternatives (see Chapters 5 and 6) and its health-based marketing message. Claiming that "health doesn't sell", Unilever, a direct competitor of P&G, is promoting a household filter whose upfront cost is much higher than PUR sachets, but whose cost per litre treated or per month of use is comparable with other household water treatment products (Clasen 2006b). They are also intentionally avoiding a health-based message, and instead promoting the product as an economical and convenient alternative to boiling (Y. Jain, personal communication).

Experience with scaling up other household-based environmental interventions may offer some of the most useful lessons for expanding the coverage of POU water treatment in the home in low-income settings. Simple filters used to remove cyclops from stored water were one component of the Dracunculiasis Eradication Initiative. A donation of monofilament nylon cloth by the manufacturer was an important contribution to the programme, but over time governments purchased the filters (Cairncross 2002). Promoters experimented with charging nominal fees for the filters, but found this to be an obstacle to adoption in certain cases. Distribution, however, was remarkably successful, even to the most remote areas of endemicity. According to persons involved in the initiative, the success of the overall initiative was attributable, among other things, to widespread political support, international cooperation, donor funding, strategic advocacy, careful planning and tenacious execution—the essential ingredients, perhaps, of any large-scale disease control programme. The Central American Handwashing Initiative (Clasen 2002) and World Bank-backed Health in Your Hands[45] are examples of how collaboration between public and private sector actors has been brought to bear on scaling up handwashing. This same collaboration characterizes initiatives to promote the distribution of condoms for the prevention of HIV/AIDS. Recently, the WHO, UNICEF and the Rockefeller Foundation sponsored a comprehensive market study and business plan designed to stimulate the development, manufacturing and widespread distribution of long-lasting insecticidal nets (WHO 2004c). It provides perhaps the best example of the type of information that stakeholders can use to determine the need and current capacity. It could also help them identify opportunities for meeting that need that are best suited for the potential implementers, including the public sector, NGO, social entrepreneurs and the private sector. The International Network to Promote Household Water Treatment and Safe Storage has recently commissioned a comparable study to help guide the scale-up of household water treatment.

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[45] http://www.globalhandwashing.org/index.html

10.2 An Agenda for Further Research

The foregoing discussion of the challenges of implementing household water treatment raises important research questions. These join the long list of issues raised previously in this thesis. The systematic review revealed, for example, that important questions remain about the effectiveness of household-based interventions in blinded and longer-term trials. The economic evaluation was limited by the cost information on which its estimates were based, and its assumptions about coverage, economies of scale and cost offsets must be supported by additional data. The particular circumstances under which an intervention has greater or lesser effectiveness—as seen in the Colombia pilot—must be understood in order to provide better guidance on optimizing deployment. And the extent to which household water treatment may play a useful role in emergency response must also be further understood.

Beyond the research questions raised by this work, there are also important issues about household water treatment that were outside the scope of this thesis. These issues fall into five main categories: performance, health impact, economics and policy implications. Collectively, and with the other questions raised about effectiveness, costs and implementation, these form an agenda for future research on POU water treatment in the home.[46]

10.2.1 Performance

(a) The microbiological performance of certain technologies used for treating water in the home has not been fully demonstrated in the laboratory or in the field. And some that have been tested are known to be deficient with respect to a certain class of pathogens—e.g., chlorination against encysted protozoa, and ceramic filters against viruses. As suggested in Part I, these differences in performance may explain some of the heterogeneity observed in the pooled estimates of effect from the interventions. However, this must still be investigated.

(b) There are also basic questions about how to optimize household water treatment. As noted in Chapter 9, for example, even basic advice on how to kill or deactivate microbial pathogens by heat (boiling) is not uniform. Whether boiling should

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[46] The International Network for the Promotion of Household Water Treatment and Safe Storage has also prepared its own research agenda. This can be found at http://www.who.int/household_water/research/en/draft_research_agenda_June2004.pdf

be promoted at all, and if so how it should be done and what steps should be taken to protect boiled water against recontamination, should be agreed and messages consistently disseminated

(c) A few POU water treatment technologies have been shown to be effective in reducing the level of non-microbial contaminants, such as arsenic (Sutherland 2002; Meng 2001; Yuan 2002; Souter 2003) and fluoride (Robinson 1991). These warrant further investigation, particularly when they can be combined with microbial treatment.

(d) Much of the faecal contamination to which drinking water is subject occurs during collection, transport and household use (Clasen 2003; Wright 2004). While there is considerable evidence that improved storage can significantly enhance the microbial quality of water in the home (Sobsey 2002), comparatively few resources have been committed to the development and promotion of affordable storage products that not only offer increased protection against recontamination but also facilitate collection, transport and drawing in the home

(e) Risk-based standards that address both microbial and chemical pathogens are needed in order to help consumers ascertain the minimum protection necessary and the actual performance that can be expected from the various options available. These should be developed in a manner that is sensitive to the particular needs of the developing country settings in which the disease burden is heaviest and balances the benefits of incremental improvements against overall targets. Such standards will also have implications for product certification, branding and advertising.

10.2.2 Health Impact

(a) There are also unanswered questions concerning the health impact of household water treatment. Perhaps most obvious is the extent to which point-of-use water treatment at the household level may affect mortality and not just morbidity. As pointed out in Part I, only two trials reported on mortality, and in neither case was death the primary outcome that determined the trial design.

(b) Little research has been conducted concerning the extent to which household-based water treatment can prevent important disease complexes other than diarrhoea, especially other types of gastrointestinal disorders and enteric fevers. As noted in Part I, a number of studies were excluded from the systematic review since their outcome was gastroenteritis, which may or may not include diarrhoea. However, insofar as these studies follow a similar definition, they could be analysed systematically and subjected to meta-analysis. Typhoid is still a major cause of morbidity and mortality

(Crump 2004), but the writer is unaware of any trials investigating the impact of household water treatment on the disease.

(c) Insofar as different types of diarrhoea (persistent, dysenteric and non-dysenteric) vary in prevalence and case fatality rate (Black 1993), it may be useful to explore how improvements in microbial water quality affect each one. This will help refine the CERs of improvements in water quality.

(d) While epidemic diarrhoea represents a smaller portion of the disease burden than endemic diarrhoea overall, it is nevertheless an important cause of excess morbidity and mortality. The extent to which household water treatment can play a role in averting or reducing the cases of epidemic diarrhoea, as well as typhoid and outbreaks of other diseases, is still unclear.

(e) As noted above, drinking water is known to be a major contributor to asenicosis and fluorosis. While there is some promising evidence that household water treatments that are effective against the arsenic and excess fluoride can dramatically reduce the level of such contaminants in persons who practice such treatment (Norton 2003), this still warrants additional investigation.

(f) The implementation of household water treatment may have broader health implications, both positive and negative, that should be explored. For example, improved storage of drinking water in the home could reduce the number of mosquitoes or other vectors breeding there. On the other hand, a policy that encourages household water treatment in lieu of household connections may continue to limit the quantity of water available for hygiene or sanitation.

(g) The description of studies on household water treatment in Chapter 3 makes clear that while many studies have focused specifically on children under 5 (including <1 and <2), only one study to date (Lule 2005) has investigated the impact of the intervention on adults living with HIV/AIDS. The aged, who may also be more vulnerable to waterborne agents (Gerba 1996), should also be the subject of targeted research on the health impact of household water treatment.

10.2.3 Economic Issues

(a) Lack of resources is perhaps the most common explanation used by governments for failing to implement effective health interventions. Such an argument is misplaced, however, in contexts such as this, where the cost savings—even those that would inure solely to the government itself—more than offset the costs of implementing the intervention. This is not a situation in which governments cannot afford the intervention; it is one in which governments are more poor because they fail to act.

(b) Although certain household-based interventions have been shown to be among the most cost-effective approaches to the prevention of diarrhoeal disease, such an analysis provides only part of the necessary information on which to make such interventions a health policy priority. As discussed in Chapter 5, interventions that combine effectiveness with potential for cost-recovery may in fact have a greater case for implementation since they require lower (and perhaps no) cost to the government.

(c) WTP studies have provided some evidence of the cost recovery potential of household-based interventions filters (Brown 2003), but additional studies in different economic settings are necessary. Ability to pay must also be considered, as there is evidence of strong *willingness* to pay for household water treatment but lower *ability* to pay, leading to non-adoption (Olembo 2004).

(d) As discussed in Part II, a CEA focuses mainly on the health benefits that may obtain from one or more interventions; it does not quantify and include non-health benefits, such as increased productivity from reduced morbidity. A CBA that compares various sources and POU interventions could provide additional insight into the nature and magnitude of these non-health benefits. Since much of the attractiveness of conventional source-based interventions is to improve the quantity and accessibility of water supplies, benefits that are not offered by household water treatment alone, a CBA would provide a more comprehensive basis on which to make policy choices among these options.

(e) PSI has shown some success in distribution the SWS in at least 17 countries and PUR in 5 countries (S. Cowal, personal communication). A US$18 million programme awarded to PSI and AED on September 30, 2005 to support the social marketing of household-based water treatment and zinc for the prevention of diarrhoea should provide additional opportunities to investigate the potential for this marketing strategy.

(f) Procter & Gamble Company has abandoned is commercial strategy for the distribution of PUR® sachets in favour of a corporate social responsibility (CSR) approach (WSJ 2005). On the other hand, Hindustan Lever Limited (HLL), an affiliate of Unilever and a comparable consumer products giant, has launched its own household-based water filter in India. It joins an otherwise fragmented POU water treatment industry that has not traditionally focused on lower-income populations. Its experience will be widely followed as a example of whether commercial companies can be successful (profitable) in marketing healthful products to vulnerable populations much like insecticide treated nets. A case study that compares and contrasts the approach and results of P&G and HLL could provide valuable insights into the role the private sector will play in the dissemination of household water treatment.

(g) To date, most of the success in scaling up household water treatment has been in the context of social marketing. This has required heavy subsidies from donors. Whether or not this approach can be sustained, and how subsidies can best be targeted to ensure optimal health impact, are issues that involve both economic analysis and policy-making.

10.2.4 Policy Implications

(a) The promotion of household water treatment as a matter of policy also presents certain policy concerns for governments. First, and perhaps most important, is whether the commitment of resources into improving water in the home would divert resources away from household piped connections which are widely believed to offer superior health and economic benefits, though at greater cost. The WHO, UNICEF, CDC and others have been careful to make clear that "the adoption of home water treatment does not preclude the need for infrastructure aimed at sustainable access to safe water supplies such as piped systems, boreholes, protected dug wells, and so on" (WHO/UNICEF 2005; CDC 2001). Improvements in water supply (quantity and access) have been shown to be cost effective even without regard to their health benefits (Hutton 2004). While the CEA in Part II demonstrates how investment in household water treatment yields high health returns, these are only part of the basis on which policy makers must set priorities. From a societal perspective, any funds that are expended on POU products and technologies are not available for infrastructural alternatives to improve water supplies. This potential trade off thus presents policy implications that warrant full investigation.

(b) The priority that policymakers attach to household water treatment is also brought into focus by certain definitions used in the MDGs and the JMP. A recent report by the Task Force on Water and Sanitation of the UNDP's Millennium Development Project observes that helping households improve and maintain water quality at home "contributes directly to meeting Millennium Development Goals" (UN Development Project 2005). In its 2005 report on progress and strategies toward the MDGs in water and sanitation, the JMP also notes the health and economic benefits of household water treatment, identifying it as a measure that can be "progressively taken in pursuit of the

MDGs" (WHO/UNICEF 2005). While clearly endorsing the strategy, both reports fell short of declaring that household water treatment would be counted as "sustainable access to safe drinking water" under Target 10 of Goal 7. This left even members of the International Network on the Promotion of Household Water Treatment and Safe Storage debating the issue at its most recent annual meeting in Bangkok (Network 2005). The JMP acknowledges the incongruity between its measurement of "improved versus unimproved" water supplies, on the one hand, and the MDGs' "sustainable access to safe drinking water" on the other hand, and is working on revising household survey questions and piloting improved field techniques for assessing the microbiological integrity of water to make the surveys more useful in assessing MDG progress. If these modifications make clear that household water treatment also satisfies the MDG safe water targets, it could attract more funding and advance governmental adoption of the strategy—though, once again, at the possible cost of diversion from other approaches.

(c) Governmental support for household water treatment also raises questions about the role of the private sector in meeting the need for "public goods" such as safe water. Private enterprise may offer an important alternative for the development and distribution of POU water treatment products and technologies. However, while the World Bank and others have promoted the privatization of water supplies in recent years, the evidence that the private sector can address existing deficiencies is unclear (Cairncross 2003). Governments have an important role in regulating and establishing standards for POU water treatment devices, since consumers are unable to ascertain manufacturer claims or product performance independently. Governments should also be transparent about the shortcomings of their own water systems. And to the extent that consumers use reliable devices to improve water quality resulting from failures in treatment or distribution systems, there may be a role for the private sector to supply these products. However, even if governments rely on the private sector to produce and deliver such devices, it is unlikely that they would reach the most remote locations or be affordable to the most destitute without some sort of targeted subsidies or other assistance. Perhaps more likely, the devices would be bought and used disproportionately by segments of the population who already enjoy the benefit of safe tap water, thus yielding little if any health benefit (Colford 2005) and accordingly, return on the investment. These issues must be addressed by any government setting a policy on household water treatment.

(d) Finally, policy makers will need to weigh the potential advantages of household water treatment as suggested by Parts I and II of this thesis against other interventions to prevent diarrhoea and other diseases. Curtis and Cairncross (2004) showed that hand washing can prevent diarrhoea at a rate comparable to the findings in Part I on household water treatment. In most other respects, Fewtrell (2005) found the effectiveness of environmental interventions to be similar to those determined by Esrey (1985; 1991). The finding described in Sections 4.1.4 and 4.2 above that compound interventions (e.g., water quality + sanitation + hygiene) do not appear to increase the effectiveness of a simple water quality intervention in preventing diarrhoea suggests that policymakers should decide to focus their efforts on just one of these interventions in a given setting, and not spend the extra funds on an integrated approach. At the same time, the absence of evidence of a synergistic effect among these interventions does not mean that they are competing. In many respects, each of these interventions is designed to raise a different barrier against faecal-oral transmission. Disease control programmes must be designed with reference to the transmission pathways to which the target population is most vulnerable. Moreover, it is important to consider the benefits that the intervention may have beyond the preventing waterborne disease. For example, unlike household water treatment, interventions to promote hand washing have been shown to prevent acute respiratory infections (Lee 2005), an even bigger killer than diarrhoea (WHO 2005a). Improved sanitation may offer protection against trachoma through control of mechanical vectors (Emerson 2004). These and other health benefits should also be considered in setting policy priorities with respect to environmental health interventions.

The length and breath of this research agenda brings to mind the hope that White and colleagues (1972) expressed for their book more than thirty years ago: to encourage those working on improving water supplies in developing countries to consider the wider implications of their actions and to measure what the writers had had to guess at. At the same time, it should not be used to justify hesitation or inaction. Thirty years hence, authors will still be expressing the same hope for their work. At the same time, they must be able to report that their predecessors did everything they could, including carefully investigating the role of household water treatment for the prevention of diarrhoea, to ensure that everyone will one day enjoy the benefits of safe drinking water.

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