



Household water storage, handling and point-of-use treatment

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FORWARD

The burden of disease associated with unsafe drinking water is particularly trying, not only because it is borne most heavily by the poor, the very young and the immuno-deficient, but also because it is largely preventable. Providing reliable piped-in water must remain a priority, given its high return not only in health gains but also in economic productivity and overall human wellbeing (Hutton & Haller, 2004). At the same time, an increasing number of field trials have demonstrated that point-of-use treatment and safe storage of water in the home can be a cost-effective way to help vulnerable populations achieve the health benefits of safe water by taking charge of their own water security.

This review carefully summarises the growing body of research on storing, handling and treating water in the home. In doing so, it builds on the pioneering report on household water management prepared by Prof. Mark Sobsey for the World Health Organisation [3]. It provides compelling evidence that interventions to improve the microbial quality of water at the point of use are as effective as other environmental measures, such as hygiene and sanitation, in preventing diarrhoeal disease, thus helping refine the paradigm that has dominated watsan policy for the last 20 years [52, 53]. Moreover, by adopting a narrative approach, the review is a valuable complement to recent meta-analyses [80, 87] which have confirmed the effectiveness of household water treatment over traditional improvements at the source (protected wells and springs, tap stands, etc.), but have also found considerable heterogeneity in the study methods and results.

The review makes clear that additional studies, including longer-term, blinded trials, will be necessary to confirm the results to date, and to provide additional guidance on the circumstances under which household water treatment can be most effective. The ultimate impact of these interventions will also depend on overcoming challenges to their adoption by the target population on a scalable and sustainable basis. By summarising the research to date and identifying these remaining issues, however, the review provides a valuable guide on household water management that will be a useful tool to policy makers, donors, researchers and program implementers as they seek to ensure the benefits of safe drinking water for all.

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SUMMARY

World Health Organisation (WHO) data on the burden of disease suggest that approximately 3.2% of deaths (1.8 million) and 4.2% of disability-adjusted-life years (61.9 million) worldwide are attributable to unsafe water, sanitation and hygiene. Of all deaths attributable to water, sanitation and hygiene, over 99.8% occur in developing countries, and 90% are of children. For decades, universal access to safe water and sanitation has been promoted as an essential step in reducing this preventable disease burden. Despite this, WHO/UNICEF estimate that up to 1.1 billion people still do not have access to “improved” sources of water for drinking, for example, a piped connection or a protected well. They also acknowledge that many of the remaining 5.2 billion people who use an “improved” water source nevertheless drink water which is unsafe, following contamination at source, in the piped distribution system or as a result of unhygienic handling during transport or in the home. Even in the European region it is estimated that 120 million people do not have access to safe drinking water. Consumption of unsafe water continues to be one of the major causes of diarrhoeal disease deaths.

Although it is accepted that diarrhoeal disease is a huge problem worldwide, obtaining reliable data on the extent of diarrhoeal illness, the causative organisms, and the extent to which this illness is water-borne is difficult. Although mortality from diarrhoeal disease in developing countries has declined, there is little change in morbidity rates compared with previously described incidences. It is estimated that residents of developing nations may experience between 5 and 20 episodes of diarrhoea per year. Drinking water quality is a problem, not only in developing countries but also in developed countries, most particularly Eastern European countries, but also in North America and elsewhere. In European countries and North America, there are now fewer risks of epidemics related to drinking water contaminated with pathogens such as cholera and typhoid or viral hepatitis, but numerous instances of water-borne disease resulting from contaminated drinking water are still reported. It is estimated that, even in developed countries, as much as 15-30% of community gastroenteritis may be attributable to municipal drinking water, despite state of the art technology for water treatment and no conventional evidence of unacceptable microbial contamination levels.

Although significant advances have been made globally in the provision of community water supplies, there is increasing concerns that the health gains from investment in water supply are being compromised by the fact that water often becomes contaminated during distribution or transport to the home, and during storage and handling within the home. One of the key options for dealing with this problem is promotion of point-of-use water treatment and safe storage in the home.

In this document we review a range of studies which show that improving the microbiological quality of household water by point-of-use treatment and safe storage reduces diarrhoeal and other water-borne diseases in communities and households. Opinions differ as to the relative extent to which diarrhoeal disease can be reduced by improving water quality at household level, rather than at source. Opinions also differ on the extent of the health impact achieved by improvements in water quality in the absence of programmes to improve sanitation, water quantity and promote hygiene measures such as handwashing. Nevertheless the evidence shows that provision of safe water alone at the household level can reduce diarrhoeal and other enteric diseases by 6 to 50%, even in the absence of improved sanitation or other hygiene measures. Importantly the data indicate that the health impact from promoting point-of-use water treatment and safe storage varies considerably from one community to another depending on a variety of technology-related as well as site-specific environmental and demographic factors. Thus the gains for some communities may be very significant, whilst in others they may be relatively modest.

A range of different simple, low-cost physical and chemical treatment methods, together with systems for safe collection, handling and storage, have been developed which can be used to improve household water quality. Increasingly the potential for use of two or more treatments in combination or in succession as a means of optimising water quality is being considered. Some of these methods have been tested in the laboratory and field trials to evaluate their ability to produce drinking water of acceptable microbiological quality, and maintain quality during storage and use. Some have also been evaluated in the field for their ability to reduce diarrhoeal and other water-borne diseases. For the interventions that have been shown to be effective, the focus has now shifted to scaling up programmes which achieve uptake within target populations.

For promotion of household water treatment and safe storage to be successful, it must also involve community education, participation and motivation. This means stressing the role of contaminated water and domestic hygiene in disease transmission, as well as teaching families how to implement water treatment and safe storage. Strategies for promoting hygiene behaviour change have been the subject of much recent research and a number of practical guides are now available which give guidance on how to implement hygiene promotion activities. It is possible that communities already sensitised by promotion of handwashing, who have observed first hand the health impact of handwashing behaviours, are more likely to respond to promotion of water treatment and safe storage. In the same way, promoting water treatment and safe storage at household level is likely to increase overall community awareness of the importance of water, sanitation and hygiene and its contribution to infectious disease prevention and improved health. Recent research suggests that “positive” perceptions rather than negative attitudes are better predictors of whether people are likely to consistently treat their water, which suggests that educational and promotional messages should focus on positive ideas, such as clarity, taste, good health, affordability, and ease of use.

A key argument for promoting household water treatment and safe storage is that it can provide safe water to underserved populations much more quickly and affordably than it takes to design, install and deliver piped community supplies. Promotion of “point of use” water treatment has the potential to provide immediate benefit to at risk populations until the long-term goal of providing community water supplies can be achieved. It is important however that point-of-use water treatment is not seen as an alternative to the provision of safe community water supplies, and an argument for decreased investment in such programmes.

Amongst public health scientists and practitioners, there is now widespread consensus that one of the past mistakes in tackling infectious disease has been to give greater priority to provision of community water supplies over provision of sanitation, and to sanitation over hygiene. In reality it is hygiene practices such as handwashing and household water treatment and safe storage, safe handling and cooking of food etc that reduces the burden of infectious disease. The neglect of hygiene goes a long way to explaining why community programmes to provide water supply and sanitation have often not brought the expected benefits. Although there is awareness of the importance of increased emphasis on hygiene promotion, this does not necessarily translate into commitment to action by national and international governments and by non-government agencies. One of the significant barriers to progress in developing and promoting hygiene is the fact that, in most countries, the separate aspects of hygiene (faeces disposal, food and water hygiene, handwashing, care of the sick, childcare etc) are dealt with by separate agencies. If hygiene promotion is to be effective ideally there should be a single lead agency in each country, and appropriate infrastructure at national, district and local level which is specific for actioning hygiene programmes that promote hygiene at household level. Unfortunately also, public health authorities usually focus on municipal services, hospitals, etc. There is a reluctance to acknowledge the home as a setting of equal importance in the chain of disease transmission.

Although the Millennium Development Goals (MDGs) demand that the emphasis is on disadvantaged communities, where the prevalence of diarrhoeal is highest, this review shows that the need to promote hygiene practices related to household water treatment, and provide effective, affordable treatment methods, is by no means confined to the poorest communities:

- In many developing countries, water quality is a significant problem even for the most prosperous communities that have access to piped water supplies. A significant proportion of families in developing countries live in this situation and are forced to rely on purchasing bottled water, which they can ill afford.
- Across Europe there are still areas where treated community water supplies of adequate microbiological quality are unavailable. This applies particularly in regions of Europe where political and economic upheaval have led to infrastructure deterioration.
- In the US, Europe and elsewhere, “small water systems” are a significant problem, because the communities often lack the resources to maintain facilities and provide continuous supplies.
- Emergency situations require a prompt response. In these situations, household or community treatment of drinking water and safe storage may play a special role in preventing large-scale diarrhoeal disease outbreaks attributable to contaminated water.

The 2002 World Health Report lists unsafe water and sanitation as “one of the top ten risks to health globally and regionally”. The report concludes “very substantial health gains can be made for relatively modest expenditures on interventions such as micronutrients supplementation, treatment of diarrhoea and pneumonia and disinfection of water at the point of use, as ways of reducing the incidence of diarrhoea”. The report suggests that “point-of-use” water treatment is particularly cost-effective in regions of high child mortality”, and that “a policy shift towards household water management appears to be the most attractive short term water-related health intervention in many developing countries”. “This would complement the continuing expansion of coverage and upgrading of piped water and sewerage services which is naturally a long-term aim of most developing nations”.

I. INTRODUCTION

WHO data on the burden of disease suggests that approximately 3.2% of deaths (1.8 million) and 4.2% of disability-adjusted-life years (DALYs) (61.9 million) worldwide are attributable to unsafe water, sanitation and hygiene (WHO, 2004 [1]). This figure corresponds to 88% of diarrhoeal diseases worldwide which is considered to be the attributable fraction of diarrhoea due to unsafe water supply and sanitation plus the disease burden from trachoma, schistosomiasis, ascariasis, trichuriasis and hookworm disease. Several other water and sanitation-related diseases are not accounted in this figure, for example vector-borne diseases such as malaria and Japanese encephalitis which are linked to the development of water projects like dams or intensified irrigation schemes; and diseases related to chemical contamination such as unsafe concentrations of arsenic or fluoride in drinking water. An estimated 99.8% of such deaths occur in developing countries, and 90% are of children. For decades, universal access to safe water and sanitation has been promoted as an essential step in reducing this preventable disease burden. Despite this, a recent WHO/UNICEF report [2] estimates that up to 1.1 billion people still do not have access to “improved” sources of water for drinking, for example, a piped connection or a protected well. They also acknowledge that many of the remaining 5.2 billion people who use an “improved” water source nevertheless drink water which is unsafe, following contamination at source, in the piped distribution system or as a result of unhygienic handling during transport or in the home. Even in the European region it is estimated that 120 million people do not have access to safe drinking water. Consumption of unsafe water continues to be one of the major causes of diarrhoeal disease deaths [2].

In fact, the actual number of people who use microbiologically unsafe water is much higher than the estimated 1.1 billion. Although communities may have access to piped water at home, it may be contaminated by defects in the distribution system. Many communities have access to water that is microbiologically safe when collected or when it leaves a treatment plant. However, substandard water distribution systems, intermittent water pressure often lead to the introduction of faecal contamination resulting in microbiologically contaminated water at the consumer’s tap or collection point, even though the water may have been obtained from a high quality, protected and centrally treated source.

In addition water can become contaminated by unsafe consumer storage and handling practices at the household level. This can happen when:

- Water has to be collected from a communal source for domestic use. Many of the world's people continue to obtain their water on a daily or other frequent basis from any available source and either carry it or otherwise have it delivered to the home for personal use.
- The municipal water supply is intermittent and water has to be stored for significant periods in the home. Typically, this water is stored in containers of various designs, materials and sizes ranging from small earthenware or other vessels to relatively large underground or overhead tanks. Often, the water is not protected from subsequent contamination during use. Factors contributing to this problem are:
 - Inadequate protection (open, uncovered or poorly covered) of water collection and storage containers
 - Use of unhygienic methods to dispense water from household storage containers, including faecally contaminated hands and dippers
 - Lack of protection against contamination introduced by vectors (flies, cockroaches, rodents, etc.)
 - Inadequate cleaning of storage tanks to prevent biofilm formation and accumulation of sediments.

Studies which assess the extent and causes of microbiological contamination of household drinking water between source and point-of-use are reviewed by Sobsey [3] and Wright et al. [4].

In 2002, the UN Millennium Development Goals (MDGs) firmly established the issues of “water and sanitation” on the global agenda. However, there is widespread consensus that one of the past mistakes in tackling infectious disease, has been to give priority to water over sanitation and to sanitation over hygiene [5]. In reality it is keeping faecal matter away from hands, food and water, etc that reduces the burden of infectious disease (ID). The neglect of hygiene goes a long way to explaining why community programmes to provide water supply and sanitation have often not brought the expected health benefits. Where previously the emphasis has been on providing access to “water for all”, increasingly it is being argued that one of the keys to reducing the burden of water-borne ID is to incorporate promotion of hygiene practices such as handwashing and household water treatment and safe storage into programmes for provision of improved water supply and sanitation. It is suggested that a cost effective way to achieve “safe water for all” is through hygiene promotion,

whereby communities take responsibility for treatment and safe storage of water in their own homes. Given the present status of water quality of the municipal supplies in developing countries, it could be argued that for the underserved urban population, point-of-use treatment of water at the household level could provide more effective and prompt health benefits to the community.

Drinking water quality is a problem, in developing and developed country situations, most particularly in Eastern European countries, but also in North America and elsewhere. In European countries and North America, there are now fewer risks of epidemics related to drinking water contaminated with highly virulent pathogens such as cholera and typhoid or viral hepatitis, but it is worrying that there are still numerous instances of water-borne disease resulting from contaminated drinking water. Payment et al. [6,7] estimate that, even in developed countries, as much as 15-30% of community gastroenteritis is attributable to municipal drinking water, despite state of the art technology for water treatment, and no other evidence of unacceptable microbial contamination levels.

Although global investors such as World Bank and USAID focus on water, sanitation and hygiene promotion for the poorest communities, it is important to remember that hygiene promotion is a global concern affecting both developed and developing country situations. In the developed world, current concerns focus largely on foodborne, water-borne, and other infectious intestinal diseases, which remain at unacceptably high levels. They also relate to antibiotic resistance which compromises treatment of bacterial diseases, to viral agents which are not treatable by antibiotics, and to new agents (e.g SARS, avian flu) and their potential for rapid global spread. Pathogens are also now increasingly implicated as co-factors in cancers and some degenerative diseases.

Of particular concern, both in developed and developing countries, is the rising proportion of the population who are more vulnerable to infection [8, 9]. At risk groups cared for at home include not only the newborn whose resistance to infection is not fully developed, but also the rapidly increasing elderly population whose immune system is declining. It also includes patients recently discharged from hospital and family members who are immune-compromised resulting from treatment with immunosuppressive drugs. All of these groups, together with those who carry HIV/AIDS, are increasingly cared for at home by a home carer who may be a family member. A survey of 3 European countries, Germany, Netherlands and UK, suggests that up to 1 in 5 of the population in the home belongs to an “at risk” group. Immunocompromised patients are at risk of acquiring a wide range of potentially pathogenic micro-organisms from drinking water. This includes environmental strains such as pseudomonads and atypical mycobacteria. Ensuring that homecare is not accompanied by increased ID risks is key, otherwise cost savings gained by the trend towards shorter hospital stays are likely to be overridden by additional costs of re-hospitalisation. Colford et al. [10] recently conducted an intervention trial of home water treatment in San Francisco, California, from April 2000 to May 2001. Fifty HIV-positive patients were randomised to externally identical active (N = 24) or sham (N = 26) treatment devices. The active device contained a filter and UV light; the sham provided no treatment. There were 31 episodes of HCGI during 1,797 person-days in the sham group and 16 episodes during 1,478 person-days in the active group. The adjusted relative risk was 3.34 (95% CI: 0.99-11.21) times greater in those with the sham device. The authors also reported on an earlier trial which suggested an association (OR 6.76) between tap water and cryptosporidiosis among HIV positive persons.

As described more fully below, there is now conclusive evidence that simple, low-cost interventions at household level can significantly improve the microbial quality of household stored water. A range of different physical and chemical treatment methods, together with systems for safe water collection and storage, have been developed. Some have been tested in the laboratory and in field trials to evaluate their ability to produce drinking water of acceptable microbiological quality and to maintain this quality during storage and use. Some have also been evaluated in the field for their ability to reduce diarrhoeal and other water-borne diseases.

This report is a review of the ID risks related to water, with particular reference to “point-of-use” water in the household setting, and the health impacts of promoting water treatment and safe storage at the point-of-use. It reviews the various methods and systems for household water collection, treatment and storage, and critically assesses data on the ability of these systems, alone or in combination, to provide water of acceptable microbiological quality. Some of the formative research which is being carried out to better understand how to achieve behaviour change in the community with respect

to water handling, treatment and storage in the home, is also described. While toxic chemicals in drinking water are an important public health concern, the focus of this report is on strategies and systems for protection and improvement of the microbiological quality of household water and prevention and control of water-borne microbial diseases. However, some of the technologies that reduce water-borne microbes also reduce certain toxic chemicals, such as arsenic. Household water treatment and safe storage has also been recently reviewed by Mintz et al. [11] and Sobsey [3]. Further details on chemical contaminants in drinking water can be obtained from the WHO Guidelines for drinking-water quality. 3rd Edition, Vol.1 - Recommendations. 2004: http://www.who.int/water_sanitation_health/dwq/gdwq3/en/print.html.

Although this review focuses on the provision of “safe drinking water for all”, it is well accepted that this depends not only on the quality of the water source available to the community, but also on their hygiene practices (e.g. practices which keep faecal matter from re-entering water via hands etc). This in turn means that facilities for disposal of faeces and for handwashing are also likely to impact on household water quality: for homes where there is access to a latrine and a convenient source of water for handwashing, the risks of contamination of household water are lower than in homes where these facilities are not available. This means that sanitation and hygiene, as well as the quality of the community water source, are relevant to the problem of achieving and maintaining household water quality.

2. HOUSEHOLD WATER AND WATER-BORNE DISEASE: SITUATIONAL ANALYSIS

The vast majority of diarrhoeal disease in the world (88%) is attributable to unsafe water, sanitation and hygiene [12]. Although it is accepted that diarrhoeal disease is a huge problem worldwide, obtaining reliable data on the extent of diarrhoeal illness and the extent to which this illness is water-borne disease, is difficult. A recent estimate [13] suggested that residents of developed countries experience 1 episode of diarrhoeal illness every 2 years, whilst residents of developing nations may experience between 5 and 20 episodes per year. With a current global population 6.5 billion individuals this adds up to 5-60 billion gastroenteritis cases annually.

Diarrhoeal diseases, because they limit normal consumption of food and adsorption of nutrients can also cause malnutrition, leading to impaired physical growth and cognitive development, reduced resistance to infection and potentially long-term gastrointestinal disorders.

From a study of the global burden of diarrhoeal disease, as estimated from data published between 1992 and 2000, Kosek et al. [14] showed that, although mortality from diarrhoeal disease has declined, there is little change in morbidity rates compared with previously described incidences. They reported that, for children under 5 year of age in developing

Table 1. Disease burden from diarrhoeal disease: total deaths and DALYs for 2000

	Global	Africa	Americas	South East Asia	Europe	E. Mediterranean	W. Pacific
% of total deaths due to diarrhoeal diseases	3.2%	6.6%	0.9%	4.1%	0.2%	6.2%	1.2%
% of total DALYs lost due to diarrhoeal diseases	4.2%	6.4%	1.6%	4.8%	0.49%	6.2%	2.5%

areas and countries, there was a median of 3.2 episodes of diarrhoea per child year. Estimates of mortality revealed that 4.9 children per 1000 per year in these areas died as a result of diarrhoeal illness in the first 5 years of life, a decline from previous estimate of 13.6 and 5.6 per 1000 per year. The decrease was most pronounced in children under 1 year. The most recent estimates of mortality and morbidity associated with diarrhoeal diseases come from population data presented in the World Health Report [1] and from Pruss et al. [15] who used risk estimates from intervention studies to calculate the diarrhoeal disease burden. Data for the year 2000 from the World Health Report, as shown in Table 1, indicate that the highest levels of diarrhoeal diseases occur in Africa and the Eastern Mediterranean region.

Although consumption of unsafe water continues to be one of the major causes of diarrhoeal disease deaths, data on water-borne disease outbreaks are generally incomplete and inconsistent. It is often difficult to establish whether a disease outbreak is water-borne as opposed to foodborne. Most disease that can be spread by water is also spread through faecal contamination by other routes such as person-to-person contact and in contaminated food. Recorded cases of disease could therefore have resulted from any of these routes of infection.

Infectious diseases associated with water are generally classified according to whether they are water-borne (e.g cholera and typhoid), water-washed, water-based or water-related (e.g malaria and dengue fever) [16]. In this review we consider only the use of household water treatment and safe storage to prevent diseases which are water-borne, i.e which relate to the consumption of contaminated drinking water. Diarrhoeal disease from consumption of contaminated water can result from a whole range of pathogens, which may be bacterial, viral, protozoal or helminths as summarised in Appendix 1. It must be borne in mind however that point-of-use-treated water is sometimes also used for other activities in the home such as washing of eating utensils, particularly for example in emergency situations.

In the following section we review the available data on diarrhoeal disease incidence in developing and developed areas of the world, with particular reference to water-borne disease, where such data is available. Data on community water sources and community water source quality is also reviewed. The WHO/UNICEF 2004 report *Meeting the MDG Drinking Water and Sanitation Target, A Mid-Term Assessment of Progress* [2] reports that the percentage of people served with some form of water supply worldwide has reached 83% (5.2 billion), while 58% (2.6 billion) have access to basic sanitation facilities. The quality of these water supplies however varies widely and depends on many factors including the quality of the raw water source, the extent and type of treatment and disinfection used, the integrity of the distribution system and the maintenance of positive pressure within the network. Epidemiological studies on water-borne disease are also reviewed by Hunter [17] and Payment [18].

2.1 Water and infectious disease in developing country situations

2.1.1 Diarrhoeal disease burden

Although water-borne diseases are of immense public health importance in developing countries, there is however relatively little systematic data available on the overall incidence and prevalence of diarrhoeal disease in these areas, and on what proportion of this disease is water-borne. Todd [19] reported that very few countries in Africa or the Middle East have surveillance programmes which publish outbreak data on food and water-borne disease.

In a review of the burden of ID in South Asia, Zaidi et al. [20] reported that, although interventions targeted at diarrhoea and acute respiratory infection have resulted in a substantial decline in deaths in South Asian children, these diseases still account for almost half of all deaths (see Table 2). Salmonella is reported to be the most common bacterial pathogen identified from blood stream infections [21,22]. Millions of cases of typhoid infections occur each year, but reliable data of the annual number of cases are not available because laboratory identification is not routinely undertaken.

In India, massive programmes aimed at supplying potable water to urban as well as rural areas have been implemented by government in recent years. Despite this, however, morbidity and mortality due to typical water-borne diseases have not declined to an extent commensurate with the increase in availability of potable water supply. Data, as reviewed by Nath [24], show that, during the last 10 years, reported cases of diarrhoea, cholera, viral hepatitis and enteric fever have continued unchecked (Figure 1). In fact these reported cases are a gross underestimate of the real figures; community studies have shown that every child under 5 years of age has 2 or 3 episodes of diarrhoea each year. The data indicates

Table 2. Selected indicators of diarrhoeal disease in South Asian children

	Afghanistan	Bangladesh	India	Nepal	Pakistan	Sri Lanka
No of annual deaths*	60,240	82,320	576,480	18,240	135,600	<1,000
% of children <5y affected by diarrhoea in previous 2 weeks*	-	18	19	34	24	-
% of children <5y affected by diarrhoea in previous 2 weeks*	20	6	19	27	26	5
% receiving fluids plus continued feeding	33**	61**	27**	11	19	34**

*Extrapolated from Black et al. 2003 [23], **Data for oral rehydration therapy only

400,000 to 500,000 children aged under 5 years die annually from diarrhoea. The incidence of viral hepatitis is estimated at 12 cases per 100,000, although 2 studies in urban communities have shown that the actual incidence may be as high as 100 per 100,000. Rates of typhoid fever as high as 980 per 100,000 population have been reported from urban slums in Delhi. In reality these figures represent a significant underestimation of the true burden of water-borne disease in India.

For Brazil, Ribeiro [25] reports that most paediatric patients experience frequent acute diarrhoea episodes. In the North East (NE) region, an average 3-5 cases diarrhoea per child per year are reported. Although the duration of each episode is short, when the episode frequency is considered over the course of a year, this means that children in NE Brazil have diarrhoea 30% of the time. In a community-based study of diarrhoeal morbidity in a peri-urban community in Lima, Peru, Yeager et al. [26] determined that the mean diarrhoeal incidence was 8 episodes per child per year, with the highest rates, 10 episodes per child per year, in the age group 12-23.

Cholera is a water-borne disease which continues to ravage developing countries. According to the most recent global data [27], during 2003, 45 countries (developed and developing countries) officially reported to WHO a total of 111,676 cases and 1,894 deaths (see Table 3). The overall number of cases and deaths has declined compared with previous years and the case fatality rate has dropped to 1.74% but had remained high among vulnerable groups, with rates up to 41% in some countries. Africa reported a total of 108,067 cases, accounting for 96% of the global total. The number of cases reported from the Americas and Asia continued to decline (and Europe notified only imported cases). Globally, however, the actual figures are estimated to be higher owing to under reporting. For typhoid fever, the global incidence in 200 was estimated at 21,650,974 cases with 216,510 deaths [28].

Table 3. Cholera cases and deaths notified to WHO in 2003

Region	Cases	Imported cases	Deaths
Africa	108,067	0	1,884
Americas	33	4	0
Asia	3,463	18	10
Europe	12	12	0
Oceania	0	0	0
World Totals	111,575	34	1,894

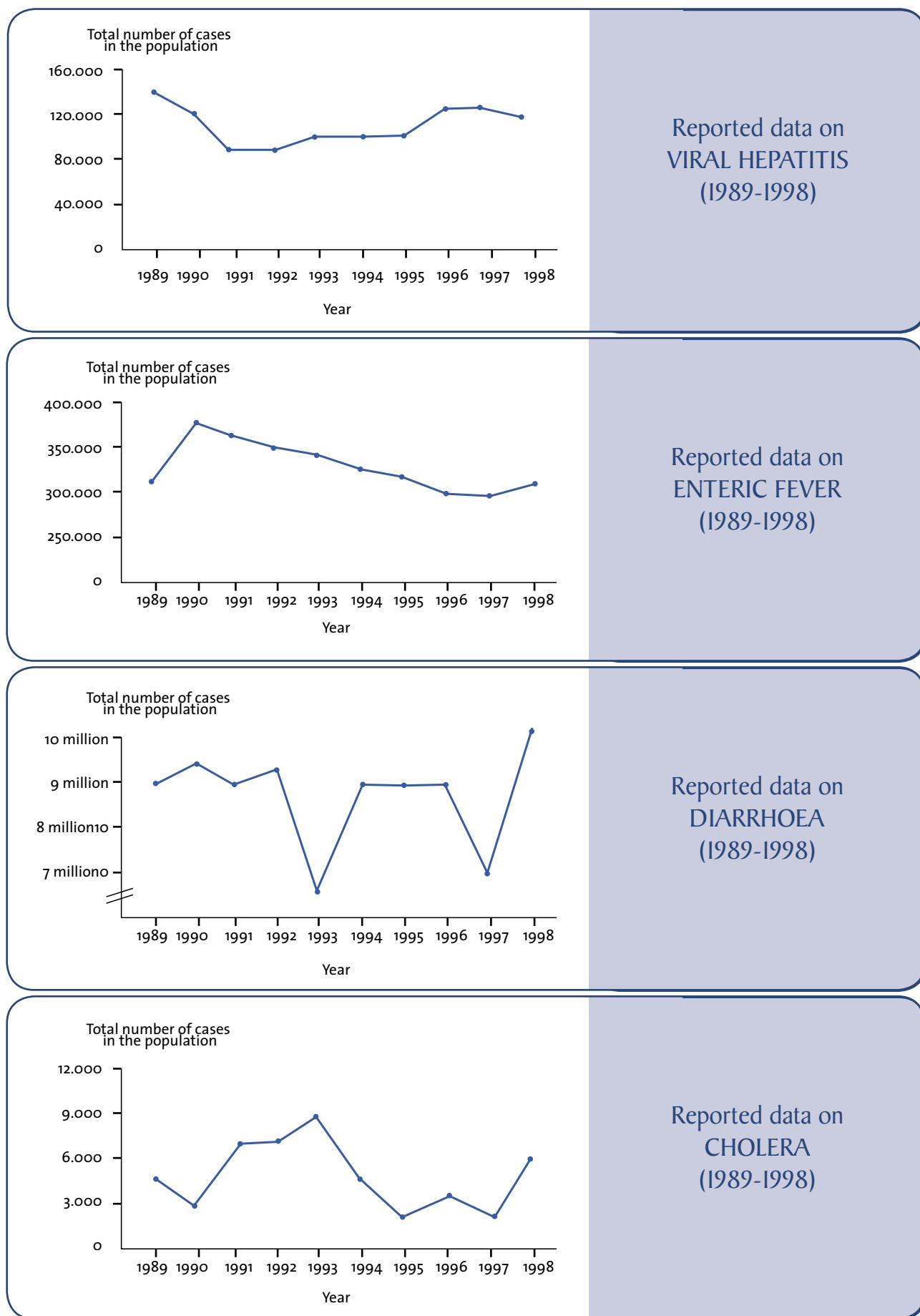
In a recent review Coker et al. [29] report that *Campylobacter* is one of the most frequently isolated bacteria from stools of people infected with diarrhoea in developing countries, a result of contaminated food or water. Generally however developing countries do not have national surveillance programmes for campylobacteriosis, therefore incidence values in terms of number of cases for a population do not exist. Most estimates of incidence in developing countries are from laboratory-based surveillance of pathogens responsible for diarrhoea. Table 4 shows isolation rates for some countries from studies of diarrhoea in children <5 years old ranging from 5 to 20 %.

Table 4. Isolation rates of *Campylobacter* from diarrhoea specimens from < 5 year olds in selected developing countries

Country	Isolation rate	Country	Isolation rate
Algeria	17.7%	Guatemala	12.1%
Cambodia	7.7%	Egypt	9.0%
Ethiopia	13.8%	Jordan	5.5%
Nigeria	16.5%	Bangladesh	17.4%
Tanzania	18.0%	Thailand	13.0%
Zimbabwe	9.1%	Laos	12.1%
Brazil	9.9%		

In addition to endemic levels of diarrhoeal disease in developing countries, large scale outbreaks attributable to contaminated water are sometimes reported, such as the hepatitis outbreak in India [30] and the outbreak of cholera in Latin America [31]. The effect of extreme conditions on water quality which may be seasonal or related to natural disasters, is also a significant factor which may be underestimated [30].

FIGURE I. Incidence of water-related infectious diseases in India 1989-1998



Source: Nath [24]

2.1.2 Water supply and sanitation coverage

Global assessments by the WHO and UNICEF in 2004 [2, 32] (Table 5), shows the distribution of child mortality against access to improved water and sanitation across the different regions of the world. It is interesting to note that China showed the lowest rates of child mortality whilst also having the lowest rates of sanitation coverage. Estimates of water

Table 5. Regional child mortality and select determinants

	India	China	Other Asian countries	Latin America/ Caribbean	Middle Eastern Crescent	Sub-Saharan Africa
Child mortality – under 5 (per 1000 live births) in 1999	90	37	65	38	92	166
Access to improved water source in 2000 (% of total population)	88%	75%	78%	85%	83%	54%
Access to sanitation in 2000 (% of total population)	31%	38%	66%	78%	76%	54%
Access to improved water source in 2002 (% of total population)	86%	77%	South-Eastern Asia 79%	89%	88%	58%
Access to sanitation in 2002 (% of total population)	30%	44%	61%	75%	79%	36%

and sanitation coverage by region and by country can be obtained from the WHO/UNICEF 2004 report *Meeting the MDG Drinking Water and Sanitation Target, A Mid-Term Assessment of Progress* [2]. The report shows substantial gains in drinking water coverage between 1990 and 2002. In India alone, drinking water coverage increased from 68 to 86%. This report shows that, of the 1.1 billion people using water from unimproved sources, nearly two-thirds live in Asia. The lowest drinking water coverage levels are found in sub-Saharan Africa and Oceania (58 and 52% respectively). By contrast, several regions including Northern Africa, Latin America and the Caribbean and Western Asia have achieved coverage levels close to 90% or more.

2.1.3 Reliability and adequacy of community water supply

As stated previously, it is likely that the proportion of the populations using safe drinking water is lower than that using “improved water supplies”. The coverage figures, as shown in Table 5, give some idea of the efforts undertaken by national governments and international organizations to extend community water supply services to unserved populations during the 1980s and 1990s, but they do not convey the full picture. In many countries in the region, particularly those with high human poverty index and low GDP (Bangladesh, Bhutan, India, Indonesia, Myanmar and Nepal), providing a street standpost in the vicinity of urban slum or squatter colony or the presence of a bore-well or protected dug-well in a rural community, qualifies the population as covered. However it often does not guarantee a reliable and continuous supply of adequate water in terms of either quantity or quality. In a country like India with the official figure of 96% [32] urban water supply’ coverage, it is still a common sight in cities like Kolkata or Mumbai to see people queuing up for a street standpipe, which has hardly any water pressure.

In a study of rural and peri-urban communities in Northern Sudan, Musa et al investigated water quality at the source and point of consumption [33]. Among nomadic pastoralists and riverine villages, both water sources and water stored for consumption had faecal coliform counts grossly in excess of WHO standards, with higher counts at the end of the rainy season. In the peri-urban community on the outskirts of Omdurman, while water quality from the distribution system had faecal coliform counts generally below 10 dl⁻¹, after storage, water was of considerably lower quality, with faecal coliform counts up to 1000 dl⁻¹.

The validity of national figures for urban water supply coverage also appear questionable when they are compared with city-specific coverage figures. For example it is reported that population coverage in Jakarta, Colombo, Kolkata and Bangalore is 27%, 58%, 66%, and 70% respectively, while the reported national water supply urban coverage figures for Indonesia, Sri Lanka and India are 89%, 99% and 96% respectively [2]. As such, it is difficult to reconcile the country coverage figures with those of cities/towns. It appears that while computing urban water supply figures for the country, the unserved and underserved areas of the cities and towns have not been given due weight.

Discontinuity of the water supply is also a problem in South Asia. According to the Asian Development Bank (Anon, 1997), cities worst affected include Kolkata (10h/ Day), Chennai (4h/day), Delhi (4h/day) and Kathmandu (6h/day). Data on water supply coverage and availability for 5 Indian cities is shown in Table 6.

Cities	Coverage (%)	Availability (hours)	Consumption (Ltr/capita)	Demand (million Ltr)
Calcutta	66	10	209	125
Chennai	97	4	80	600
Delhi	86	4	200	3600
Mumbai	100	5	178	3200
Bangalore	70	2.5	105	970

Source: Asia Development Bank [34]

2.1.4 Water quality of public and municipal supplies in developing countries

Although the WHO/UNICEF survey data showing trends in access to improved drinking water sources is a good indicator of progress, it is not a direct measure of progress in achieving “safe water for all” since it does not provide information on the quality of water, either at source or at household level. The Joint Monitoring Program, on which the survey is based, recognises that even sources that meet the definition of “improved” do not necessarily provide drinking water that is microbiologically safe [2]. In response to this need for such data, WHO and UNICEF are conducting a pilot study to develop procedures for monitoring drinking water quality. The study is being carried out in China, Ethiopia, Nicaragua, Nigeria and Tajikistan.

Data from the South East Asia Region (SEAR) gives some idea of the microbiological quality of water which is available to the community. According to unpublished data reported to WHO in 1999 [35], only half of SEAR countries (India, Maldives, Nepal, Sri Lanka and Thailand) reported that disinfection was practiced in all urban water distribution systems. Only two countries (Maldives and Thailand) satisfied the dual criteria in urban systems of universal disinfection and continuous positive pressure in distribution. Only four SEAR countries reported adopting national drinking water quality standards equivalent to the WHO guideline values, and two reported adopting standards that are less stringent. The remaining four SEAR countries reported having no national drinking water standards. In most SEAR countries drinking water quality surveillance is the responsibility of the health authorities. Irrespective of the institutional responsibility for

drinking water quality surveillance, it remains a function that is seldom fulfilled in SEAR countries. In most rural systems it is non-existent. In a survey in some 50 water utilities in 31 Asian countries, 33% of domestic consumers reported that they drank tap water without boiling, yet 80 percent considered that the water was of acceptable quality [34].

In 2004 the National Environmental Engineering Research Institute (NEERI) reported the results of a study of municipal drinking water supplies in a number of major cities in India [36]. Samples were taken during early and later monsoon seasons from homes in low and high income groups, and also from nearby villages. The results (Table 7) showed that a significant proportion of samples were contaminated with faecal coliforms (including *E. coli*), and that some samples were also contaminated with *Entamoeba histolytica* and *Giardia Lambli*a.

Table 7. Bacteriological contamination of municipal tap water in Indian cities

City	Number of samples +ve/number of samples processed			
	Faecal coliforms	E-coli	Entamoeba histolytica	Giardia lamblia
Ahmedabad	26/96	14/96	6/18	5/18
Kolkata	50/88	6/88	3/9	0/9
Chennai	50/89	47/89	3/18	1/18
Cochin	93/104	68/104	5/12	1/12
Delhi	16/86	8/86	4/11	1/11
Hyderabad	39/78	34/78	4/11	1/11
Jaipur	42/91	26/91	1/10	0/10
Kanpur	37/84	20/84	2/10	1/10
Mumbai	59/242	20/242	0/10	0/10
New Mumbai	22/88	15/88	9/24	1/24
Thane	26/84	16/84	-	-
Nagpur	84/84	75/84	7/17	1/17

Source: Kumar [36]

In a sample survey conducted in Kolkata [24] it was observed that most of the population in urban and rural areas used piped water or ground water (tube well water) for drinking. The quality of the water from these sources is variable as shown in Table 8.

Table 8. Sources of drinking water according to different sectors of the population in Kolkata

	Source of drinking water according to Population sector				% of samples faecally-contaminated
	Higher Income	Middle Income	Slum	Rural	
Municipal community piped water supply	63%	17%	23%	5%	>20%
Hand pump tube wells	37%	83%	77%	83%	>20%
Open wells	0	0	0	12%	85%
Village ponds	0	0	0	0%	100%
Household water reservoirs, household taps in-house water containers etc	-	-	-	-	>60%

Source: Nath [24]

In a more recent study reported by Nath [37] of the municipal water supply system in Kolkata (Table 9) which included consumer points in the distribution system, overhead/ underground reservoirs in houses, hand pump-operated shallow bore-wells and deep tube wells, it was found that, on average, more than 50% of the samples were bacteriologically contaminated. Presence of salmonella was found in 50% of the contaminated samples, 42% contained staphylococcus spp, and in 14% of samples, Shigella spp were found. It is also interesting to note that contamination levels were highest in the household tanks.

Table 9. Water quality status of Kolkata city

	Deep tube-well (owner's own)	Municipal consumer points	Municipal hand pumps	Overhead/ Underground tank inside houses
No. of samples collected	40	600	150	200
No. of samples bacteriologically contaminated	27.5%	63.66%	24.66%	87.5%

Source: Nath [37]

A survey of viral contamination of drinking water taken from taps in the city of Chennai, India, gives some idea of the problems related to viruses [38]. In this study, 50 drinking water samples were collected in different places of Chennai and evaluated for the presence of rotavirus, Hepatitis A virus and Hepatitis E virus. Thirty-nine of 50 samples (76%) tested positive for the presence of Hepatitis E virus, 33 of 50 samples were positive for the presence of hepatitis A virus, and 32 of 50 samples (64%) were positive for rotavirus sequences.

It is most unfortunate that in many cities and towns of the SEAR countries, faecal contamination of distribution systems including domestic reservoirs has been accepted by people with a sense of resignation and the consequent faecal-oral infection of diarrhoeal diseases as a fact of life. In urban systems many consumers are so used to poor service that they refuse to drink municipal tap water. In a consumer survey carried out by the ADB, which obtained data from 100

randomly selected customers in some cities in 31 Asian countries (including many in SEAR), only 33% of domestic consumers reported that they drank water directly from the tap. In a similar survey in Kolkata, less than 25% of surveyed households used municipal tap water without any treatment. Those who can afford it are increasingly using bottled water. It is quite apparent that the lack of water quality management is affecting the poor and the lower middle class groups the most.

2.2 Developed country situations

In general, it is assumed that treated community water supplies in developed countries are of high microbiological quality and therefore safe with respect to water-borne microbial disease risks. As described below, this is not necessarily the case, particularly in regions of Europe where political and economic upheaval have led to infrastructure deterioration, but also in areas where communities rely on small water supplies.

Of significance also is data which showed increased risks of water-borne gastrointestinal illness from a centralised community water supply system in Quebec, Canada, where water was extensively treated by modern methods and met all microbial quality requirements [6, 7]. These findings suggest that bacterial indicators used to assess water quality were inadequate or that pathogens, at levels below detection but high enough to cause measurable gastrointestinal illness, either penetrated the multiple treatment barriers or entered the treated water subsequently in the community distribution system or within household plumbing. Hence, in developed as in developing country situations, there are indications that even extensively treated community drinking water of high microbiological quality and assumed to be of low risk may still be contributing significantly to community diarrhoeal illness.

2.2.1 Europe

In 2002 WHO published a report entitled *Water and Health in Europe* [39]. The following section summarises some of the key findings from this report related to the incidence of water-borne diarrhoeal disease, water coverage and water quality across the region.

2.2.1.1 Diarrhoeal disease

Although water quality standards are high in most countries, outbreaks of water-borne disease continue to occur across Europe. Standards for public drinking water supplies vary considerable across the region. In most Western European countries, it was found that the percentage of drinking water samples exceeding national standards for total and faecal coliform bacteria was less than 5%, but for many Eastern European countries figures of between 5 and 15% were recorded. Of particular concern are the “small private supplies” e.g in a 1999 survey the percentage of samples taken from private supplies exceeding national limits for total coliforms in Ireland, Croatia and Lithuania was reported at 47, 30% and 55% respectively.

For the period 1986 to 1996, surveillance data from 17 countries in the European region reported a total of 2,567,210 cases of gastrointestinal disease, 2% of which were linked to drinking water (see Table 10). These 17 countries (estimated population 220 million), on average, reported 233,383 cases of gastrointestinal disease per year. These figures are much lower than the data recorded for the US (estimated population 267 million) where the estimated number of cases of foodborne disease alone (i.e not including e.g water-borne disease and GI disease transmitted from person to person) is 6-80 million. Thus the European data most likely underestimates the true incidence of gastrointestinal illness in the reporting countries. This conclusion is further supported by recent surveys in the UK and Netherlands [40,41] which show that food borne disease may be 200-350 times more frequent than reported cases tend to indicate. It appears that the number of outbreaks of water-borne diseases has been increasing in countries which have experienced recent breakdown in infrastructure, although reliable data on drinking water quality and the incidence of disease in most countries are lacking.

For 1984 to 1996, 710 water-borne disease outbreaks were reported. Of these, 55% occurred in rural and 45% in urban areas; 36% of outbreaks were associated with public water supplies, 18% with individual water systems, 6% with standpipe public supplies and 41% with unspecified supplies or recreational water. Remarkably, no outbreaks were reported in Germany, Lithuania or Norway, whereas 208, 162 and 53 outbreaks respectively were reported for Spain, Malta and

Table 10. Reported cases of gastroenteritis or other possibly water-borne diseases linked to drinking water in 17 European countries 1986-1996

Causative agent	Total number of cases reported	No (%) of cases linked to drinking water
Bacteria: bacterial dysentery, cholera, typhoid fever, Salmonella, Campylobacter	534,732	15,167 (2.8%)
Viruses: hepatitis A and norovirus	343,305	6,869 (2.0%)
Parasites: amoebic dysentery, cryptosporidiosis, Giardiasis, meningoencephalitis	220,581	4,568 (2.1%)
Unspecified cause: gastroenteritis and severe diarrhoea	146,171	22,898 (1.6%)
Total	1,244,789	49,502 (4%)

Sweden. These differences are most likely due to differences in detection and reporting (e.g. some countries do not report water-borne diseases) rather than real differences. As shown in Table 10, cases of water-borne disease attributable to bacteria include bacterial dysentery (*Shigella* spp.), cholera, typhoid fever, *Salmonella* and *Campylobacter*. Since its emergence in the 1970s, *Campylobacter* has become one of the predominant foodborne pathogens, but water-borne outbreaks are also quite frequently reported for this pathogen, which usually occur when surface water becomes contaminated with sewage from farm animals and wildlife. Six outbreaks were recorded in Sweden between 1986 and 1996. *Campylobacter* outbreaks are most often associated with wells providing private supplies. These small rural systems are most likely to be contaminated with animal waste. For the same reason *E. coli* 0157 outbreaks may be found in rural situations.

The number of cases of amoebic dysentery in countries which maintain records is generally low; in 1996 the number of cases per 100,000 population ranged from <1 in countries such as Hungary, Lithuania and Austria to between 1 and 5 in UK, Sweden, Norway and Finland. By contrast, outbreaks of *Shigella* dysentery are regularly reported in many countries, the number of cases per 100,000 population ranging from <10 for countries such as UK, Austria, Norway, Germany and Belgium to between 10 and 70 for Romania, Estonia, Lithuania, Slovakia and Albania. Cholera epidemics have re-emerged since 1991 in traditional cholera-free areas, although the number of reported cases in European countries is low, and all of these are estimated to be imported from elsewhere. The incidence of typhoid fever is low in most European countries that keep records and, as with Cholera, a significant proportion of recorded cases are imported; during the last decade Albania, Croatia, Romania, Slovakia, Greece and Spain have reported cases of typhoid fever linked to water.

Of the water-borne diseases attributable to viruses, outbreaks due to hepatitis A and norovirus are quite frequently recorded in the European region, although the incidence varies widely between countries. Outbreaks due to norovirus have been a significant concern in Norway and Sweden. As part of an intensified monitoring program for foodborne disease outbreaks in Finland, water-borne outbreaks were investigated for viruses. Of the total 41 water-borne outbreaks reported during the observation period (1998–2003), samples from 28 outbreaks were available for analysis. As judged by RT-PCR results from patient samples, noroviruses caused 18 outbreaks. In 10 outbreaks, the water sample also yielded a norovirus. In all but 1 instance, the amplicon sequence was identical to that recovered from the patients [42].

Inadequate removal of *Cryptosporidium*, and less frequently *Giardia* and *Toxoplasma*, have led to outbreaks when chlorination has been the only barrier or sand filters have become contaminated. *Cryptosporidium parvum* infection occurs across the region; from 1986 to 1996, 13 outbreaks of cryptosporidiosis were recorded in England and Wales. Outbreaks related to *Giardia* are also reported, although the contribution of water-borne infection to the total disease burden varies significantly between years. In Sweden more than 23,000 cases were recorded between 1990 and 1996; in 1990 and 1991 water-borne outbreaks comprised less than 1% of total infection, whilst in 1996 the figure was 14%. Similar variations were reported in Slovenia. Infection by water-borne helminths is not a significant concern in most parts of the European region.

2.2.1.2 Water supply coverage

Towns and cities of Europe are generally well supplied with running water. Installing a water network is a large capital project and, once installed, maintenance is required to ensure its efficient operation, Financial restrictions may prevent the installation of a distribution system or result in the deterioration of a network already in place. The quality of community drinking water supplies depends on many factors, including the quality of the raw water source, the extent and type of treatment and disinfection used, the materials integrity of the distribution system, and the maintenance of positive pressure within the network.

By contrast with urban populations, rural populations are less likely to have piped water and house connections, and as a result have to rely on small private non-piped supplies. This is not always the case however: for example, similar proportions of the population of Croatia and Finland are rural (about 35%), but 87% of the population of Finland is connected to a public water supply (1996 data) compared to only 70% of the population of Croatia (1997 data). The proportion connected to public water supplies can also vary between different areas of the same country. For example, 78% of the population in the NE part of Italy is connected to a public supply, compared with only 27% of the population of the Italian islands. In some countries, all the rural population is connected to home water supply. This is the case for example in Iceland and Norway. In contrast, the homes of as few as 5 and 12% of the rural population of Turkmenistan and Ukraine respectively, are connected to a water supply. In Romania 84% of the urban population is supplied by the centralised system versus 32% of the rural population.

Community managed (private) supplies are usually wells or boreholes supplying residents with groundwater. However the wells may be very shallow and therefore prone to contamination from the surrounding agricultural land and from excreta. In some countries, water supplies from shallow wells close to surface waters are commonly used. This rudimentary bank filtration may also be prone to contamination.

Some countries in Central and Eastern Europe, including some newly independent states, provide continuous public water supplies, whilst some areas in a number of European Countries do not receive a continuous supply of water. Satisfactory treatment of water for potable supply and maintenance of the distribution network are compromised in many European countries, particularly in the Eastern part of the region, by financial limitations or a shortage of human or technical resources.

2.2.2 North America

2.2.2.1 Diarrhoeal disease

In the USA most citizens expect to have low cost, high quality water available in their domestic water tap. However, water-borne disease outbreaks still occur in the USA providing a reminder that contaminated water continues to pose health risks even in developed countries. Table 11 summarises the number of reported outbreaks of disease associated with drinking water for the years 1999-2002, and the etiological agents responsible for these outbreaks (Anon 2000 [43, 44, 45]).

In a 2005 review article [46], Shuster reported that 288 known outbreaks occurred during the period 1974-2001. Ninety-nine, 138 and 51 of these outbreaks occurred in municipal, semi-public (facilities with own supply serving the public, for example schools, hotels, nursing homes, etc. in rural areas) and private supplies respectively.

In the US and Canada, a number of outbreaks have been reported which show that household water treatment is important not only as a routine measure for those who do not have access to good quality water, but also in controlling outbreaks which result from a breakdown in the system. In the spring of 2000, residents of Walkerton, Ontario, were exposed to contaminated drinking water after heavy rains compromised the municipal well and the water treatment process. In all 23,000 cases of *E. coli* O157 and *Campylobacter jejuni*, and 7 deaths, were recorded [47]. *Cryptosporidium parvum* was not recognised as a human pathogen until the 1970s. One of the largest recorded water-borne outbreaks occurred in Milwaukee, USA, during 1993. The outbreak occurred because one of the city's water treatment plants failed to filter out the parasite from the untreated water. The outbreak affected some 400,000 people with 54 deaths [48].

Table 11. Infectious disease water-borne outbreaks caused by contaminated drinking water systems in the United States

Etiological agent	1971-1994	1999-2000	2001 - 2002
Total outbreaks	579	36	20
Total cases	560,421	2,068	1,020
% outbreaks for which organism was isolated	325/579	56.4%	13/20
Salmonella	13	2	-
Shigella	40	0	-
Campylobacter	15	2	2
E. coli O157	-	4	1
Cryptosporidium	10	1	1
Giardia	113	6	3
Hepatitis A	28	0	-
Norovirus	20	4	5
Naegleria fowleri	-	-	1

2.2.2.2 Water supply coverage and small water systems

In the US most of the population receive their water from community systems, but these vary considerably in the number of people they serve [49, 50]. A particular problem in the US arises from “small water systems” (i.e systems serving 10,000 or fewer people). The infectious disease risks from faecally contaminated and microbially unsafe water is considered to be greater for the water supplies of smaller communities than the larger ones. Small communities face the greatest difficulties in supplying water of adequate quality and quantity because they have small customer bases and often lack the resources needed to maintain and upgrade water supply facilities. Small water systems may also be less likely to be adequately chlorinated and routinely monitored for contaminants. Interruptions in supply as well as violations of drinking water standards are problems for some of these systems. Although the problems of supplying water through small systems are well known, the number of small water systems continues to increase. In 1993 there were 54,300 of these systems. Olsen et al 2002 [51] maintain that small water systems collectively serve approximately 40 million people, or 15% of the USA population. This contrasts significantly with other countries e.g in England and Wales, 10 regional water organisations and 22 water companies provide water and sewerage for 99% of the 50 million population. Issues related to small water systems are further reviewed in a US National Research Council Report [49].

Most water-borne outbreaks in the USA are due to systems with no or inadequate treatment, vulnerable watersheds and aquifers, distribution system deficiencies and serving smaller communities. Olsen et al [51] reported that, of 18 water-borne outbreaks of *E. coli* O157:H7 infections reported to CDC from 1982-1998, 5 were caused by contaminated drinking water. All 5 outbreaks involved small water systems or wells that supplied rural areas or camps. Olsen et al. maintain that, because of under-reporting and under-diagnosis, reported outbreaks probably represent only a small fraction of the true number of *E. coli* O157:H7 outbreaks associated with drinking water in the USA.

In the US the drinking water systems are monitored for coliform bacteria. Most violations for the maximum contaminant level for total coliforms occur in ground water systems or in small systems serving 500 or fewer people. The total recorded number of violations for total coliforms between 1992 and 1994 was 23.5%; violations for systems serving populations serving communities of 500 or less was 29.5% as compared to 14.4% for systems serving 10,000 people.

Approximately 27.5 million Canadians (87% of the population) have access to safe drinking water provided by centralised treatment plants or through individual systems whose construction and operation are subject to regulatory requirements. The remaining 3.8 million Canadians rely upon private supplies, typically groundwater. Monitoring of these supplies is the responsibility of the homeowner but the provinces and territories provide advice and free or subsidised water quality testing. Approximately 150 small, remote Northern communities rely upon trucked water and home storage in cisterns. The vast majority of these are First Nation communities [46].

3. FIELD STUDIES OF THE HEALTH BENEFITS OF PROMOTING INTERVENTIONS IN THE HOME TO ACHIEVE AND MAINTAIN WATER QUALITY

In deciding how best to reduce the burden of diarrhoeal diseases (both in developed and developing countries), one of the key needs is to make a quantitative assessment of the health impact of promoting household water treatment and safe storage, relative to the impact of providing improved community water sources. It is also necessary to assess the health impact of interventions which focus on household water quality, relative to that which would result from programmes which focus on improving sanitation facilities or which promote hygiene practices such as handwashing.

In 1991, Esrey et al. made an assessment of 144 published studies to determine the impact of improving the quality of the community water supply and sanitation [52]. Their overall assessment, based on this data, was that improved access to water, together with improved hygiene and sanitation, are key to reducing diarrhoeal and other water-borne and water-washed diseases. They also concluded that, in this respect, water quantity may be more important than safe water.

The evidence linking the quality of point-of-use drinking water, as opposed to source water, and diarrhoeal disease has been recently reviewed by Trevett et al [53]. In this review the authors develop a conceptual framework to evaluate the principle factors which determine the pathogen load in household (as opposed to source) drinking water in the light of current literature and field observations in rural communities in Honduras. The authors conclude that there is considerable evidence to indicate that “recontaminated” drinking water represents a significant health risk particularly to infants, but also to those with secondary immunodeficiency. They argue that, most particularly, the type of storage container, and hand contact with drinking water, is associated with increased risk of disease, but that there is also circumstantial evidence linking factors such as sanitary conditions, cultural norms and poverty with the pathogen load of household drinking water.

Since the review of Esrey et al., many additional intervention studies involving improvements in drinking water, sanitation and hygiene practices in less developed countries have been reported. In this section we review some of the most recent studies which have been carried out to evaluate the relationship between drinking water supply contamination and diarrhoea. These studies cover a range of different treatments, alone or in combination with systems designed to achieve safer storage. Most of the studies relate to point-of-use water treatment in the home. All but one study were carried out in developing country situations under non-epidemic conditions and cover both urban and rural situations. Quantitative assessments of the health impact of these interventions, using combined data from these studies, are described in section 4.

3.1 Treatments to improve community water source

Three studies are reported in which the intervention was aimed at improving the quality of the water source. **Ghannoum et al. (1981) [54]** evaluated the impact of installing water treatment plants on the incidence of water related diseases in the Brak area of Libya over a 3-year period. Significant reductions in bacillary and amoebic dysentery (59% and 10% respectively) and some reduction in hepatitis were recorded, but no impact on Giardia infection. More recently, **Jensen et al. (2003) [55]** carried out an intervention study in rural Pakistan which involved chlorinating the public water supply system to evaluate the importance of public-domain transmission of pathogens in drinking water. Drinking water quality and the occurrence of diarrhoea were monitored weekly over 6 months during 1988/9. The study involved 2 villages that regularly used ground water for drinking rather than water from the water supply system. There were 82 children under 5 in the village where the intervention took place and 144 children in the control village. Despite the improvement in drinking water quality, the incidence of diarrhoea was not lower than in a neighbouring village where drinking water

was not chlorinated and where water quality was poor. Similarly a study by **Gasana et al. (2003)** [56] in a population of 3,062 people in Rwanda suggested that interventions to improve the microbiological quality of the community water supply had no significant impact on diarrhoea morbidity.

3.2 Point of use interventions involving boiling or pasteurisation, filtration, UV and solar disinfection

Sathe et al. (1996) [57] described a study of 1195 participants from 274 urban middle class families in Pune, India over a 1 year period. The study showed that the incidence of reported diarrhoea was lower (mean incidence 0.26 episodes per person) in the non-users of treatment than amongst those who boiled water or used commercially available water purifier systems (filters, ion exchange and UV irradiation equipment) where the mean incidence ranged from 0.319 to 0.757 episodes per person. The authors could find no explanation for these results, although there was no data to indicate the relative quality of the household water in relation to the method of treatment.

Conroy et al. (1996) [58] described a 12 week study carried out with 206 Maasai children, 6–14 years old, in Kenya. The children were allocated plastic water bottles that were filled with water from the local source. The test group were instructed to expose the water to sunlight on the roof of the house whilst the control group kept the bottles indoor in the shade. Among the 106 children allocated to solar disinfection diarrhoea was reported on 439 occasions (average 4.1 episodes per child) compared with 444 episodes were reported for the 98 children in the control group (average 4.5 episodes per child). After adjustment for age, solar treatment of drinking water was associated with a reduction in all diarrhoeal episodes (odds ration 0.66) and in episodes of severe diarrhoea (0.65). In a 1 year follow up study, by Conroy et al. [59], of 349 Maasai children younger than 6 years, again children drinking water which had been disinfected by exposure to solar radiation had significantly fewer episodes of diarrhoea than the control group (odds ratio 0.69). In a further study [60], the impact of solar disinfection on incidence of cholera was measured in 131 Maasai households. There was no significant difference in the risk of cholera in adults or older children in households randomised to solar disinfection; however there were only 3 cases of cholera in the 155 children aged <6 years drinking solar disinfected water compared with 20 out of 144 controls.

Lijima et al. (2001) [61] describe a 4 month study on the effects of heat treatment of water in 4 rural villages in Kenya where the main source of water was well, pond or river water. A simple thermoindicator which changes colour at 70°C was used as the indicator that the process was successfully completed. The number of households in which drinking water was free from coliforms increased from 10.7% to 43.1% after adoption of the heat treatment pasteurisation practice. The incidence of severe diarrhoea reported during the study period was 45 in the intervention group (209 households, 1,779 people) compared with 74 cases in the control group (192 households, 1,641 people). The incidence of diarrhoea was significantly lower in the intervention group (odds ratio 0.55).

Colwell et al. (2003) [62] reported a study on the effects of water filtration on the incidence of cholera in Bangladesh villages. These workers devised a simple cloth filtration system (sari or nylon) which was effective in removal of *Vibrio cholera*, associated with zooplankton, from the untreated surface water or tubewell water which was collected for household use. The intervention was tested over the period July 2001 to July 2002 in 65 rural villages (25 villages in the nylon group, 27 in the sari group and 13 in the control group), with a population of about 44,000 individuals in each of the 3 groups. The workers reported a high acceptance and compliance by the villagers of water filtration. Overall the workers reported a 43% reduction in the incidence of cholera in the test groups compared with the control group. The number of cases per 1,000 population was reduced from 1.16 in the control group to 0.65 in the sari group and 0.79 in the nylon group.

3.3 Interventions involving safer storage of household drinking water

Roberts et al. 2001 [63] conducted a 4 month trial in a Malawi refugee camp that had experienced repeated outbreaks of cholera and diarrhoea, to evaluate the health impact of promoting the use of a covered water container with a spout as a means of keeping water clean during transport to, and storage in the home. The water from the source wells had little or no contamination, but quickly became contaminated, mainly through contact with the hands. Analysis of samples of the household water showed that there was a 69% reduction in mean faecal coliform levels amongst the group using the improved bucket system. Associated with this, the 301 study participants who received the improved container experienced 60 episodes of diarrhoea during the test period (an attack rate of 44.5 episodes/1000/month) whilst the 950 control participants in control households experienced 207 episodes of diarrhoea (an attack rate of 48.6 episodes/1,000/month). Thus the improved container users experienced 8.4% fewer diarrhoeal episodes. Although this figure is not statistically significant, when the diarrhoea rate was compared for children under 5 a significant reduction of 31% in the incidence of diarrhoeal disease was observed (84.3 episodes/1,000/month compared with 122.4 episodes/1,000/month). To evaluate the source of contamination in the household water, the fingers of 10 women using the control bucket, and their buckets, were rinsed with 125ml water at the time of arriving at the well. On average 2,000 faecal coliforms were recovered from the hand rinse and 300 coliforms from the bucket rinse. Interestingly, before the women filled their buckets, they almost always rinsed it with a small amount of water, and rubbed their hands around the inside of the pail.

3.4 Interventions involving chlorination alone or in combination with improved storage

Kirchoff et al. (1985) [64] reported an 18 week blind cross over study of the impact of in-home water chlorination in 20 families (112 participants) in 12 rural villages in Brazil where there were known high rates of diarrhoea in children and high levels of faecal coliforms in household water. Household water came from a pond and was stored in clay pots. The chlorination was carried out by a trained fieldworker who established that the mean faecal coliform count in the chlorinated household water was significantly lower than in the untreated water (70 compared with 1500 organisms/dl). People drinking the treated water had a mean of 11.2 days of diarrhoea per year; the highest rate of 36.7 days of diarrhoea per year was amongst children less than 2 years old. Diarrhoeal rates were not significantly lower in the group who used the chlorinated water

In 1995, a study was reported by **Mahfouz et al. (1995)** [65] that evaluated the impact of chlorination of water in domestic storage tanks on childhood diarrhoea in 9 rural communities in Saudi Arabia. The 6 month study involved 171 families (159 children) who added calcium hypochlorite to the water storage tank each time it was filled up from the nearby wells, and 154 control families (152 children) who did not. Analysis of the well water showed that all samples taken were unfit for consumption (92.3% positive for *E. coli*, 100% positive for coliforms). Although a small number of samples of household water were found positive for *E. coli* and coliforms in the study group at the outset of the intervention, by the end of the study all samples were consistently negative. The study showed that the use of chlorination was associated with a 48% reduction in the incidence of diarrhoea in children under 5 years of age. The number of bouts of diarrhoea per hundred children was reported at 17.1 for the control group and 9.4 for the test group.

Semenza et al. (1998) [66] carried out a 9.5 week study of the effect of chlorination of household water in a municipal area of Uzbekistan. The study involved 120 households with, and 120 households without, access to municipal piped water. Of the households without access to piped water, 62 were trained to chlorinate their water. All participants (1,593) were monitored bi-weekly for self-reported diarrhoeal illness. The home chlorination intervention group had the lowest incidence of diarrhoeal illness (28.8/1,000subjects/month) compared with 75.5/1,000subjects/month and 179.2 /1,000subjects/month in the control group with and without access to piped water. The results suggest that residents without access to piped water who chlorinated their water had an 85% reduction in diarrhoeal illness compared with those without piped water who did not chlorinate their water and 62% reduction compared with those with access to piped water. Many of the residents with access to piped water reported absence of detectable chlorine in their water supply and intermittent supply.

Deb et al. (1986) [67] carried out a study in the slum areas of Calcutta, on the effect of chlorination and safer storage of water on the incidence of transmission of cholera from an infected person to uninfected persons in the same household. Out of 151 persons in the 31 family groups who chlorinated their drinking water, 11.73% were detected with cholera

infection (mean residual chlorine level in the treated water was 0.2 mg/l). Seven (4.4%) infected persons were detected among the 159 persons in the 30 family groups who stored their water in narrow neck pitchers. In contrast, 27 (17.3%) infected person were identified among the 156 persons in the 30 control family groups. The results showed that the chlorination and safe storage interventions produce a significant reduction in the spread of cholera infections among household contact to the extent of 57.8% and 74.6% respectively.

Quick et al. (1999) [68] carried out a 5 month trial in Bolivia to evaluate the impact of promoting chlorination and safe storage (referred to as the “Safe Water System”) on water-borne diarrhoeal disease. The study involved 127 households (791 participants) in 2 peri-urban settlements who used water from shallow uncovered wells. The families were divided into intervention (water chlorination and storage in a special container) and control groups (no intervention). Stored water in intervention households exhibited less *E. coli* contamination and families in the intervention had 43% fewer diarrhoea episodes than those in the control group. The mean number of reported diarrhoea cases per household was 1.3 for intervention families and 2.35 for the control group. The protective effect was strongest amongst infants for whom the reduction was 53%. *Campylobacter* was the organism most frequently isolated from stool specimens. Other organisms isolated include enterotoxigenic *E. coli*, *Salmonella*, *Shigella* and rotavirus. The authors commented that the relatively frequent isolation of *Campylobacter* may reflect the high percentage of families who possessed animals, particularly poultry, and had inadequate sanitation. The relatively high reduction observed in this study was achieved despite the fact that families lived in high risk environments where drinking water sources were heavily contaminated with *E. coli*, where only 53% of families had a latrine, and where human and animal faeces were on the ground around most homes.

Quick et al. 2002 [69] also carried out a similar 3 month study of water, treatment, safe storage and education in Zambia in 1998. The study involved 260 households (1,584 participants) in 2 peri-urban settlements that used water from shallow wells. The families were divided into 166 intervention (water chlorination and storage in a special container) and 94 control households (no intervention). As well as being instructed on chlorine disinfection of water and use of the safe storage vessel, intervention families were also told about the importance of clean drinking water, and its relationship to health. Stored water in intervention households exhibited less *E. coli* contamination and families in the intervention had 48% fewer diarrhoea episodes than those in the control group. The number of reported diarrhoea cases was 22 for the 1,003 intervention families and 28 for the 578 control families.

Sobsey Handzel and Venczel (2003) [70] carried out 2 separate studies in Bolivia (6 months) and Bangladesh (8 months) to evaluate the impact of promoting chlorination and safe storage to householders on water-borne diarrhoeal disease. The study in Bolivia involved 275 households in 2 peri-urban settlements where shallow groundwater was collected for use by households. The other involved 140 households in an informal settlement in Dhaka city where households extracted water from the municipal system which provided water of a variable quality for only a few hours per day. Families were divided into intervention (water chlorination and storage in a special container with a narrow mouth to prevent ingress of contamination) and control groups (no intervention). Tests showed that microbes in the stored water were extensively inactivated by the treatment with 1-5 mgm/L chlorine. In Bolivia, monthly episodes of diarrhoeal illness were reduced from 2.2 in the control group to 1.25 in the intervention group indicating that 43% of the community diarrhoea was preventable using the intervention. In Bangladesh, mean episodes of childhood diarrhoeal illness/1,000days were reduced from 24.8 in the control group to 19.6 in the intervention group indicating that 24% of the observable diarrhoea was preventable using the intervention.

3.5 Interventions involving chlorination in combination with flocculation and improved storage

In promoting household water treatment, a key challenge has been encouraging people to use disinfectants such as chlorine that may adversely affect the taste of drinking water and may not improve its appearance. A further problem with chlorination is that it is less effective in highly turbid water. This has been the basis for the development of products which combine flocculation with chlorine disinfection.

Reller et al. (2003) [71] conducted a 1 year study in 492 rural Guatemala households (12 villages, 29,82 persons) who obtained their drinking water from shallow wells, rivers and springs. Few households had latrines or other sanitary

facilities. The impact of 4 water treatment methods involving chlorination alone or in combination with flocculation (prior to disinfection) and use of a safe storage vessel (a container with a narrow mouth to prevent ingress of contamination) was tested. In the intervention villages, fieldworkers discussed the importance of water treatment and demonstrated the appropriate treatment process. During the period of observation, residents of 96 control households had 4.31 episodes of diarrhoea per 100 person weeks. As shown in Table 12, the incidence of diarrhoea was 24% lower (odds ratio 0.79) among the 102 intervention households using flocculation and chlorination (FDC) and 29% lower (odds ratio 0.74) among the 97 households using flocculation, chlorination and safe storage vessel (FDC+SS), 25% lower (odds ratio 0.74) among the 97 households using chlorination alone (C) and 12% lower (odds ratio 0.97) among 100 households using

Table 12. Impact of flocculation, chlorination and safe storage of drinking water on diarrhoeal disease incidence in rural households in Guatemala

	All participants		Children <12 months		Children < 5years		Water samples	Median free	Water samples
	Reduction in diarrhoea cf control	Odds ratio	Reduction in diarrhoea cf control	Odds ratio	Difference in severe diarrhoea cf control	Difference in prolonged diarrhoea cf control	With Effective free chlorine levels	Chlorine level (mg/l)	Meeting WHO Guidelines
Flocculant disinfectant	-24%	0.79	17%	1.05	-16%	1%	27%	0.6	40%
Flocculant disinfectant + vessel	-29%	0.74	-21%	0.69	-9%	-9%	34%	0.8	57%
Bleach alone	-25%	0.74	-13%	0.77	-20%	-16%	36%	1.9	51%
Bleach + vessel	-12%	0.97	-3%	0.92	-13%	-21%	44%	1.2%	61%
Control	-	-	-	-	-	-	2%	0.3	7%

chlorination plus safe storage vessel (C+SS). The difference in diarrhoea incidence between FDC+SS households versus the FD households resulted from differences among infants. The incidence of diarrhoea among participants >12 months old was similar for households using FDC+SS and those using FDC alone, but among children <12 months those in the FDC+SS households had 3% fewer episode of diarrhoea. Children <12 months received breast milk during 97% of weeks but most also received supplementary liquids and solids.

Luby et al. (2004) [72] reported a 9 month study carried out with around 800 households in Karachi. The 2 intervention groups used either chlorination alone or chlorination in combination with flocculation for treatment of water. The difference in prevalence of diarrhoea compared with the control was -64% in the flocculation-disinfection group and -55% in the chlorination only group.

Crump et al. (2005) [73] reported a 20 week study carried out with 6,650 people in 605 family compounds in Kenya. The families occupied an area where source waters were both heavily faecally contaminated and highly turbid. The two intervention groups used either chlorination alone or chlorination in combination with flocculation for treatment of water. The difference in prevalence of diarrhoea compared with the control was -19% in the flocculation-disinfection group and -26% in the chlorination only group. There were significantly fewer deaths in the intervention groups than in control group. Forty percent of water samples from the control group had *E. coli* concentrations of <1 cfu/100 ml compared with 82% in the flocculation-disinfection group and 78% in the chlorination only group.

3.6 Interventions involving filtration in combination with improved storage

Clasen et al. (2004a) [74] carried out a six month study in Bolivia which involved 50 households (280 participants) in rural villages. The 25 intervention households used a gravity water filter system consisting of 2 porous ceramic filter elements (nominal pore size 0.2 μ and impregnated with silver for bacteriostasis) suspended within a 15 litre container, mounted over a second 15 litre receiving/storage vessel with a spigot for dispensing the filtered water. The remaining households acted as controls. In 4 rounds of sampling following distribution of the filters, 100% of the 96 water samples from the filter households were free of thermotolerant coliforms, compared with 15.5% of the control household samples. Diarrhoeal disease risks for individual in intervention households was 70% lower than for controls. For children less than 5 years old the risk reduction was 83%.

4. QUANTITATIVE ASSESSMENT OF THE HEALTH BENEFITS OF PROMOTING INTERVENTIONS IN THE HOME TO ACHIEVE AND MAINTAIN WATER QUALITY

Although there is extensive evidence demonstrating that water, adequate hygiene and sanitation have an impact in reducing the risks of diarrhoeal and other diseases, there is continuing uncertainty and debate about the extent of the impact from these interventions either singly or in combination. Most particularly there is uncertainty regarding the magnitude of the contribution of safe water (i.e water quality as opposed to water quantity) to this outcome. As many water-borne 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, it is argued that improvements in water quality alone may not necessarily interrupt transmission.

In their 1991 assessment [52], Esrey et al. used 144 published studies to determine the impact of improving the quality of the community water supply and sanitation on ascariasis, diarrhoea, guinea worm, hookworm, schistosomiasis and trachoma. Of the seven rigorous studies involving improved water quality (out of 16 studies reviewed) a median reduction of 15% in diarrhoeal morbidity was found using the 4 studies for which this could be calculated. Of these, one (in Nigeria) reported little or no association between drinking water quality and diarrhoea incidence amongst children [75], another reported an 8% reduction in the prevalence of *Shigella* spp [76], whilst 2 studies (in Philippines and Lesotho) found some association with childhood nutritional status, but none with diarrhoea [77, 78]. Esrey et al estimated that, whereas provision of improved water quantity can produce a 20% reduction in diarrhoeal diseases (as calculated from 10 rigorous studies), the reduction attributable to adequate water quality was only 15%. For sanitation, using results from 18 rigorous studies, the mean reduction in diarrhoeal morbidity was estimated at 36%, whilst for hygiene promotion, the estimate (from 6 rigorous studies) was 35%. With respect to hygiene, several studies focussed specifically on handwashing, whilst other looked at the combined effects of handwashing with other hygiene behaviours. The overall assessment of Esrey et al., based on this data, was that improved access to water, together with improved hygiene and sanitation, are key to reducing diarrhoeal and other water-borne and water-washed diseases; but that water quantity may be more important than safe water. More recent data does not necessarily support this view.

Since the reviews of Esrey et al [52] many additional intervention studies involving improvements in drinking water, sanitation and hygiene practices in less developed countries have been reported. In 2005, Fewtrell et al. [79] published a systematic review and meta-analysis of these studies (most of these are reviewed in the previous section). The results of this study are also reported in more detail in a 2004 World Bank Report [80]. Of the 15 studies which evaluated the impact of water quality, the overall relative risk estimate was 0.69 (95% CI: 0.53-0.89). Overall, Fewtrell et al found that sanitation, hygiene, water quality and water quantity interventions had a more or less similar impact on ID rates; whereas provision of adequate water gave a relative risk estimate of 0.69, the risk reduction estimate attributable to improved water quantity was 0.75. For sanitation and hygiene, the risk estimates were 0.68 (95% CI: 0.53-0.87) and 0.63 (95% CI: 0.52-0.57) respectively. The relative risk estimate for hygiene is in agreement with the results of a systematic review of the impact of handwashing by Curtis and Cairncross [81] which suggests that the relative risk estimate for diarrhoeal disease is 0.68, i.e handwashing can reduce the risks of diarrhoeal disease by 42-47%.

Table 13. Estimated relative reduction in risk of diarrhoeal disease associated with water sanitation and hygiene interventions

Intervention	Esrey et al. (1991)		Fewtrell et al. (2004)		Curtis & Cairncross (2003)	
	Relative Risk AS*	Relative Risk RS**	Relative Risk AS*	Relative Risk ***	Relative Risk AS*	Relative Risk RS***
Hygiene	0.67	0.67	0.63	0.55	0.57	0.58
Sanitation	0.78	0.64	0.68	-		
Water supply	0.78	0.81	0.75	-	-	-
Water quality	0.83	0.85	0.69	-	-	-
Source treatment only			0.89			
Household treatment only	-	-	0.65	0.61	-	-
Multiple	0.80	0.70	0.67	-	-	-

*All Studies (AS); **Rigorous Studies (RS); ***excluding poor quality studies

To facilitate comparison, Fewtrell et al. [79] converted the percentage risk reduction as calculated by Esrey et al. [52] to obtain relative risk estimates. The data as shown in Table 13 suggest that the assessments of Fewtrell and co-workers of the impact of water quantity, sanitation and hygiene are broadly similar to those of Esrey et al. and Curtis and Cairncross, but suggest that water quality interventions are generally more effective. Fewtrell and co-workers did however express some concerns about the data related to hygiene and water quality interventions, suggesting that there was some evidence of publication bias. This raises the possibility that some studies that show negative effects were not submitted or accepted for publication. In general, hygiene and water quality intervention were also studied for shorter periods than sanitation and water quality interventions.

There are a number of factors that could account for the discrepancy between the assessments of Esrey and Fewtrell regarding the health impact of drinking water quality. Esrey and co-workers pointed out that, because drinking water is only one of many sources of diarrhoea infection, it is to be expected that the impact of improved water quality will vary from one study to another, e.g an improved quality water source is likely to have a lower impact in communities where the key intervention is preventing faecal matter from entering food or water through safe disposal of faeces and handwashing at critical times, than in communities where faecal:oral contamination may be less of a problem (i.e communities which use toilets and latrines). One probable reason for the higher impact value for water quality obtained by Fewtrell and co-workers is that, whereas all the assessments by Esrey involved improved community sources of drinking water (where drinking water may become contaminated during storage and use), of the studies examined by Fewtrell, only 3 related to improved water source, while the other 13 involved “point-of use” interventions. Because of the relatively large number of studies available for analysis, Fewtrell et al. were able to do some sub-group analysis (see Table 11). For the 3 interventions which targeted only the water source. the relative risk reduction was 0.89, whilst point-of-use treatment studies gave a relative risk estimate of 0.65 (0.61 if poor quality studies were excluded). This suggests that to maximise the health impact of water quality, ensuring microbial quality at the point of consumption is key.

Based on data from studies, as reviewed by Sobsey [3] and Wright et al, [4] which show evidence of decreased microbial quality and increased disease risks associated with inadequately stored water, it would be expected that interventions which combine water treatment with safe storage would produce a greater reduction in risk of diarrhoeal disease than water treatment alone. Looking at the various chlorine-based interventions, with and without safer storage (Quick et al. [68, 69], Sobsey et al. [70] Reller et al. [71]), there is some, but not consistent, evidence of a trend which suggests that this is the case. If improved drinking water quality is key, it might also be expected that a relatively higher impact would be observed for community subgroups who are more susceptible to infection, i.e infants and young children (children under

5, but not necessarily children under 1 year who are predominantly fed breast milk). The studies of Kirchoff et al. [64], Conroy et al. [59] and Sobsey et al. [70] do not necessarily support this. Reller et al. [71] actually reported that water treatments were less, rather than more, effective than predicted amongst the youngest. In their study, none of the tested interventions produced the predicted 30% reduction in diarrhoeal disease; only the 21% reduction which was found in the flocculation/disinfection plus vessel group when compared with the control group (see Table 12) was statistically significant. The fact that these workers also reported limited effects of water treatment on episodes of prolonged diarrhoea among children less than 5 years old provides further evidence of limited effect in the highest risk population. A possible reason suggested by Reller et al. for the less than expected effectiveness of the interventions was inconsistent use. In 92% of the observed weeks, children <1 year drank liquids other than breast milk, and thus were potentially exposed to water-borne pathogens. They also suggested that, because of the increased vulnerability of this group to lower doses of pathogens, inconsistent use of water treatment is more likely to be ineffective in preventing infections in this age group.

The intervention studies by Reller et al. [71] are intriguing for a number of reasons. Although various combinations of flocculation, chlorine disinfection and use of safe storage vessels produced a reduction in the incidence of diarrhoea of between 12 and 29%, the magnitude of reduction in the incidence of diarrhoea was lower than the 44-48% reduction seen in previous studies involving chlorine disinfection in Saudi Arabia (Mahfouz et al. [65]), and in Bolivia and Zambia (Quick et al. [68, 69]). Reller et al. suggest that this possibly reflects rates of uptake by the study participants. As shown in Table 12, Reller et al. found that only 36% of households receiving bleach alone and 44% of households receiving bleach plus storage vessel had water with detectable free chlorine in un-announced follow-up visits. This contrasted with 63% of Bolivia and 83% of Zambian households who had water with detectable free chlorine, and 81% of Saudi households that had no coliforms in stored drinking water. Overall these data suggest that when families treat their water intermittently, the reduction in diarrhoea is less than would occur with regular treatment. The fact that there was a significant reduction in diarrhoeal disease (25%, 29% and 24% respectively) in the groups using chlorine disinfection alone, and flocculation plus chlorine disinfection (with and without vessel), but in the group using chlorine disinfection plus vessel there was not (12% reduction), was also surprising, particularly in view of the fact that this latter group recorded higher mean chlorine levels and the highest recorded value for the number of sample meeting WHO guidelines. A possible explanation is that the unpleasant taste associated with higher levels of chlorine in the disinfection alone group may have caused reduced compliance.

Despite the fact that the studies were done in a wide range of settings, in many countries and over many years, there is, overall, a strong consistency in the finding that “point-of-use” water quality interventions can reduce the incidence of diarrhoeal diseases. The fact that these observations show considerable inconsistencies between different studies suggests (as also suggested by Thompson and Khan [35], and Clasen and Cairncross [82]) that the health impact which comes from point-of-use water treatment probably depends on a whole range of (often unpredictable) “community-specific” factors such as the effectiveness of the technology which they use, the nature of the social group and their customs, uptake of the method, the prevalence of different diseases within the group (and their modes of transmission), the nature of the community water source and its accessibility, and other environmental and demographic factors. It is possible, for example, that the extent to which a reduction in microbial count of drinking water produces a reduction in the risk of diarrhoea depends on the nature of the disease causing organisms prevalent in the study group. Whereas some pathogens such as *Salmonella* spp. may have a high infectious dose, others, such as norovirus, can have a very low infectious dose. In a study of bacterial indicators of risk of diarrhoea disease from drinking water in the Philippines, Moe et al. [83], reported little difference between illness rates of children drinking good quality water (<1 *E. coli*/100ml) and moderately contaminated water (2-100 *E. coli*/100 ml), but children drinking water with greater than 1,000 *E. coli*/100ml had significantly higher rates of diarrhoea. These workers suggested that in developing countries where the quality of drinking water is good or moderate, other transmission routes of diarrhoea may be more important; however grossly contaminated water is a major source of exposure to faecal pathogens. Similarly, VanDeslice and Briscoe [84] calculated that improving drinking water quality would have no effect in communities with little or no environmental sanitation, but, in areas with better community sanitation, reducing the concentration of faecal coliforms by 2 orders of magnitude could lead to a 40% reduction in diarrhoea. Interestingly, a systematic review by Gundry et al. [85] showed that, although there was a clear relationship between improved water quality by home water treatment and storage intervention and incidence of cholera, for general diarrhoea, no clear relationship was found with point-of-use quality, although interventions significantly reduced diarrhoeal incidence.

In a recent review, Clasen and Cairncross [82] also question the validity of the currently held paradigm that greater emphasis should be given to safe excreta disposal and proper use of water for domestic and personal hygiene than to drinking water quality or - put another way - that interventions aimed solely at improving drinking water quality would have relatively little impact in reducing diarrhoeal disease. In their review, they critically analyse aspects of the methodology of earlier studies such as the inclusion criteria, systematic review methods and statistical approaches. From a brief analysis of 21 controlled field trials over the last 20 years dealing specifically with interventions designed to enhance drinking water quality at household level, Clasen [86] reports a median reduction in endemic diarrhoeal disease of 42% compared with control groups. The result was fairly consistently regardless of the nature of the intervention (chlorination, filtration, flocculation/disinfection or solar radiation). These workers are now undertaking a more rigorous study of this data following the procedures for disciplined systematic review recommended by the Cochran Collaboration and its Infectious Diseases Review Group [87]. It is hoped that this review will help resolve some of the unanswered questions, and allow more focussed guidance to be given on the health impact of different water quality interventions in different situations.

It should be borne in mind that all of the studies reported above were carried out in developing country situations with high levels of diarrhoeal disease, where the health impact of improved water quality would be expected to be the highest. Some intervention studies carried out with middle class suburban population in Canada by Payment et al. [7] suggest that point-of-use water treatment could also have a significant impact in reducing the incidence of gastrointestinal disease (GI) in situations normally considered at much lower risk of water-borne disease. The 16 month study, which was carried out with groups of 350 families, found that families who drank bottled purified water (water treated by reverse osmosis or spring water) experienced 14% fewer episodes of GI illness than families who drank tap water. Children 2-5 years old were the most affected with an excess of 17% GI illness in the tap water group. These differences occurred despite the fact that the tap water came from a treatment plant producing water that met or exceeded current North American regulations for drinking water quality. The distribution system was found to be in compliance for both coliforms and chlorine. The results show that tap water can be a significant source of gastro-intestinal illness even if it meets water quality criteria. Over the observation period, the fraction of these illnesses attributable to tap water consumption was 14-19%, most of the observed effects being due to illnesses reported in children.

5. PROMOTING HYGIENE BEHAVIOUR CHANGE

Perhaps the greatest problem in improving home hygiene practice standards is developing the means to communicate with the target audience and to motivate behavioural change. Experience now shows that, if promotion of household water treatment and safe storage practices is to be successful in reducing the incidence of diarrhoeal disease, a number of aspects must be addressed:

- How best to introduce HWTS to households (e.g. through social marketing, communications materials etc.) and maximise uptake within the community
- How to ensure correct use of technology/hardware (correct dosing of disinfectants, proper maintenance and cleaning of household filters etc.) within the community
- How to ensure safe handling and storage of water
- How to ensure that water treatment technology is acceptable to the community in terms of water quality (taste, appearance) and cost
- How to ensure sustainability of behaviour change

Studies focussing on these issues are now giving valuable insights on how to optimise the promotion of household water treatment and safe storage. Whereas those who manage hygiene improvements often want to promote hygiene by educating people on the links between good hygiene and better health, one of the key lessons which has been learnt is that approaches which “lecture” at mothers and threaten them with disease in their children if they do not comply, have had disappointing results. Indications are that, if a hygiene practice such as household water treatment and safe storage or hand washing is to become a universal norm, hygiene promotion on a mass scale is needed to persuade people of the benefits. Participatory approaches that involve the community and engender ownership and commitment by the community are also needed to ensure that behaviour change is sustained rather than short-term. Building sustainability is also about building knowledge and skills in the community to allow communities to take over the management of their own programmes.

Whereas some programmes to promote household water treatment and safe storage systems in conjunction with activities aimed at education and motivating behaviour change have shown significant improvements in behaviour, others suggest little or no change.

Quick and co-workers at CDC [88] made a comparative review of the results of a series of studies utilising different behaviour change techniques to promote the Safe Water System (SWS) (combined chlorine disinfection and safe storage in modified vessels) in households in 3 countries (Zambia, Madagascar and Kenya). Three different techniques, or combinations of techniques were used:

- Social marketing (SM). This involves the use of marketing techniques to promote socially useful products through generation of demand. SM is defined by the 4 “P”s. The “product” should be high quality and attractive; the “price” should be affordable and permit at least partial cost recovery; the “promotion” is the use of information, education and communication to generate demand, and “placement” is widespread distribution to sales outlets for easy access.
- Motivational interviewing (MI). This involves the use of simple counselling techniques, including listening, reflecting back themes and eliciting from the client their own arguments for change, in such a way that the client then realises the need for change.
- Community mobilisation (CM). This involves training community members in the technology and reasons for use of the methods. There is also active community participation in research, planning, implementation and monitoring, so that the community develops a sense of commitment to, and ownership of, the project.

In all 3 projects Quick et al. used SM as the main implementation approach because it rapidly and effectively disseminates the SWS product. In the Zambia project [89, 90], 3 months after implementing SM, 14% of households in the SM group had adopted the disinfectant compared with 78% of households in the SM plus MI group. In the Madagascar project [91], social marketing of SWS was implemented and households were subdivided into 2 groups according to whether they were in the early or late stages of a CM programme. Evaluations showed that 8% of households in early stage of the CM process were using a disinfectant compared with 20% of households at a late stage of the CM process. In Kenya, where SWS was implemented with SM and CM, adoption of the water disinfectant exceeded 60% in intervention households and diarrhoea rates decreased by 58% in children under 5 years [92]. From these studies, Quick concluded that SM is a very effective tool for disseminating product awareness, motivating uptake by individuals who are already hygiene conscious, creating access to products and enabling a response to behaviour change triggers such as disease outbreaks. He also concluded, however, that since the hygiene conscious group generally make up a relatively small proportion of the community (5-15%) there is a need to combine SM with additional MI and CM interventions in order to mobilise the much larger “sceptic” proportion of the community into product adoption.

Jagals et al. [93] carried out a study in a community of a developing urban area of South Africa which was subjected to an 8 month “health and hygiene awareness” programme aimed at improving practices of storing water in, and handling water from, storage containers at home. The programme was based on the system of “Participatory Hygiene and Sanitation Transformation” (PHAST) developed by the World Health Organisation [94]. Structured interviews and statistical analyses assessed 3 variables – container hygiene, container storage and hand hygiene. In this study there was no evidence of significant improvements either in practices or in the microbiological water quality and the workers concluded that these programmes are only effective if they are sufficiently long term.

From their research on household perceptions/motivation in Pakistan, Agboatwalla and co-workers [95] concluded that, for hygiene promotion to be effective, one of the important aspect of communication programmes is that they should emphasise “positive” (rather than “negative”) attitudes such as clarity, taste, good health, affordability, and ease of use. These were found to be better predictors of whether people were likely to adopt and sustain water treatment practices. They concluded that these preferred attributes of water should be used to promote water treatment, and that campaigns should emphasise “staying healthy” rather than “preventing disease”. They observed that mothers were not aware of the concept of “germs”, but indirectly linked good health with clean water, and bad quality water with diarrhoea and stomach upsets.

Indications are that acceptability of the water treatment system also plays an important role in determining uptake within a community. One of the limitations of chlorine-based water disinfectants is the disagreeable taste or odour that may result when they are used to treat water with excessive amounts of organic material. The household study by Reller et al. [71], comparing the impact of chlorination only with combined flocculation-chlorine disinfection, suggested that the unpleasant taste associated with higher levels of chlorine may have reduced compliance. Reller et al. also reported evidence that families receiving bleach were not strictly following instructions. In a recently reported study on the impact of SODIS water treatment on water quality in households in a village close to Kathmandu, Nepal, it was found that SODIS was routinely adopted by only 10% of households, despite the fact that the intervention involved a comprehensive community promotion programme [96]. By contrast Clasen et al., [74] reported that an intervention which involved placing ceramic water filter units with families (accompanied with education on correct usage) was successfully introduced without the need for motivational campaigns. They concluded that this, together with the relatively higher reduction in diarrhoea associated with the filter (as compared with other types of interventions), could be attributed to its acceptability and favourable perception among users. The differing results of these studies suggests that the ability to elicit behaviour change through promotion of household water treatment depends on a range of factors, which may relate to the nature of the device or treatment or may be community-specific.

At the present time, the upper and middle class people in the urban areas in developing countries like India, are well sensitized about the poor quality of municipal tap water and its health impact. A case study in Kolkata (Table 14) [37] shows people's reluctance to drink municipal tap water and their willingness to pay for household treatment (which were perceived as less expensive than the costs of treatment of water-borne infections). In a survey undertaken by Jadavpur University, Economics Department (Kolkata) it was found that out of 240 households, only 53 drank water collected from municipal taps without any treatment. The rest spent time and money or both to purify the same.

Feedback from the consumers suggested that they are willing to pay for water just as for any other commodity, provided the civic authority ensures its credibility by providing the best quality drinking water. However, while the affluent class can afford to pay for the best quality bottled waters readily available in the market, it is the middle class and the low income group who need an appropriate and low cost treatment at the household level.

Table 14. Citizens in Kolkata willing to pay for in-home water quality improvement

Number of houses surveyed	240
Number of households using untreated water	53
Number of households using own purification methods	187
Minimum amount spent monthly per household for purification	Rs. 5
Maximum amount spent monthly per household for purification	Rs. 140

In developing national programmes for promotion of hygiene practices such as household water treatment and safe storage, it is now recognised that one of the key activities is developing capacity for hygiene promotion at local level, i.e building a sufficient network of “community/ fieldworkers/ professionals” (community health workers, community nurses, paediatricians, NGOs, school teachers) with expertise in, and commitment to, hygiene promotion. Community workers are vital to successful hygiene promotion because only they understand their local community and local conditions. It is important however that these workers also have an understanding of the principles of infection prevention through hygiene and the technical means to achieve this, and how to use their combined knowledge of hygiene and local conditions to develop hygiene promotion programmes appropriate to their community. A number of practical manuals are now available which give guidance on developing hygiene promotion programmes [94, 97, 98, 99]. IFH has also recently developed a manual, for use in conjunction with these materials, which explains in simple practical language, the principles and practice of household water treatment and safe storage [100].

6. THE MICROBIOLOGICAL EFFECTIVENESS OF METHODS FOR TREATMENT, HANDLING AND STORAGE OF WATER IN THE HOME

Treatment of water for drinking and cooking within the home is a widespread practice even when the house may be plumbed into a supply or a water tap is available nearby. The reasons for treatment primarily relate to the poor microbiological quality of the supply and removal of particulates, although in developed countries concern over chemical contamination or simply taste can result in treatment of otherwise good quality potable water. The necessity to further treat “treated” municipal water frequently results from poor infrastructure maintenance in the water supply system., This leads to contamination during distribution or (because of unreliable /intermittent supply) the need for the householder to store water often in bulk in cisterns/tanks, which themselves become contaminated.

Storage of water within the home is often a problem (see Section 3.3). Water that has to be collected from some distance either directly by the householder or delivered via tankers is at particular risk of contamination in relation to the hygienic quality of the transport and storage system. On the household scale, storage vessel design has been a major interest of CDC and they have clearly shown the hygiene benefits of clean spigotted vessels with narrow necks. When combined with chlorination, this provides an effective and low cost solution to faecal contamination problems [68, 69].

Both the time spent treating water and the cost can be a significant proportion of the household budget. Recommended technologies need to be:

- simple
- appropriate
- affordable
- effective

The following sections consider the merits of different technologies based on heat, physical removal by flocculation and filtration, and disinfection by chemical means. The primary basis for comparison is effectiveness against microbial pathogens since, in the vast majority of situations where water quality is substandard, this is due to microbial causes. A fuller discussion of the merits of different approaches to household water treatment can be found in the excellent WHO report *Managing Water in the Home: accelerated health gains from improved water supply* [3]. A second edition of this report is currently in press.

6.1 Standards and Guidelines

The WHO have issued guidelines for the quality of potable water which include measures of microbial, chemical and organoleptic quality (WHO, 2004 [101]). The reason for a guidance document rather than a set of mandatory standards is that the WHO recognise the need to take local or national environmental, social and economic conditions into account. However the guidelines emphasise the over-riding importance of ensuring that drinking water supplies are protected from microbial contamination. Notes on the application of these guidelines in specific circumstances have also been published which include discussion of emergency situations where some flexibility in national standards is encouraged so as not to restrict the availability of water. This applies especially to water for hygiene purposes, drinking water for travellers, water in schools, and bottled waters. It also applies to water for special groups at high risk from opportunistic pathogens (e.g. pseudomonads, non-TB mycobacteria, acinetobacteria).

National governments set water quality standards that are appropriate to their particular circumstances. For example in the USA there are legally enforceable standards defined under the National Primary Drinking Water Regulations that apply to all public water systems, and non- enforceable guidelines (National Secondary Drinking Water Regulations) regulating contaminants that may cause cosmetic or aesthetic effects (US EPA [102]). Maximum contaminant levels (MCL) and maximum contaminant level goals (MCLGs) are specified for each key microbial contaminant. The MCLGs define the level of contaminant below which there is no known or expected risk to health. The MCLs are set as close to the MCLGs as possible, and taking into account the best available technology and costs. For microbial pathogens the MCLGs are invariably zero and apply to *Giardia*, *Cryptosporidium*, faecal coliforms, *E.coli*, *Legionella* and enteric viruses. The MCLs may also be defined by the percentage removal or inactivation expected of the treatment process, e.g. 99.9% for *Giardia*, 99.99% for viruses. Many other countries have similar strict standards for microbial pathogens; however the enforcement of these standards can vary greatly, and frequent deviations mean that, in some countries, householders

cannot rely on the security of their supply, even if it comes from a public / regulated source.

In-home treatment devices (e.g filter units, UV lamps) are generally not subject to regulation regarding microbiological performance, but can carry certification from internationally recognised testing laboratories. The most influential is the US National Science Foundation (NSF) who have a range of test standards which ensure that devices are capable of delivering safe potable water together with audits of production facilities to ensure quality consistency. The NSF website (www.nsf.org) provides consumers with advice on the selection of in-home treatments [103]. An important point to note is that monitoring of source water quality, or the distribution system, is often restricted to measurement of indicator organisms (usually thermotolerant coliforms or *E. coli*). Whereas this approach may be justified for monitoring of water in communities where the major hazard is faecal pollution, point of use devices should be able to demonstrate effectiveness against all relevant water-borne pathogens i.e. specific viruses, bacteria and protozoal cysts.

6.2. Physical processes: Heat and UV

Boiling water is a widespread practice despite its costs in both fuel and time. For bacterial pathogens it should be sufficient to pasteurise water and even temperatures of 55°C or above will inactivate most bacteria over a period of several hours. Many viruses are also rapidly inactivated at temperatures above 60°C, for example Hepatitis A [104], but there are other reports of persistence at these lower temperatures particularly in the presence of stabilising cations or if the viruses are bound to particles (for review see Carter, 2005 [105]). Because of the problem of monitoring the thermal process, householders are usually recommended to heat to a vigorous or rolling boil. Ideally the heat-treated water should be stored in the same container in which it is heated, but the practice of dispensing to smaller, more convenient containers, especially plastic drinks bottles, is common. Handling large volumes of boiling water is a hazard and time is required to cool the water and dispense it into suitable clean containers.

In poor communities where fuel is scarce and an expensive resource, boiling is an unrealistic option. Solar pasteurisation in vessels which are painted black or have non-reflective surfaces can be a low cost alternative and temperatures in excess of 60°C can be obtained on a regular basis. In many parts of the world the amount of solar radiation is sufficient for this to be a realistic option for much of the year. Alternatively water is put into clear plastic bottles or simple containers with a reflective side and exposed to sunlight. Here the thermal effect is increased by exposure to UV light in sunlight. Over several hours temperatures in excess of 55°C can be achieved. The down side is the relatively small volume of water that can be treated at any one time, although the use of multiple containers and capturing more radiation by using solar reflectors can substantially increase the output of a domestic system. Low cost temperature indicators have been developed based on melting soybean wax or other waxes, adding to the reliability of the process.

SODIS – a process developed by the Swiss institute EAWAG (Swiss Federal Institute of Aquatic Science and Technology) - has improved solar disinfection by introducing steps to remove turbidity by settling or filtration and increasing the effectiveness of UV inactivation by aeration i.e. simply shaking the container at regular intervals to aerate the water [106]. Plastic containers made of PET are recommended as they are both easier to handle and less likely to leach chemical constituents into the water that may be harmful and/or affect the taste. Using this system, 10 litre amounts of water will take 5 hours or more to reach a sufficient temperature to inactivate pathogenic micro-organisms. Several studies have shown that although heat is the major factor leading to pathogen destruction, the combination of UV, heat and oxygenation is significantly more effective [107, 108]. The formation of free radicals derived from oxygen under the influence of UV radiation may play a significant part in pathogen inactivation.

Bacterial pathogens vary in their sensitivity to the SODIS conditions with *Shigella dysenteriae* being much more sensitive than *Vibrio cholera* [109]. These authors calculate that even under cloudy conditions there is sufficient radiation to inactivate Shigella. There is little available data on the virucidal performance of the SODIS system; however if temperatures of 60°C or above can be maintained for several hours, it would be expected that significant viral inactivation will occur. Other studies have shown that predicted solar radiation e.g. from satellite data, may not be reflected in actual SODIS performance on the ground e.g. Haiti [110]. The amount of solar radiation predicted to give adequate disinfection is around 500W/m² over a 5 hour period. However in field trials in Haiti, exposure of up to 2 days was required in January to give 100% inactivation of total coliforms and *E. coli* [110]. Introduction of SODIS requires adequate support in the

form of consumer education and community involvement to ensure the limitations of the process are fully understood. In a field study of the impact of SODIS water treatment on water quality in 42 households in a peri-urban village close to Kathmandu, Nepal, it was found that the faecal coliform count was reduced from a mean value of 111 cfu/100ml in untreated water to 12 cfu/100ml of treated water [96]. However it was found that SODIS was routinely adopted by only 10% of households, despite the fact that the intervention involved a comprehensive community promotion programme.

UV irradiation

The use of UV light for destroying water-borne pathogens has been common for a long time but has received renewed interest following the realisation that protozoal cysts of pathogens such as *Cryptosporidium* or *Giardia* were relatively resistant to chlorination but sensitive to quite low (<10mJ/cm²) doses of UV. The destruction of viruses also occurs with UV, but there is evidence that some viruses may require higher doses than bacteria or protozoa (WHO, 2004). Most small scale (community or household) UV systems use low pressure Mercury lamps which provide UV at 254nm wavelength which is suitable for causing damage to cellular nucleic acid. These lamps operate under low pressures and temperatures and consume little power. Medium pressure lamps, which emit a broad range of wavelengths and have higher energy output, are also available. The drawback of UV is clearly the need for a reliable electricity supply although the low power demands of the low pressure lamps means they can be powered by solar or wind turbine generators. Energy costs are considerably less than those for boiling water and, for community systems, they may be as little as \$1 per household per annum. For individual households, the initial outlay to buy a system as well as the routine maintenance costs become significant and this means the systems are not suitable for low income families.

UV systems may be batch or flow-through and the lamps can be suspended above the water channel or submerged in the water flow. Flow-through systems have an advantage in the home of providing safe water on demand and this overcomes the potential problem with UV of no residual chemical protection if the water is stored for any time. Submerged systems are potentially more efficient but only if the lamps sleeves are cleaned regularly to prevent fouling of the lamp surface. The key features of UV systems are reviewed by Gadgil [111]. The effectiveness of a UV system was demonstrated in a study which showed that the incidence of cryptosporidiosis was significantly less in a group of HIV-positive patients who used a filter and UV light system for treatment of household drinking water as compared with a similar group who drank untreated water [10].

6.3. Physical processes: settlement, flocculation and filtration

Settlement can be useful as a pre-treatment to remove especially larger inorganic materials. A few hours may be sufficient to settle larger particles whereas clays, even the large clays, will require several days. Some pathogens such as helminth ova will also settle under gravity but generally bacteria and protozoal cysts are too small unless they are attached to larger particles (see flocculation below). In practice, physical processes such as settlement perform better than predicted due to the co-settlement of pathogens with inorganic particles. Vessels used for settlement need to be regularly cleaned and accumulated sediment removed. Microbial films will also tend to grow on the vessel walls and these too need to be removed by scrubbing and or chemical disinfection. As a pre-treatment process, settlement is very cost-effective requiring only a suitable vessel, labour and time.

Filtration

Filtration covers a wide range of technologies from simple straining out of large particulates to sophisticated membrane systems operating under high pressure capable of removal of particles down to nanometer size. Filter media for removal of larger particles can include cloth or plastic gauze.

Filtration for domestic water treatment uses one of two general mechanisms:

- **straining** - where the size of the pores in the filter medium are smaller than the particle being removed. This can occur on the filter surface or within the depth of the filter wherever the water flow channels narrow to a size smaller than the particles.
- **depth filtration** - which occurs when particles passing through the channels become trapped on the surface of the channel wall by a variety of physical mechanisms e.g. hydrophobic or charge attraction. These absorptive processes may be reversible and/or the number of sites become eventually largely occupied such that breakthrough of the particles/pathogens is observed.

A further mechanism involves cake formation at the surface of the filter where, either the initial straining of larger

particles reduces the effective pore size and more and more small particles are excluded, or particle aggregation causes bridging of the pores. In some sand filters the surface layer is also biologically active and the growth of slime-forming micro-organisms provide an effective straining layer which removes most pathogens (bacteria, viruses and cysts).

Slow sand filters are most usually associated with public or community water treatment plant, but small-scale versions have been developed for domestic use [112]. The main problem with sand filters is they require a certain level of technical knowledge and regular maintenance to ensure they are working efficiently. Further, to be effective, a sufficient depth of sand is required and hence the units are often bulky. They require time (around 1 week) to establish the surface biofilm layer and hence it is necessary for households to have at least two systems working in synchronisation. Attempts to produce smaller domestic versions have been made. UNICEF's upflow sand filter combines the more rapid flows seen in upflow rapid sand filters with a sandwich of charcoal. This is combined with the use of biological mechanisms to remove at least some of the micro-organisms [113]. Duke and co-workers describe a study of the performance of a low cost household slow biosand filtration system carried out with 107 households in Haiti [114]. It was reported that the system achieved 98.5% removal of bacteria and a reduction in turbidity from 6.2 to 0.9 NTU.

In addition to sand, a wide variety of media have been used for depth filters including organic materials, coal, and inorganics. More appropriate for household use, especially if the input water is not excessively turbid, are ceramic filters. The most common form is a candle filter which comprises a cast hollow ceramic tube which is usually mounted between an upper chamber for the untreated water and a lower chamber to collect the filtered clean water. A field study by Clasen et al. [74] of the effectiveness of a candle filter system in reducing microbial contamination of household water is described in section 3.5.

Candles work by depth filtration, which means that breakthrough of bacteria and viruses can occur after a time. Since they also gradually become blocked, especially on the surface, there is a need to regularly remove the filter units, scrub the surface and boil the filters to kill any pathogens trapped in the ceramic body. Candles can be inexpensive, but low cost units are often of poor manufacturing quality with the seals between the ceramic body and metal fittings being particularly vulnerable to leaks which allow unfiltered water to pass through. Damage in the form of cracks also occurs during routine cleaning. More expensive candles with activated carbon cores and/or silver impregnation are available and are often used in pressurised in-line systems. These are however generally too expensive for general use.

Diatomaceous earths (DE) are used in combination with a coarser material in the pre-coat or body-feed filter process. These systems, in which the very fine DE coats a coarser permeable support material, can be very effective at absorbing particulates including pathogens. Generally these systems are not suitable for domestic use as they require considerable skill to set up and maintain. Pre-coated filters are available commercially, but are relatively costly.

Most recently the National Chemical Laboratory, Pune, India, report the development of a low cost membrane filtration unit which is suitable for use in both rural and urban situations. The unit filters water in 5 stages, the last being the ultra-filtration done by an acrylic membrane filter. The device can be operated using a hand pump, and has been shown to be effective in removal of Hepatitis A virus.

Filtration can be a cheap and effective way to improve water quality providing care is taken in both setting up the filter device and in its regular maintenance. Potential risks include:

- leakage especially around seals so that some water is not filtered
- channelling of water through poorly packed filtration media or through cracks in solid filters
- growth of bacteria within the filter if a bacteriostatic agent (e.g. silver) is not employed and eventual breakthrough of pathogens.

Coagulation and flocculation

This is an old process that still forms an important technology for larger scale water treatment. It requires a degree of skill and technical competence that makes it less attractive for household use, although recently simple sachets of chemicals which combine coagulation–flocculation (CF) with chemical disinfection have become available, which go some way

towards simplifying the process (see below). Typically CF involves adding a coagulant to a vessel of water, stirring rapidly to disperse the coagulant, followed by a period of standing with slow stirring to encourage the formation of large flocs. The flocs are polycationic and attract negatively charged colloidal particles and micro-organisms. Thus the process achieves a significant improvement in turbidity, and under optimum conditions can remove 90-99% of pathogenic bacteria and viruses. However the pathogens remain viable in the floc and separation is essential by settlement or filtration to prevent re-contamination of the clean water. Alternatively the treated water can be further dosed with a chemical disinfectant such as hypochlorite. Field studies have confirmed the validity of this approach especially where water has a high turbidity [73].

Souter et al describe a new point-of-use water treatment system that is based on flocculation, sedimentation and chlorine disinfection [115]. The system was evaluated for the removal of bacterial, viral and parasitic pathogens. Results indicated that the treatment system reduced the levels from $10^8/1$ to undetectable (<1) of 14 types of representative water-borne bacterial pathogens including *Salmonella typhi* and *Vibrio cholerae*. No *Escherichia coli* were detected post-treatment in 320 field water samples collected from five developing countries. In addition, the water treatment system reduced polio and rotavirus titres by greater than 4-log values. *Cryptosporidium parvum* and *Giardia lamblia* inocula were reduced by greater than 3-log values. Field studies of the effectiveness this system in reducing the incidence of diarrhoeal disease are described in section 3.4 [71, 72, 73].

The most common chemical flocculants are alum or iron hydroxides. These are effective, but moderately expensive. Alternative lower cost materials include clays and natural plant extracts. Of the latter group, proteins extracted from the seeds of the Moringa tree have received considerable attention and field trials have shown that, used properly, they can be as effective as alum [116]. These natural materials have the additional advantage that the moringa tree provides a number of other resources including a valuable oil from the seed, fodder and fuel. Other plant materials which have been used are polysaccharides (e.g. *Strychnos potatorum*). In general natural materials have great promise but require further work to optimise effectiveness and also to establish safety.

A variation on flocculation is to use either alum or iron salts coated onto a cheap filter material e.g. coal, or sand. These systems have been shown to reduce both bacteria and viruses in contaminated waters by absorption processes [117].

Addition of lime is also used to precipitate impurities, and can reduce bacterial loads. With this system, however, it is necessary to reduce the pH of the treated water, which is too alkaline for most domestic purposes. Flocculation and precipitation processes may also be used to remove certain chemical contaminants (see WHO Guidelines Chapter 8 for a fuller discussion of chemical contaminants), however the problems of chemical contamination are difficult for the householder to deal with as they require either attention to the quality of the source water or distribution system.

6.4. Chemical Disinfection

For domestic use, chlorine remains the simplest and most effective chemical disinfectant for treatment of water. It is freely available in a number of forms or can be generated from salt solution by a simple electrochemical process. Despite concerns over production of chlorinated disinfection by-products, the effectiveness of chlorine in killing all types of bacterial and viral water-borne pathogens make it the disinfectant of first choice. The main disadvantages with chlorine is its lack of activity against protozoal cysts at the low concentrations normally used for water treatment. Its reactivity with almost any organic material also means its activity can be easily quenched, if the correct process is not used.

Iodine is another halogen which is very effective at destroying water-borne pathogens and has been widely used for drinking water treatment in emergency or leisure situations. Iodine is available in the form of tablets or as ion-exchange resins. The latter may contain polymeric forms of iodine such as penta-iodide which are claimed to be more effective antimicrobials. Although water treatment filter devices based on iodine resins are available for routine household use, including simple on-tap filters, these cannot be recommended for everyday use. The major problems are the short contact time and poor control over the amount of iodine released which is determined by water quality and flow rates. High levels of iodine impart an unpleasant taste to the water. Long-term consumption can be damaging to health, whereas too low a level may fail to inactivate all pathogens. Water-borne enteric viruses are significantly more resistant than bacteria to inactivation by iodine.

Silver has traditionally been used for keeping water “sweet” and has a beneficial role in preventing bacterial growth. Domestic water filters are often impregnated with a silver compound to prevent growth of bacteria within the filter body, but this is not sufficient to destroy pathogens in the water being filtered. Water treatment products for domestic water purification based on direct addition of silver salt solutions (“colloidal silver”) are available in many countries but are not recommended by the WHO for routine use. This is because silver is slow acting and has limited activity against water-borne viruses and protozoal cysts.

Few other chemicals are suitable for routine domestic water treatment. Hydrogen peroxide and potassium permanganate have been added to water used for washing fruit and vegetables, and have some activity against enteric bacteria. They are not however sufficiently broad spectrum to deal with all water-borne pathogens. Acids especially natural fruit acids such as lime juice have been used to inactivate cholera bacteria but are again limited.

The extensive literature on the antimicrobial efficacy of chemical disinfectants used for water treatment is reviewed in detail by Russell et al. [118]. Field trials which demonstrate the effectiveness of chlorine disinfectants in reducing microbial contamination levels in household water supplies, and diarrhoeal incidence, are reviewed in section 3.4.

6.5. The Multiple Barrier Approach

Although removal of the health risks associated with water-borne pathogens are, and will remain, the primary benefit from in-home water treatment, the householder is also frequently faced with other problems such as the appearance and taste of the water which determine its acceptability, or the presence of e.g. arsenic, nitrates or pesticide residues which pose a health threat. Water with high turbidity interferes with and reduce the effectiveness of treatment processes such as the addition of a chemical disinfectant or treatment with UV. A multi-barrier approach which uses combinations of technologies is therefore appropriate in many situations. The key components of treatment systems are:

- reduction of turbidity and particulates by settlement or prefiltration or flocculation
- removal of parasites / protozoal cysts by filtration or flocculation or heat
- inactivation of bacterial and viral pathogens by chemical (especially chlorine), heat or UV treatments
- removal of chemical contaminants by active carbon /charcoal or specific process e.g. arsenic
- safe storage in a closed, spigotted container and/or by providing a disinfectant residual

A number of combinations of flocculation with chlorination, filtration plus chlorination and SODIS, in combination with safe storage, have been developed for household use. Field studies of these systems, as described in section 3, indicate that they are effective in improving the microbiological quality of drinking water, and can make a significant contribution to family health, by reducing the incidence of diarrhoeal disease. Some of these processes also reduce chemical contamination.

However there remains much work to do in optimising multi-treatment systems to ensure that they meet criteria of convenience, acceptability and affordability as well as efficacy. i.e the system must not only have the capacity to consistently produce water which is safe for consumption, it must also be simple to use, must operate under all household conditions (e.g without power of high water pressure), and must not include combinations of components which might take the overall cost beyond the reach of the householder. A recently launched device which includes filtration, disinfection with chlorine, activated carbon and safe storage appears to meet these requirements combining broad-spectrum antimicrobial performance with low costs per litre. Laboratory tests indicate that the device can produce a reduction in bacterial and viral titre of 7 and 6 logs respectively, and a 3 log reduction in protozoal cysts (Clasens et al. in press [119]).

6.6 Selection of appropriate technologies for household water treatment

In this section we have reviewed the diverse range of technologies which can be used for household water treatment. If promotion of household water treatment and safe storage is to be successful, it is important that the most appropriate intervention is selected for the community in question. The choice of technology depends on a range of factors such as availability, cost, ease of use, microbial efficacy, etc. A summary of the general properties of the different categories of water treatment systems is given in Appendix 2.

7. CONCLUSIONS

The evidence cited in this review shows that diarrhoeal disease is a significant problem worldwide, and is a concern not only in developing, but also in developed countries. A significant part of this disease relates to the consumption of contaminated drinking water, and could be prevented by provision of adequate water and sanitation, and promotion of household hygiene practices such as handwashing and point-of-use water treatment and safe storage.

Although significant advances have been made globally in the provision of community water supplies, there are increasing concerns that, even for those communities who have access to an “improved” source of water, nevertheless drink water which is unsafe, following contamination at source, in the piped distribution system or as a result of unhygienic handling during transport or during storage in the home. One of the key options for dealing with this problem is promotion of point-of-use water treatment in the home.

In this document we have reviewed a range of studies which show that improving the microbiological quality of household water by point-of-use treatment and safe storage in improved vessels, reduces diarrhoeal and other water-borne diseases in communities and households in developing and also developed countries. Opinions continue to differ as to the relative extent to which diarrhoeal disease can be reduced by improving drinking water quality at household level, as opposed to at source. Opinions also differ on the extent of the health impact achieved by improvements in drinking water quality in the absence of programmes to improve sanitation, water quality and other household hygiene measures such as handwashing. Nevertheless the evidence shows that provision of safe water alone can reduce diarrhoeal and other enteric diseases by 6% to 50%, even in the absence of improved sanitation or other hygiene measures. Sobsey [3] points out that reducing household diarrhoeal disease by more than 5% is an important achievement, because this is the minimum achievable target reduction in disease burden considered worthy of promotion and implementation by health authorities. It must be borne in mind however that the health impact gained from promoting point-of-use water treatment and safe storage varies considerably from one community to another and depends on a variety of technology-related as well as site-specific environmental and demographic factors. Thus the gains for some communities may be very significant, whilst in others they may be relatively modest.

If point-of-use water treatment in the home is to be effective as a means of reducing water-borne diarrhoeal disease, communities must have ready access to water treatment technologies which are appropriate to the community, effective, easy to use and affordable. Indications are that combinations of flocculation or filtration with chemical or physical inactivation of pathogens are required in most situations and often need to be followed by the additional barrier of safe storage. There remains scope to improve current multi-barrier systems and optimise these with respect to the range of microbiological and chemical hazards faced by particular communities. In addition, because the types and degree of chemical contamination can be so varied from one location to another (in contrast to microbiological issues which are often common) there is a need for flexibility in the design of simple low cost point-of-use treatments to accommodate specific treatments for toxic materials where appropriate.

As stated by Thompson et al. [120], the use of technologies to treat and safely store household water is best accomplished if it is accompanied by, or supported with, programmes designed to support community participation, education and efforts to achieve acceptance and sustainability. Where such components are absent or lacking, successful implementation and sustained use are unlikely to be achieved. This includes educational campaigns which stress the role of contaminated water and domestic hygiene in disease transmission and teach communities how to implement point-of-use treatment and safe storage. Strategies for promoting hygiene behaviour change have been the subject of much recent research and a number of practical guides are now available which give guidance on how to implement hygiene promotion activities such as those related to point-of-use water treatment and safe storage [94, 97, 98, 99]. It is likely that communities already sensitised by exposure to programmes to promote handwashing, who have observed first hand the health impact of handwashing behaviours, are more likely to respond to programmes promoting point-of-use water treatment. In the same way, the introduction of improved water treatment and storage at the household level, if done effectively, is likely to increase personal and community knowledge and awareness of the importance of water hygiene and sanitation and its contribution to infectious disease prevention and control and improved health. The close and interdependent relationship between hygiene and sanitation was demonstrated in a recent study in Salvador, Brazil, by Strina et al. [121] who observed

that there was a significant association between a positive hygiene score and the presence of adequate excreta disposal facilities in the home; families predisposed to acquire adequate sanitation in their homes had a measurably better awareness of hygiene, which was expressed in their behaviour.

One of the key arguments for promoting point-of-use water treatment and safe storage is that it can provide safe water to underserved populations much more quickly and affordably than it takes to design, install and deliver piped community water supplies. Promotion of “point-of-use” water treatment has the potential to provide immediate benefit to at risk populations until the long-term goal of providing safe, piped, community water supplies can be achieved. A number of recent studies have shown that hygiene promotion activities can prevent the death of a child at only a fraction of the cost of water supply and sanitation [122, 123] . It is important however that point-of-use water treatment is not seen as an alternative to the provision of safe community water supplies, and an argument for decreased investment in such programmes.

Although there is awareness amongst public health scientists, health professionals and others about the importance of increased emphasis on hygiene promotion, this does not necessarily translate into commitment to action by national and international government and non-government departments/ agencies (Bartram et al. [124]). We need to persuade governments/funding agencies to invest in hygiene promotion. Since measuring the health impact of hygiene promotion is difficult compared with measuring the success of programmes to increase water and sanitation coverage, this makes hygiene promotion programmes inherently less attractive to funding agencies, in the current situation where “accountability” has become a key factor. One of the significant barriers to progress in developing and promoting hygiene is the fact that, in most countries, the separate aspects of hygiene promotion (faeces disposal, food and water hygiene, handwashing, care of the sick, childcare etc) are dealt with by separate agencies. If hygiene promotion is to be effective ideally there should be a single lead agency in each country, and appropriate infrastructure at national, district and local level which is specific for actioning hygiene promotion.

Although the current focus on the MDGs means that the emphasis is on improving access to safe drinking water for the most disadvantaged communities in developing countries, where the prevalence of diarrhoeal is highest, this review shows that the need to develop and promote of point-of-use water treatment and provide affordable means of water treatment is by no means confined to these communities. This report identifies a number of other situations where access to point-of-use treatment and safe storage is key to prevention of water-borne disease:

- In many developing countries, as stated previously, water quality is a significant problem even for the most prosperous communities that have access to piped community water supplies. A significant proportion of families in developing countries live in this situation. Although, from a government perspective, the risk of ID for this group may be orders of magnitude less than for the rural and urban poor living without access to water and sanitation, this is of little help to these families who, here and now, want to know how to raise a healthy family. The ID risk for these families is as great or even greater than that of families in developed countries. These groups equally have the right to have access to education on water hygiene and access to affordable means of water treatment and storage, but tend to be overlooked because they live in the “shadow” of the much larger disease burden which affects the rural and urban poor. Many of these people are forced to rely on purchasing bottled water, which they can ill afford.
- Across Europe there are still areas where treated community water supplies of adequate microbiological quality are unavailable. This applies particularly in regions of Europe where political and economic upheaval have led to infrastructure deterioration, but also in areas where communities rely on small water supplies.
- In the US “small water systems” are a significant problem. Small communities face difficulties in supplying water of adequate quality and quantity because they have small customer bases and often lack the resources needed to maintain and upgrade facilities, and provide continuous supplies.
- Emergency situations occur regularly and require a prompt response. These may be seasonal problems such as flooding or natural disasters. In these situations, treatment of drinking water and safe storage are key to preventing large-scale diarrhoeal disease outbreaks attributable to contaminated water.
- Emergency situations, which require communities to undertake treatment of drinking water supplies are not confined to developing countries. Typical examples are the frequent outbreaks of *Cryptosporidium* which occurred in England and Wales during the 1980s and 1990s and the large outbreak in Milwaukee in 1993.

In the 2002 World Health Report, WHO lists unsafe water and sanitation as “one of the top ten risks to health globally and regionally”. The report concludes however that “very substantial health gains can be made for relatively modest expenditures on interventions such as micronutrients supplementation, treatment of diarrhoea and pneumonia and disinfection of water at the point of use, as ways of reducing the incidence of diarrhoea”. The report suggests that “point-of-use” water treatment is particularly cost-effective in regions of high child mortality”, and that “a policy shift towards household water management appears to be the most attractive short term water related health intervention in many developing countries”. “This would complement the continuing expansion of coverage and upgrading of piped water and sewerage services which is naturally a long-term aim of most developing nations”.

Appendix 1. Water-borne pathogens and their significance in water supplies

Pathogen	Health significance	Persistence in water supplies	Relative infectivity	Important animal source
Bacteria				
Burkholderia pseudomallei	Low	May multiply	Low	No
Campylobacter jejuni, C. coli	High	Moderate	Moderate	Yes
Escherichia coli – Pathogenic	High	Moderate	Low	Yes
E. coli – Enterohaemorrhagic	High	Moderate	High	Yes
Legionella spp.	High	Multiply	Moderate	No
Non-tuberculous mycobacteria	Low	Multiply	Low	No
Pseudomonas aeruginosa	Moderate	May multiply	Low	No
Salmonella typhi	High	Moderate	Low	No
Other salmonellae	High	May multiply	Low	Yes
Shigella spp.	High	Short	Moderate	No
Vibrio cholerae	High	Short	Low	No
Yersinia enterocolitica	High	Long	Low	Yes
Viruses				
Adenoviruses	High	Long	High	No
Enteroviruses	High	Long	High	No
Hepatitis A	High	High	No	
Hepatitis E	High	High	Potentially	
Noroviruses and Sapoviruses	High	Long	High	Potentially
Rotavirus	High	High	No	
Protozoa				
Acanthamoeba spp.	High	Long	High	No
Cryptosporidium parvum	High	Long	High	Yes
Cyclospora cayatanensis	High	Long	High	No
Entamoeba histolytica	High	Moderate	High	No
Giardia intestinalis	High	Moderate	High	Yes
Naegleria fowleri	High	May multiply	High	No
Toxoplasma gondii	High	Long	High	Yes
Helminths				
Dracunculus medinensis	High	Moderate	High	No
Schistosoma spp.	High	Short	High	Yes

Source: Guidelines for Drinking Water Quality, 3rd edition, Vol.1, WHO, 2004)

Appendix 2. General properties of household water treatment systems

Treatment	Availability and practicality	Technical difficulty	Cost	Microbial efficacy
Boiling at 100°C	High	Low-moderate	Varies	High
Chemical treatment (chlorine or iodine)	High to moderate	Low-moderate	Moderate	High
Solar disinfection	High	Low-moderate	Low	Moderate
UV lamp treatment	Varies	Low-moderate	Moderate-high	High
Coagulation/ Flocculation/ Sedimentation/ Filtration	Varies	Low-moderate	Varies	Varies

A multi-barrier approach which uses combinations of these technologies is appropriate in many situations.

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