# Chapter 16

## Unsafe water, sanitation and hygiene

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### Summary

The disease burden from unsafe water, sanitation and hygiene (WSH) is estimated at the global level taking into account various disease outcomes, principally diarrhoeal diseases. The risk factor is defined as including multiple factors, namely the ingestion of unsafe water, lack of water linked to inadequate hygiene, poor personal and domestic hygiene and agricultural practices, contact with unsafe water, and inadequate development and management of water resources or water systems.

For estimating disease burden of infectious diarrhoea, exposure scenarios are established according to water supply and sanitation infrastructure, the level of faecal–oral pathogens in the environment and populations assigned to these scenarios. The total burdens from schistosomiasis, trachoma, ascariasis, trichuriasis and hookworm disease are all wholly attributable to unsafe WSH and have been quantified at global level as an additional exercise.

Unsafe WSH is an important determinant in a number of additional diseases, such as malaria, yellow fever, filariasis, dengue, hepatitis A and hepatitis E, typhoid fever, arsenicosis, fluorosis and legionellosis, some of which present a high disease burden at global level.

For infectious diarrhoea, six exposure levels were defined, with the lowest risk level corresponding to an ideal situation where WSH plays no role in disease transmission. Exposure prevalence, in terms of infrastructure, was determined from the Global Water Supply and Sanitation Assessment 2000. This assessment is a synthesis of major international surveys and national census reports covering 89% of the global population. The parameters considered included access to improved water sources and improved sanitation facilities.

Relative risk estimates were based on reviews and large multi-country studies for areas with high faecal–oral pathogen loads in the environment (i.e. principally in developing countries). The proportion of disease

due to unsafe WSH in regions with low faecal–oral pathogen loads was based on a study analysing the relative importance of etiological agents causing diarrhoeal diseases, supported by evidence from selected studies considered to be of high quality. A low faecal–oral pathogen load in the environment was assumed if sanitation coverage exceeded 98% (which corresponds to the situation in most developed regions).

For the high faecal–oral pathogen exposure group, Esrey's multi-country study (1996) suggests that a mean reduction in diarrhoea of 37.5% is possible following the introduction of improved water supply and sanitation in developing country environments. For the low faecal–oral pathogen exposure group, data from the study by Mead et al. (1999) suggested that the proportion of diarrhoeal illness attributable to food in the United States of America was approximately 35% (excluding those illnesses wholly transmitted by food). We have therefore estimated that approximately 60% was attributable to unsafe WSH. A review by Huttly et al. (1997) of epidemiological studies on hygiene practices in seven nations identified a median reduction of diarrhoea incidence of 35%.

Selected additional studies have suggested ranges of reductions in diarrhoea incidence that could be achieved by reducing the transmission of faecal–oral pathogens through the implementation of interventions, such as point of use treatment and disinfection of stored water (Quick et al. 1999; Semenza et al. 1998). However, this transition has been poorly documented by exposure–risk information, and we considered it appropriate to examine both optimistic and pessimistic estimates in defining the uncertainty around these values.

The disease burden from unsafe WSH was estimated to have been 1.73 million deaths in the year 2000, and 88% of the global burden of diarrhoeal disease due to infectious diarrhoeal diseases. In addition, schistosomiasis, trachoma, ascariasis, trichuriasis and hookworm disease are fully attributable to WSH-related factors. Typically, the fraction of diarrhoeal disease attributed to unsafe WSH in developed countries is approximately 60%, whereas in developing countries as much as 85–90% of diarrhoeal illness can be attributed to unsafe WSH. The major part is borne by children in developing countries.

This estimation of the global disease burden caused by unsafe WSH suggests a significant burden of preventable disease attributable to this cause in developing nations, and a non-negligible burden in developed countries.

## 1. Introduction

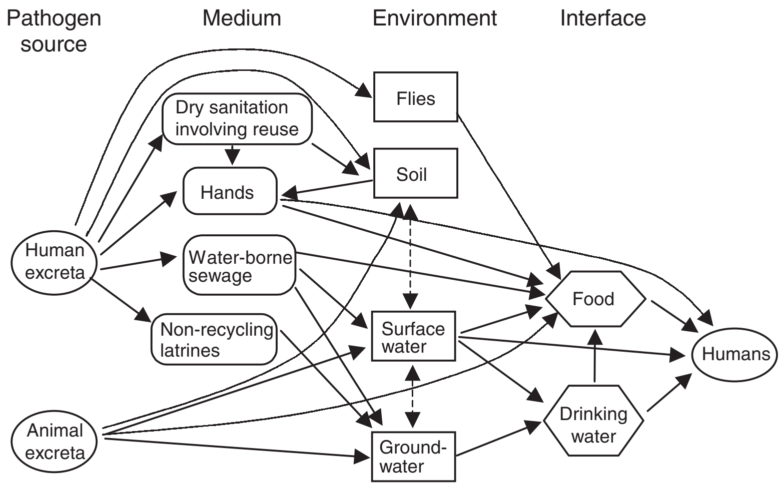
The disease burden caused by the risk factor unsafe WSH was estimated at the global level in 1990 (Murray and Lopez 1996a). This original estimate examined WSH in terms of diarrhoeal and selected parasitic diseases, based on the partial attribution of their disease burden to the risk factor. It was found that worldwide the risk factor accounted for 5.3% of all deaths and 6.8% of all disability-adjusted life years (DALYs). Other communicable (e.g. hepatitis A and E, malaria) and noncommunicable diseases (arsenicosis, fluorosis, methaemoglobinaemia) were not considered in that assessment.

### 1.1 Rationale for a composite risk factor

Faecal–oral diseases account for the dominant health outcome of the unsafe WSH risk factor and are the main focus of this chapter. However, not all of them could be included in this estimate (e.g. hepatitis A and E). For infectious diarrhoea, the unsafe WSH risk factor comprises a number of transmission routes mediated by a complex interaction of infrastructure issues, which might affect, for example, microbiological hazards from poor quality drinking water, water availability, microbial risks from inappropriate disposal of faecal wastes and behavioural aspects. The transmission routes interact with the efficiency of interventions such as hygiene within the home, hand-washing and rigorous application of point-of-use treatment within domestic properties. Clearly, in any global assessment, the contribution of each element, together with the plethora of interactions, cannot be precisely quantified in every setting. However, as hazard estimates come from large surveys performed in several countries (Esrey 1996), variations in behaviour and their effects on the transmission of faecal–oral pathogens have, to some extent, been internalized in our estimates.

It is likely that the relationship between faecal–oral pathogen dose and the probability of infection is log-linear for many of the infectious diarrhoeal diseases, reaching a plateau for higher exposures (Briscoe 1984; VanDerslice and Briscoe 1995). Sometimes several component causes (see Figure 16.1) may produce similar infection outcomes. This can mean that the introduction of a single intervention in isolation (e.g. the provision of cleaner water supplies) designed to break an infection pathway may result in a negligible reduction in overall disease burden. This is particularly true in communities where the environmental load of faecal–oral pathogens is high (e.g. a community with low sanitation coverage, faecally contaminated drinking-water supplies, irregular refuse collection and poor hygiene practices). This renders the attribution of a disease fraction to a specific factor particularly difficult and, indeed, potentially misleading to the policy-making community. For this reason, it is necessary to consider WSH as interrelated parts of a single causal web in which cutting one major pathway of transmission may well show no (or minimal) effect on the total disease burden, but may, in other circumstances, provoke a dramatic response. Importantly, however, removing a basic pathway (e.g. by providing safe drinking water or improved sanitation) is likely to be a precondition for the success of subsequent interventions to reduce disease burden.

**Figure 16.1** Transmission pathways of faecal–oral disease




Management actions concerning water supply and sanitation often involve water resource management, including the control of insect vectors of disease (such as malaria) and soil-borne helminths (such as ascaris). Similarly, environmental management to control disease vectors impacts directly upon water supply and sanitation. Furthermore, access to improved water sources has a significant impact on exposure to agents of some water-based diseases (such as schistosomiasis) and diseases with water-related insect vectors, and improved sanitation reduces certain vector-borne diseases such as trachoma. These intimate interconnections of exposure pathways and control mechanisms suggest that treating water, including supply and resource management, as an integral part of the risk factor unsafe WSH is rational.

### 1.2 Definition of risk factors

Unsafe WSH adversely affects health through multiple routes.

1. Transmission through contact with water that contains organisms such as *Schistosoma spp*.

2. Transmission through vectors proliferating in water ecologies related to dams, irrigation schemes and other water resources projects (e.g. malaria, schistosomiasis, lymphatic filariasis). This should be included although it is currently unclear how or whether it can be quantified.

3. Transmission through the ingestion of water as it occurs during drinking and, to some extent, bathing. This category includes diseases from faecal–oral pathogens, dracunculiasis, arsenicosis, fluorosis, from other toxic chemicals and due to excess proliferation of toxic algae.

4. Transmission caused by poor personal, domestic or agricultural practices, including when personal hygiene is affected by lack of water. This includes person-to-person transmission of faecal–oral pathogens, foodborne transmission of faecal–oral pathogens as a result of poor hygiene or use of contaminated water for irrigation or cleaning. Lack of water is in particular linked to diseases such as trachoma and scabies.

5. Transmission through contaminated aerosols from poorly managed water systems (e.g. legionellosis).

Water-related injuries that could be prevented by appropriate water management were not considered in the current estimate because of the different management approaches to their remediation. They were, however, covered by the World Health Organization (WHO 1998), although their disease burden was not quantified. Many social, geographic and behavioural factors, such as hygiene, the domestic storage and potential contamination of potable water, the use of sanitation facilities, etc. are important determinants of health outcome. This set of factors has complex social and behavioural drivers that are highly heterogeneous both within and between nations. In reality, they would modify the effects of the pathways defined in (i) to (v) above. It is beyond the scope of the current assessment to attempt to quantify the unique impacts of this set of factors in each setting.

Diseases relating to unsafe WSH, and their inclusion in the current estimate, are listed in Table 16.1. This first assessment of disease burden should be considered an initial estimate, which will benefit from refinement as additional information becomes available. Table 16.1 is not exhaustive, as the linkages between water and health are extensive and complex. For example, it is likely that the role of inadequate water for food production, and therefore nutrition, will be particularly important, in addition to the direct impact of infectious diarrhoea on nutrition.

### 1.3 Evidence of causality on infectious diarrhoea

As illustrated in Table 16.1, numerous separate faecal–oral illnesses fall under the "umbrella" of infectious diarrhoea. Their commonality derives from their mode of transmission, in that the source of the pathogen is human (or less commonly, animal) faeces which can cause infection in a new host upon ingestion. The shortest route of transmission is from person-to-person (a hygiene issue), while longer routes include transfer of pathogens to a food crop, as well as to drinking water or recreational

**Table 16.1** Diseases related to unsafe water, sanitation and/or hygiene

| *Disease outcome* | *Included in current estimate* |
|---|---|
| Infectious diarrhoea, including: cholera, salmonellosis, shigellosis, amoebiasis, other bacterial, protozoal and viral intestinal diseases[a] | Yes (acute effects only) |
| Typhoid and paratyphoid fevers | Partly included in estimate for infectious diarrhoea, but would benefit from separate, more precise consideration |
| Hepatitis A | No |
| Hepatitis E | No |
| Fluorosis | No |
| Arsenicosis | No |
| Legionellosis | No |
| Methaemoglobinaemia | No |
| Schistosomiasis[a,b] | Yes |
| Trachoma[a,b] | Yes |
| Ascariasis[a,b] | Yes |
| Trichuriasis[a,b] | Yes |
| Hookworm[a,b] | Yes |
| Dracunculiasis[b] | No (disease close to eradication) |
| Scabies | No |
| Dengue[a] | No |
| Filariasis[a] | No |
| Malaria[a] | No |
| Japanese encephalitis[a] | No |
| Onchocerciasis[a] | No |
| Yellow fever | No |
| Impetigo | No |
| Drowning[a] | No |

[a] Included in this analysis.

[b] Considered to be 100% due to unsafe WSH.

water, as summarized in Figure 16.1. The predominant route will depend upon the survival characteristics of the pathogen as well as local infrastructure and human behaviour. While some of the diseases contained in the group diarrhoeal disease, as defined for the purpose of this project, are relatively mild and self-limited, others may be more severe and cause long-lasting sequelae (Hunter 1997). The disease burden based on these studies has not been taken into account in this estimate.

The fact that faecal–oral pathogens can be spread via the water route is well established (Andersson and Bohan 2001; Esrey et al. 1991; Hunter 1997; Snow 1855). The following sections briefly outline the evidence for infectious diarrhoea causality in relation to water, sanitation and hygiene. For the most part, studies examining the issue have been intervention studies, which have looked at changes in water supply, excreta disposal or hygiene practices, and assessed the effects on diarrhoea morbidity or mortality rates (generally in young children). Another significant group of investigations comprise case–control studies, particularly following outbreaks suspected to be caused by potable water contamination in developed nations.

*Sanitation*

Ideally, sanitation (i.e. human excreta management) should result in the isolation or destruction of pathogenic material and, hence, a break in the transmission pathway. In a comprehensive literature review, Esrey et al. (1991) identified 30 studies, from a variety of different countries (including Bangladesh, Brazil, Chile, Guatemala, Kenya, Malaysia and Panama), that examined the impact of sanitation on disease transmission. Twenty-one of those studies reported health improvements (median 22% reduction in diarrhoea morbidity), with a greater median reduction being seen in the rigorous studies (36% reduction). Several studies have isolated various faecal–oral pathogens from the faeces of sick people and the transmission of such pathogens isolated from infected faeces to human hosts has been shown in numerous studies (e.g. for *Shigella* [Dupont et al. 1989]). Clearly, the relationship is both plausible and coherent.

*Water*

The number of outbreaks of infectious diarrhoea caused by faecal–oral pathogens in developed countries attests to the efficiency of this mode of transmission. In the United States, for example, 14 outbreaks of infectious etiology associated with drinking water were reported for the two-year period 1997–1998 (Barwick et al. 2000).

In developing countries, it is not only water contaminated at source or during distribution that is an issue, but water stored within the home which may also become contaminated (arguably a hygiene issue). For example, in a literature review, VanDerslice and Briscoe (1993) found 11 observational studies showing that mean coliform levels (an indicator of contamination) were considerably higher in household water containers than in the original source waters.

Numerous epidemiological studies and outbreak investigations have found an association between poor water quality and infectious diarrhoea. In France, water that did not meet microbiological standards was associated with an increased risk of gastroenteritis (RR 1.36, CI 1.24–1.49) (Ferley et al. 1986). In the Philippines, Moe et al. (1991) reported an odds ratio (OR) of 1.92 (CI 1.27–2.91) for diarrhoea following consumption of water contaminated with high levels of *Escherichia coli* (a faecal indicator bacteria). Mahalanabis et al. (1991)

reported that children with prolonged diarrhoeal illness (more than 14 days) were more likely to drink water from an unprotected water source (OR 1.56, CI 1.18–2.06). Birmingham et al. (1997) conducted an epidemiological investigation to identify sources of infection and risk factors for cholera in Burundi during an epidemic in 1992. Water from Lake Tanganyika was implicated, as a case–control study found that both bathing in the lake (OR 1.6, CI 1.1–2.1) and drinking its water (OR 2.78, CI 1.0–7.5) were independently related to illness; additionally *Vibrio cholerae O1* was isolated from the lake water.

As seen above, the causal relationship between ingesting water of poor sanitary quality and diarrhoeal illness has been observed worldwide, using a variety of techniques and assessing quality in a number of different ways. The biological gradient can be illustrated by increases in infectious diarrhoea morbidity as contamination levels increase, and also as consumption of water from a single contaminated source increases. For example, Njemanze et al. (1999) examined the annual diarrhoeal incidence rate (per 1000 population) in 39 communities in Imo State, Nigeria, in relation to the characteristics (including pollution) of their drinking water source. Sources were classified from A to C with A representing the most desirable sources (with favourable geology, sparse population and clean and unpolluted water). Diarrhoeal incidence rate was found to show a statistically significant increase with a mean of 1.61 for category A, a mean of 6.25 for category B, and a mean of 15.6 for category C.

The relationship between infectious diarrhoea and transmission of pathogens through water is both plausible and coherent. Isolation and enumeration of specific pathogens in water are often not feasible or very imprecise; thus a more common measure of faecal contamination is derived from the use of indicator bacteria. There have been many studies using such indicator species that have demonstrated the faecal contamination of drinking water sources in both developed and developing countries (e.g. Ampofo 1997).

#### *Hygiene*

A number of studies have attempted to examine the role of personal and domestic hygiene, although in many cases some of the "hygiene" measures or interventions could also impact on sanitation, and hygiene interventions may also interact with water quality.

Six studies examined by Esrey et al. (1991) identified reductions in diarrhoea morbidity associated with the uptake of hygiene interventions. These ranged from 14% to 48%, with a median reduction of 33%. In a more recent review, Huttly et al. (1997) identified a further four studies addressing the impact of improved hygiene. All four studies showed a decrease in diarrhoea, as did a subsequent study of Curtis et al. (2000). These studies were conducted in diverse locations including Bangladesh, Burma, Guatemala and the United States.

The temporal adoption of hygiene measures can be illustrated by the study by Ahmed et al. (1993). This group compared cleanliness and diarrhoea levels in villages with and without hygiene education interventions. Higher adoption rates of the intervention were associated with a better cleanliness state, which was paralleled by a decrease in diarrhoea and malnutrition rates. These differences were found to increase over time as more villagers adopted the intervention.

Alam et al. (1989) studied the effect of four different hygiene measures (source of washing water; presence of faeces in the yard; hand-washing before serving food; and hand-washing after defecation). They showed decreasing diarrhoea incidence as the number of adopted hygienic practices increased (4.9 cases per child-year for one practice to 2.6 cases for all four; $P < 0.01$).

A review by Feachem (1984) documented the presence of pathogens on the hands following toilet activities. In the same review, Feachem also noted a number of studies on hand-washing which demonstrated the almost complete removal (98–100%) of seeded bacteria.

## 1.4 Evidence of causality on other outcomes

### *Schistosomiasis*

Schistosomiasis is caused by infection with trematodes of the *Schistosoma* species. Transmission of the disease occurs when people come into contact with water containing cercariae (the mobile larval stage of the life cycle), which penetrate the skin. Water is contaminated by infected humans who excrete the schistosome eggs in their faeces or urine (depending upon the *Schistosoma* species). The final link in the chain of infection is provided by an intermediate snail host, which the parasite needs in order to complete its life cycle. Current knowledge on disease transmission indicates that the disease is fully attributable to unsafe WSH.

Esrey et al. (1991) identified 12 studies that related water and sanitation facilities to the rates of schistosomiasis. Reported decreases in infection rates varied between 59% and 87%, with the median value of the rigorous studies being a 77% reduction. Numerous studies, in addition to those identified above, have noted the relationship between contact with contaminated water and high levels of infection with schistosomiasis (Hunter 1997). These have been conducted in various countries and have examined different *Schistosoma* species. Lima e Costa et al. (1991) found that individuals reporting water contact less than once a week had a smaller excess risk of schistosomiasis than those reporting water contact at least weekly (OR 3.0, CI 1.3–6.6 in comparison to OR 4.3, CI 2.6–7.0).

A number of studies have examined reinfection with schistosomiasis following an intervention programme (such as treatment of infected individuals). In China, Zhaowu et al. (1993) found that reinfection was associated with the frequency of water contact, the type of water contact and the proximity of residence to snail-infected water. In Brazil, discontinuation of a control programme led to an increased prevalence of schistosomiasis (Coura-Filho et al. 1994). Risk factors for the disease included any form of water contact (OR 2.79, CI 1.19–6.85).

The relationship is plausible and the results of numerous studies are coherent and do not conflict with what is known about the disease. Interventions centring on water and sanitation provision designed to either decrease water contamination or decrease contact with contaminated water have proved to be effective in reducing the rates of schistosomiasis (e.g. Barbosa et al. 1971; Jordan 1972).

*TRACHOMA*

Trachoma is a chronic contagious eye disease, which can result in blindness, caused by *Chlamydia trachomatis*. Transmission occurs by several routes (Dolin et al. 1997), all of which are hygiene related (e.g. direct infection by flies, person-to-person from clothing used to wipe children's faces and by hand-to-face contact). Risk factors for the disease include lack of facial cleanliness, poor access to water supplies, lack of latrines and a high number of flies.

A total of 16 studies were identified by Esrey et al. (1991) which examined the role of WSH on the level of trachoma. The median reduction in trachoma was 50% (0–91) from all the studies and 27% (0–9) when considering the rigorous studies. More recently Prüss and Mariotti (2000) identified 39 studies which examined the level of trachoma in relation to environmental causation; they report that relative risks ranged between 1 and 4. Thirteen of the 16 studies identified by Esrey et al. (1991) reported positive effects, i.e. a water, sanitation or hygiene intervention resulted in lower levels of trachoma. The studies were conducted in a variety of locations including Australia, China, India, Mexico, Mozambique, the Sudan and Tunisia.

Prüss and Mariotti (2000) reported that the biological gradient was verified in most of the studies in which it was investigated, although they also noted that few studies examined this issue. Preventative measures through hygiene education and interventions aimed at reducing fly numbers have both resulted in decreases in trachoma (Emerson et al. 1999; Sutter and Ballard 1983).

*ASCARIASIS*

Ascariasis is caused by the large roundworm *Ascaris lumbricoides*. Eggs are passed in the faeces of an infected person and in poor sanitation conditions may contaminate the soil. Ingestion of infective eggs, from contaminated soil or from uncooked products contaminated with soil or wastewater containing infective eggs, cause the disease. Transmission does not occur from person to person. The knowledge on transmission pathway indicates that the disease is fully attributable to unsafe WSH.

The eggs can survive for months or years in favourable conditions and can, thus, pose an infective hazard for a considerable period of time.

A total of 14 studies examining the level of ascariasis and water and sanitation provision were identified by Esrey et al. (1991). These studies reported reductions between 0–83%, with a median reduction from all the studies of 28%. More recently, Cifuentes (1998) reported big differences in infection between children exposed to untreated wastewater and those exposed to either partially treated wastewater or rainwater irrigation (OR 5.71–13.18, depending upon the age group under consideration). Similar results were reported by Habbari et al. (2000), who showed that *Ascaris* infection was five times higher in children in the wastewater impacted regions compared to control regions. In Indonesia, Toma et al. (1999) reported a 64% reduction in *Ascaris* infection in people who used a latrine compared with those who did not.

A biological gradient is suggested from the results of the four rigorous studies identified by Esrey et al. (1991) where the rate of morbidity reduction was dependent upon the level of sanitation facility. The work of Cifuentes (1998) also indicates a dose–response relationship with children exposed to increasingly contaminated water having increased rates of infection.

The relationship is plausible and the study results are coherent. Eggs have been isolated from faecal samples, soil samples, water samples and hand-washing samples (Jonnalagadda and Bhat 1995). Additional experimental evidence is provided by the studies that have examined the increased use of latrines and noted the parallel decrease in both egg counts in soil and levels of infection (e.g. Arfaa et al. 1977).

#### *Trichuriasis*

Trichuriasis is caused by ingestion of the human infectious eggs of the whipworm *Trichuris trichiura*. The infection is not directly transmissible from person to person. As with other faecal–oral transmitted diseases, the mode of transmission indicates that the disease is fully attributable to unsafe WSH, although the risk factors for trichuriasis in relation to WSH do not seem to have been as well researched as the other illnesses covered here. Studies of prevalence often show an association between *Ascaris* and *Trichuris* infection (Anderson et al. 1993; Saldiva et al. 1999; Smith et al. 2001), suggesting similar modes of transmission.

Of the studies that were identified, Henry (1981) found that *Trichuris* infections decreased by 50% after water supplies and latrines were installed in a rural area of Saint Lucia. Rajeswari et al. (1994) noted that the prevalence of infection was associated with a number of factors, including socioeconomic status, water supply, sanitary disposal of faeces and family size. Similarly, Narain et al. (2000) found that open field defecation and large family size were independently associated with *Trichuris* infection.

*Hookworm disease*

Hookworm infection is caused by *Ancylostoma duodenale* or *Necator americanus*, and results from the ingestion or skin penetration of the hookworm larvae that live in the soil. Larvae develop in the soil through the deposit of faeces containing eggs from infected persons. The disease is therefore caused by poor sanitation and hygiene practices. The disease is not transmitted from person to person.

Eleven studies were identified by Esrey et al. (1991) which examined water, sanitation and hookworm infection. From the nine that could be used to calculate a reduction in morbidity, the range was 0–100%, although only one of these was considered to be rigorous. Sorensen et al. (1994) found that the severity of hookworm infection was lower in children coming from communities with good sanitary facilities.

Norhayati et al. (1995) studied the reinfection of children in a hookworm endemic area. In the absence of any interventions the reinfection rate at 4-months post-treatment was 30%. The authors suggested that long-term strategies incorporating education on personal hygiene, provision of toilets and safe water supply were required to control the rapid reinfection. Humphries et al. (1997) reported that hookworm egg counts were significantly higher in Vietnamese women who used fresh human faeces as a fertilizer in comparison to those who used either treated human faeces or did not use human faeces as a fertilizer.

## 2. Methods

The approach builds on methods presented in Prüss et al. (2002), which are further developed in this estimate.

There is strong evidence that, even in developed nations, there is a considerable burden of disease associated with poor-quality potable water or inappropriate sewage disposal and sanitary control. This was demonstrated by disease outbreaks such as the cryptosporidiosis and *Escherichia coli O157* epidemics, which affected Canada, the United States and the United Kingdom of Great Britain and Northern Ireland (Andersson and Bohan 2001; Bouchier 1998; Bruce-Grey-Owen Sound Health Unit 2000). In addition, there is a background of sporadic cases in which unsafe WSH has been implicated (Fewtrell and Delahunty 1995). Hence significant health gain is achievable through further improvement in developed nation WSH conditions. This improved condition represents the theoretical minimum exposure in which no disease transmission would occur through unsafe WSH.

As the five transmission pathways of the various outcomes caused by unsafe WSH are quite different (see section 1.2 of this chapter), two approaches for estimating the disease burden were chosen according to the outcome. The estimates of the burden of infectious diarrhoeal disease caused by unsafe WSH are based on exposure information. The burden of other diseases is entirely due to unsafe WSH.

## 2.1 Estimating exposure for diarrhoeal diseases

For estimating the burden of diarrhoeal disease caused by unsafe WSH, we used a scenario-based approach to define exposure categories. In this approach the risk of diarrhoeal disease is conditioned by a typical exposure or a representative combination of risk factors at commonly encountered levels. Six scenarios[1] (Table 16.2) were defined on the basis of the following:

**Table 16.2** Exposure scenarios

| *Level* | *Description* | *Environmental faecal–oral pathogen load* |
|---|---|---|
| VI | Population not served with improved water supply and no improved sanitation in countries which are not extensively covered by those services (less than 98% coverage), and where water supply is not likely to be routinely controlled | Very high |
| Vb[a] | Population having access to improved water supply but not served with improved sanitation in countries which are not extensively covered by those services, and where water supply is not likely to be routinely controlled (less than 98% coverage) | Very high |
| Va[a] | Population having access to improved sanitation but no improved water supply in countries where less than 98% of the population is served by water supply and sanitation services, and where water supply is likely not to be routinely controlled | High |
| IV | Population having access to improved water supply and improved sanitation in countries where less than 98% of the population is served by water supply and sanitation services, and where water supply is likely not to be routinely controlled | High |
| III[b] | IV and improved access/quality to drinking water; or<br>IV and improved personal hygiene; or<br>IV and drinking water disinfected at point of use, etc. | High |
| II | Population having access to improved water supply and sanitation services in countries where more than 98% of the population is served by those services; generally corresponds to regulated water supply and full sanitation coverage, with partial treatment for sewage, and is typical in developed countries | Medium to low |
| I | Ideal situation, corresponding to the absence of transmission of diarrhoeal disease through WSH | Very low |

[a] Transitions between exposure levels Va and Vb do not generally occur.

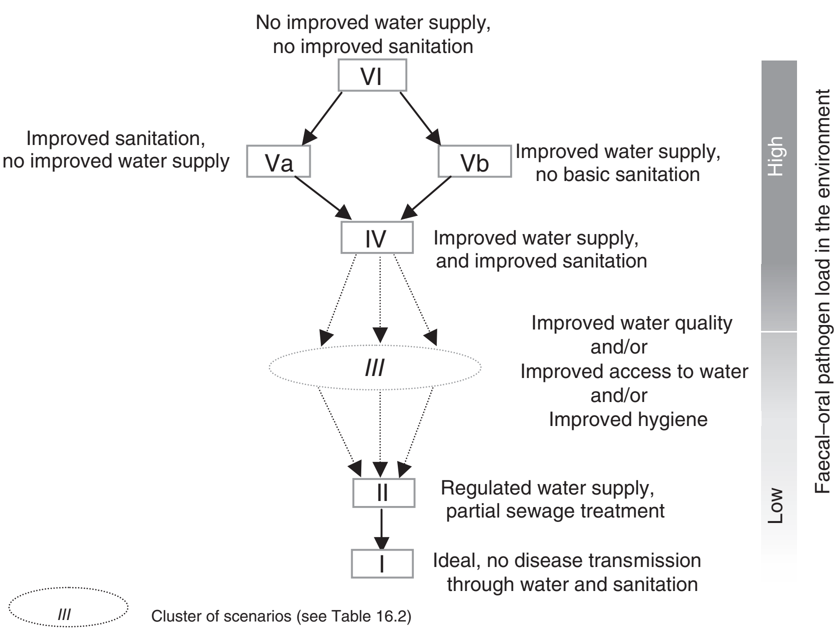
[b] Cluster of possible improvements over scenario IV, but not reaching scenario II.

- the type of water and sanitation infrastructure; and
- the load of faecal–oral pathogens in the environment based on qualitative assessment of sources and disease circulation in the community.

This choice was based on the absence of comprehensive exposure information at individual level and also the lack of relative risk information relating to individual exposure. Risk information was gathered from the literature to match each of the scenarios.

Scenario I represents the minimum theoretical risk and II the situation typically encountered in developed countries. These two scenarios have very low to medium loads of faecal–oral pathogens, characterized by more than 98% coverage in improved water supply and sanitation and a regional incidence of diarrhoea of less than 0.3 per person per year (Anonymus 2000; Murray and Lopez 1996b). Scenarios IV–VI are in a high faecal–oral pathogen environment, typical for developing countries. Scenario III represents any intervention that improves on scenario IV, and does not currently occur widely. As such, various transitions can be proposed for scenario III and so it is represented as a cluster of possibilities rather than a specific scenario (see Figure 16.2).

**Figure 16.2** Scenarios determining risk of diarrhoeal disease from unsafe WSH



*Data sources and quantification of exposure*

The exposure scenarios were selected according to available information on exposure–risk relationships and exposure information from the *Global water supply and sanitation assessment 2000* (WHO/UNICEF/WSSCC 2000). The data on water supply and sanitation coverage provided in this assessment are a compilation of two main sources: household surveys, and to a lesser degree assessment questionaires. Relevant information from available household surveys performed on a large scale was accessed, including:

- Demographic Health Surveys (DHS) performed by Macro International and funded by the United States Agency for International Development;
- United Nations Children's Fund's (UNICEF) Multiple Indicator Cluster Surveys (MICS);
- national census reports; and
- other national sample household surveys.

DHS and MICS are national cluster sample surveys, covering several thousand households in each country. The samples are stratified to ensure they are representative of urban and rural areas of each country. In household surveys, consumers are asked to identify the type of water facility they use from a list of technologies. In estimating coverage for the Global Water Supply and Sanitation Assessment 2000, the types of access to services were categorized into "improved" (e.g. borehole, protected dug well, simple pit latrine) and "not improved" (e.g. unprotected well, vendor-provided water, bucket latrines). In addition, national assessment questionnaires were completed by the relevant national agencies in cooperation with WHO and UNICEF country staff. The resulting country estimate for coverage was then based on linear regressions prepared according to available survey data. In the rare cases where household survey data were not available, the coverage figures adopted were those estimated by a local expert committee, based on national assessments and information provided by the country's water authorities.

The Assessment 2000 provides data for water supply and sanitation for almost every country, with information typically available for more than 90% of the population in every region. It is the only comprehensive assessment of this kind and is, therefore, the single source used for assessing exposure in this analysis. Overall, the Assessment 2000 represents more than 89% of the global population. Only the European and Western Pacific Regions contain large data gaps, with information on water supply and sanitation coverage lacking for some large countries. Subregions[2] with low information coverage include EUR-A (25% information coverage), EUR-B (65%), EUR-C (11%) and WPR-A (15%). In each case (based on those countries responding), we considered that the available figures on coverage were likely to be representative of the whole subregion. Countries without information were ascribed subregional coverage rates.

Using data from the Assessment 2000, it is not possible to assess whether those served with improved water corresponded to those with improved sanitation, as only coverage was reported. Reports suggest a strong societal and individual preference for improved water supply over improved sanitation, and this is further supported by the higher levels achieved worldwide for improved water supply when compared to improved sanitation. In apportioning populations among exposure scenarios IV and Vb, we therefore assumed that people with improved water supplies were likely to have access to improved sanitation.

The population of each country was thus assigned to the various scenarios based on the Assessment 2000 as described above, and population-weighted regional means were calculated. The resulting exposure distribution is represented in Table 16.3. In 2000, the percentage of people served with some form of improved water supply worldwide reached 82% (4.9 billion), and 60% (3.6 billion) had access to improved sanitation facilities. In 2000, one sixth (1.1 billion people) of the world's population was still without access to improved water supply and two fifths (2.4 billion people) lacked access to improved sanitation.

**Table 16.3** Distribution of the population in exposure scenarios, 2000

| *Subregion* | *II (%)* | *IV (%)* | *Va (%)* | *Vb (%)* | *VI (%)* |
|---|---|---|---|---|---|
| AFR-D | 0 | 54 | 5 | 6 | 35 |
| AFR-E | 0 | 42 | 10 | 9 | 38 |
| AMR-A | 99.8 | 0 | 0 | 0 | 0.2 |
| AMR-B | 0 | 76 | 1 | 9 | 14 |
| AMR-D | 0 | 68 | 0 | 7 | 25 |
| EMR-B | 0 | 83 | 5 | 8 | 4 |
| EMR-D | 0 | 66 | 0 | 16 | 18 |
| EUR-A | 100 | 0 | 0 | 0 | 0 |
| EUR-B[a] | 0 | 79 | 8 | 1 | 12 |
| EUR-C[a] | 0 | 94 | 5 | 0 | 1 |
| SEAR-B | 0 | 70 | 3 | 7 | 19 |
| SEAR-D | 0 | 35 | 0 | 53 | 12 |
| WPR-A | 100 | 0 | 0 | 0 | 0 |
| WPR-B | 0 | 42 | 1 | 33 | 24 |

[a] Low data coverage.

Source: Based on data from the *Global water supply and sanitation assessment 2000* (WHO/UNICEF/WSSCC 2000), assuming that improved water supplies are most likely to have sanitation coverage.

Scenario I does not occur on a large scale and, in global terms, is probably negligible, hence its omission from Table 16.3. Scenario III is a poorly characterized series of transition states between IV and II and is not separately accounted for. Such scenarios are nevertheless important concepts in policy development and are therefore retained in the model described in Figure 16.2.

### 2.2 Risk factor–disease relationships for diarrhoeal diseases

*Approach*

We selected major reviews, multi-country studies or studies of superior design to quantify the transition between two or more chosen exposure scenarios. This included the review and multi-country study by Esrey (Esrey 1996; Esrey et al. 1991), the reviews by Huttly et al. (1997) and Mead et al. (1999), in conjunction with key literature and high quality studies published since the review papers (Payment et al. 1991, 1997; Quick et al. 1999; Semenza et al. 1998). The majority of this literature was based on intervention studies and surveillance information. The final selection of used studies depended largely on the degree to which the study exposure data could be matched with the chosen exposure scenarios and also the sample size and quality of studies. Brief details on the chosen studies are outlined in Table 16.4.

*Relative risk for exposure scenario II*

The ideal situation (scenario I) is the theoretical minimum (RR = 1). In scenario II, the pathogen load is mostly transferred from land to water (e.g. in discharge of normally treated sewage, such as biological secondary treatment, to surface water). Such pathogens can potentially pass through potable water treatment systems, which can not guarantee 100% pathogen elimination in even the most advanced plants used in developed nations. Water contaminated with such pathogens is also used for other purposes such as recreation and irrigation. Hygiene behaviour is still imperfect in scenario II, and small population groups may still be served with poorly regulated community supplied water. In scenario I, the ideal scenario, all this would not occur.

Relative risk for scenario II was based on the review by Mead et al. (1999). Mead et al. assessed the level of all infectious foodborne illness in the United States, using data from a large number of surveys and other sources (including FoodNet, the National Notifiable Disease Surveillance System, the Public Laboratory Information System, the Foodborne Disease Outbreak Surveillance System, the National Hospital Discharge Survey, the National Vital Statistics System and a number of published studies). Based on the literature, they also estimated the percentage of each disease caused by foodborne transmission. This is a very comprehensive study based on more than 400 000 diagnosed cases, bringing

**Table 16.4** Key studies and reviews

| *Reference* | *Study population* | *Sample size* | *Outcome measured/ reported* | *Reductions* | *Comments* |
|---|---|---|---|---|---|
| Esrey (1996) | Representative populations from Bolivia, Burundi, Ghana, Guatemala, Morocco, Sri Lanka, Togo, Uganda | 16880 | Diarrhoea morbidity nutritional status, child development | 20.8–37.5% according to type of infrastructure | Detailed examination of effects of incremental improvements in water and sanitation based on survey data |
| Huttly et al. (1997) | Bangladesh, Burma, India, Indonesia, USA for hand-washing; Bangladesh, Guatemala, Thailand, Zaire for various other forms of behaviour | NA | Diarrhoea morbidity | Median reduction 35% for hand-washing; median 26% for other hygiene behaviours | Review paper/5 intervention studies on hand-washing and 5 on other hygiene behaviours |
| Mead et al. (1999) | Gastrointestinal illness in the USA population | More than 400000 diagnosed patients | Foodborne illness | Approx. 60% of gastrointestinal illness due to unsafe WSH[a] | Surveillance data |
| Payment et al. (1991) | 606 households in Montreal, Canada | 2408 | Diarrhoea morbidity | 35% | Water quality intervention |
| Payment et al. (1997) | 1400 families in Montreal, Canada | 5253 | Diarrhoea morbidity | 14–40% | Water quality intervention |
| Quick et al. (1999) | Two Bolivian communities | 791 | Diarrhoea morbidity | 45% for all age groups | Water quality intervention |
| Semenza et al. (1998) | Householders in Nukus, Uzbekistan | 1583 | Diarrhoea morbidity | 62–85% | Water quality intervention |

NA Not applicable.

[a] Extrapolated from study results for the purpose of this analysis.

together numerous different data sources and some assumptions relating to likely levels of underreporting. According to this study, about 35% of intestinal illness in the United States is foodborne. The level of faecal–oral illness due to unsafe WSH was estimated as 100% of the cases of infectious diarrhoea, less the percentage due to foodborne transmission. This is probably an underestimate as it is likely that unsafe WSH play a role in some foodborne transmission (e.g. through irrigation of food products with pathogen-contaminated water or via an infected food handler). After deduction of the portion of foodborne transmission and accounting for likely ratios of person-to-person transmission through aerosols of certain viruses (estimated as up to 25% for rotavirus and astrovirus), the remaining fraction attributable to unsafe WSH is about 60%. This order of magnitude is supported by intervention studies acting on point-of-use treatment of drinking water in Canada (Payment et al. 1991, 1997) and hand-washing in the United States (Black et al. 1981), reporting reductions of 40%, 35% and 48%, respectively. A 60% reduction in disease corresponds to a relative risk of 2.5 (RR = 1/(1 – 0.6)) for exposure scenario II.

*Risk transition between scenarios II and IV*

Scenarios II and IV represent high and low environmental pathogen loads. Intervention studies were not available, as it is not possible to transform environments high in pathogen load into environments low in pathogen load; doing so would imply completing the coverage in improved water supply and sanitation in a reasonable time frame and without simultaneous change in other major determinants of health. Therefore, relative risks for scenarios between II and IV were estimated using selected studies.

- *Scenario IV and improved drinking-water quality:* Quick et al. (1999) examined the level of diarrhoea prevention that could be achieved through point-of-use water treatment along with safe water storage. This study was selected as the intervention strongly reduces the pathway of transmission through drinking water, and "simulates" the reduction that could be achieved by improved drinking water quality and its handling inside the house. The study randomized 791 participants into two groups. The intervention group received a special storage container (preventing hand contact with the stored water) and a supply of disinfectant. The control group not receiving the intervention was similar in terms of demographic characteristics, sanitary conditions and baseline water quality. During the baseline investigations only 5% of household samples were free of *E. coli*. During the study period this varied between 0% and 13% of the control group (with the median level being between 5000 and 85 000 of *E. Coli*/100 ml), while the intervention group exceeded 50% of households at all times, rising to almost 80% on one occasion (median *E.*

*coli* counts were zero, throughout). Overall diarrhoea reductions of 44.7% in the total population and 54.5% in children have been reported by Quick et al. (RR=1.81 and 2.20). The reduction of 44.7% was selected as a component in the transition between II and IV in this analysis.

In a randomized intervention study in 240 households (120 with and 120 without access to municipal piped water) with a total population of 1583 in Uzbekistan (Semenza et al. 1998), approximately half of the households without piped water were trained to chlorinate their drinking water within the home and store it in a safe manner. Diarrhoea morbidity was markedly lower in the home-chlorination group (28.8/1000 subjects per month), compared to 75.5/1000 in the piped water group and 179.2/1000 in the no piped water group (i.e. a 62% reduction in diarrhoea rates for an intervention with home chlorination of drinking water, as compared to those living in areas with access to piped water [RR = 2.6]; in individuals without a piped supply, the same intervention achieved a 85% reduction in disease [RR = 6.7]). The authors considered that home chlorination of water was unlikely to affect disease transmission via other routes, and suggested that a large fraction of the diarrhoeal pathogens in this area were spread through water.

- *Scenario IV and improved personal hygiene:* reductions in diarrhoea morbidity have been reviewed by Huttly et al. (1997), and handwashing resulted in a median 35% reduction in diarrhoea incidence (RR = 1.5). The results of this review outlined possible achievements due to a reduction in the transmission pathway of hygiene, which in itself is conditioned by the pathogen load in the environment.

*RISK TRANSITION BETWEEN SCENARIOS IV AND VI*

The multi-country study conducted by Esrey (1996) provided data to allow calculation of relative risks between scenarios IV, Va, Vb and VI. This study examined whether incremental health effects relating to diarrhoea and nutritional status resulted from incremental improvements in water and sanitation conditions and was based on DHS from eight countries from five different regions (Bolivia, Burundi, Ghana, Guatemala, Morocco, Sri Lanka, Togo, Uganda). DHS included information on diarrhoea prevalence, child weight, child height, child age, source of drinking water and type of sanitation facility. In addition, the survey data were supplemented by field studies that determined current levels of diarrhoea prevalence in children aged 3–36 months. According to this study, a reduction of 20.8% in diarrhoeal disease rates (RR=1.26) could be observed when progressing from scenario VI to Vb (i.e. when providing an improved water supply), and 37.5% (RR=1.6) when progressing from VI to Va (i.e. when providing improved sanitation facilities). When progressing from VI to IV (i.e. when providing both an improved water

**Table 16.5** Relative risks

| | Exposure categories or transition between scenarios | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | *I* | *II* | *III* | *IV* | *Va (to IV)* | *Vb (to IV)*[a] | *VI (to Vb)* | *VI (to Va and IV)* |
| Risk reduction[b] | NA | 60% | Various[c] | 45% and 35% | 0% | — | 20.8% | 37.5% |
| Partial relative risk[a] | NA | 2.5 | Various[c] | 1.81 and 1.54 | 1.0 | 1.60/1.26 = 1.27 | 1.26 | 1.60 |
| Absolute relative risks (compared to scenario 1) | 1 | 2.5 | Various[c] | 6.9 | 6.9 | 8.7 | 11.0 | 11.0 |

NA Not applicable.

— No data.

a Obtained by calculating the remaining risk differences between VI to Vb as compared to VI and IV.

b Relative to the scenario below.

c See text.

supply and improved sanitation facilities), a reduction of 37.5% was also achieved. This implies that no further reduction in diarrhoeal disease is achieved when implementing an improved water supply, when improved sanitation is already available. These data are supported by the review of Esrey et al. (1991), which provides similar results for the same types of interventions.

The resulting relative risks are obtained by multiplying the relative risks between each scenario, summarized in Table 16.5.

According to our model, the risks of diarrhoea incidence in developing countries are 2.8 to 4.4 times higher (Table 16.5) than current risks in developed countries. The same order of magnitude of difference in diarrhoea rates was reported by various compilations of health statistics or studies (Esrey 1996; Murray and Lopez 1996b).

## 2.3 Estimating risk factor–disease relationships for diseases other than diarrhoeal diseases

The *World health report 2001* (WHO 2001) provided estimates of the burden of additional diseases that are exclusively (or virtually exclusively) caused by unsafe WSH (Table 16.6).

## 2.4 Sources of uncertainty

### *Method*

The method is based on typical scenarios, characterized by a combination of sub-risk factors, which should represent most of the world's situations. Certain population groups may not be captured by any one of these scenarios, but the number of groups is probably small, which may

**Table 16.6** Global disease burden caused by selected water-related diseases other than infectious diarrhoea in 2000

| *Disease* | *Deaths (000s)* | *DALYs (000s)* |
|---|---|---|
| Schistosomiasis | 11 | 1713 |
| Trachoma | 0 | 1161 |
| Ascariasis | 6 | 1252 |
| Trichuriasis | 2 | 1640 |
| Hookworm disease | 6 | 1829 |
| Total | 25 | 7595 |

Source: WHO (2001).

be partly internalized in the risk estimates. For example, differences are likely to exist in the specific WSH practices in the various households in the same exposure scenario. The effect of these differences should, however, largely be captured in the large samples on which this study is based. The current study is therefore based on average risks for large population groups within which a variety of individual practices and situations are represented.

*Exposure estimates*

The Water Supply and Sanitation Assessment 2000, which reports individual country data, exhibited variable precision between respondents, particularly in relation to rural and tribal populations. A more precise exposure estimate would require actual assessments, such as the water quality of the supply. Such measures are impractical on a large level. The Assessment 2000, however, captures exposure information for a majority of the world's countries and represents a solid source of information. Uncertainty in water supply and sanitation coverage has therefore not introduced major uncertainty into our analysis.

*Risk estimates*

This analysis used large surveys and multi-country studies where available. It is therefore based on risk averages, i.e. the average of risk related to the described scenarios across the world and across an array of situations. While this method may not be suitable for specific local settings, it should provide a reasonable estimate for large regions.

Where no large surveys, reviews or multi-country studies were available (i.e. in part the transition between scenarios IV and II), the use of sentinel studies for "global" application may constitute a significant source of error. Therefore, this analysis has been selective on the basis of study quality and coverage, to ensure maximum transferability.

As much of the described imprecision will remain largely unquantifiable, upper and lower uncertainty boundaries are based on varying the

**Table 16.7** Low and high relative risk estimates

| | *Exposure scenario* | | | | | | |
|---|---|---|---|---|---|---|---|
| | *I* | *II* | *III* | *IV* | *Va* | *Vb* | *VI* |
| Lower estimate | 1 | 2.5 | Variable | 3.8 | 3.8 | 4.9 | 6.1 |
| Best estimate | 1 | 2.5 | Variable | 6.9 | 6.9 | 8.7 | 11.0 |
| Upper estimate | 1 | 2.5 | Variable | 10.0 | 10.0 | 12.6 | 16.0 |

estimates of the potentially greatest source of uncertainty—the transition between scenarios IV and II (i.e. from an environment with a high faecal–oral pathogen load to one with a low faecal–oral pathogen load). The lower estimate was based solely on the improvement that can be achieved by implementing personal hygiene measures (35% risk reduction or a RR of 1.54). This is comparable with the best estimate, which is based on a combination of improved water quality and improved hygiene (see Table 16.5). For the upper estimate, the additional risk reduction relating to the provision of continuous piped water supply (i.e. improved access to water) was considered in addition to hygiene improvements. This is represented by a relative risk of 2.6 (from a 62% risk reduction from the study by Semenza et al. 1998) in addition to that resulting from hygiene improvements. The resulting relative risks for each of the estimates are summarized in Table 16.7.

The same relative risk is assumed for all age groups. As most of these rates have been assessed for children and the largest disease burden also occurs in that age group, the error of applying the same relative risks to adults is probably small. Also, several studies that have assessed both relative risks for children and adults have shown that figures do not generally differ dramatically, although the impact on young children tends to be higher (e.g. Quick et al. 1999).

It should be noted that faecal–oral disease transmission is partly conditioned by the prevalence of the risk factor at community level. For example, protection of drinking water depends on the effective implementation of an intervention by all members of the community, whereas studies have often been performed at individual level, generally resulting in underestimation of the benefits of community-wide interventions.

### *Sequelae and delayed effects*

Estimation of the burden of disease due to infectious diarrhoea is based upon the acute diarrhoeal episode and associated mortality. Several of the agents of infectious diarrhoea are associated with other health effects, often delayed. These may add significantly to the burden of disease, as is the case of campylobacteriosis, for example. Inadequate evidence was available to reliably estimate the additional burden of disease.

## 3. Results

The attributable fractions, deaths and number of DALYs are listed in the annex tables (see CD-ROM accompanying this book), for the 14 subregions, males, females and eight age groups.

Globally, in the year 2000, almost 1.73 million deaths due to diarrhoeal diseases were attributable to unsafe WSH as defined in the exposure variable used in this work; 68% of them are children. Most of these deaths, >99%, occur in developing countries. The attributable fractions of diarrhoeal disease vary between 60% in developed countries to 85–90% in developing countries. The difference in disease burden between developed and developing subregions, despite the relative similarities in attributable fractions, is largely due to the lower incidence and case fatality rates of diarrhoeal disease in developed nations. The African subregions alone, together with SEAR-D and EMR-D, bear 88% of the death burden. The disease burden in males and females is similar. The disease burden from the five other diseases that have been quantified separately is 25 000 deaths and 7.6 million DALYs, also concentrated in developing countries. This chapter highlights and confirms the concentration of the burden of disease due to the risk factor unsafe WSH in poor countries and on children—99.7% of DALYs and 99.8% of deaths occur in developing countries, with 80% of DALYs among children. Globally, 3.1% of all deaths and 3.7% of DALYs were attributable to water, sanitation and hygiene, caused by the diseases we could include in this analysis. In the age group 0 to 4 years, these percentages amounted to 11% of all deaths and 9% of all DALYs, which shows the importance of this risk factor.

## 4. Projections of future exposure

As the methods for estimating disease burden rely heavily on water supply and sanitation coverage, these are the main parameters that need to be projected for estimating future burden. Progress with water supply and sanitation coverage is affected by factors such as demographic change, income, policies and investments, education, technology, types and management of infrastructure, and involvement of the community and the public and private sectors. In practice, these vary widely within and between countries, making future projections difficult and complex.

To some extent these factors respond to major national and international policy initiatives. The International Drinking-water Supply and Sanitation Decade (1981–1990) established momentum that certainly produced an acceleration of investments from 1981 to 1990 and beyond this period. The Millennium Declaration established the targets of halving the proportion of the population not served with safe water supply by 2015 and improving sanitation for the urban poor. The impact of these historic and future activities on either overall progress with service levels or upon the factors outlined above is difficult to assess. The proposed coverage forecast method and respective coverage figures generated are presented below.

While efforts are ongoing to develop a model for forecasting improved water supply and sanitation coverage based upon understanding of the factors outlined above, the lack of sufficient data has limited the value of this in preparing future projections. Water supply and sanitation coverage may be predicted by certain distal causes such as income and education; however, in the given time frame a prediction based on past evolution and future demographic changes was preferred. Prediction on the basis of the Human Development Index provided similar results at global level. Global data sets on service coverage generated by WHO in the 1980s were primarily based on country reporting and provided results with limited comparability. More recently, WHO and UNICEF have assessed water supply and sanitation coverage in 1990 and 2000 (WHO/UNICEF/WSSCC 2000), based on household survey data and data by service providers (water agencies, ministries) in the absence of survey data. This shift in methodology provided more reliable and comparable data. The prediction was thus based on the following points.

- It was assumed that the same number of people that acquired coverage between 1990 and 2000 would acquire coverage per decade during the next three decades.
- Population projections from the United Nations Statistics Division (UN 2001) were used.
- For EUR-B and EUR-C, progress in the decade 1990–2000 shows declining trends and does not provide a reasonable basis for projection. Zero change in absolute numbers served was assumed.

It is important to note that this projection assumes that local, national and international efforts as undertaken in the last decades, will continue. The method further assumes no development of approaches or technologies that will enable a shift for part of the population into exposure scenario I, the ideal scenario.

Coverage was projected separately for each subregion. A summary of projected water supply and sanitation coverage is provided in Table 16.8, and a detailed projection per subregion, according to the exposure scenarios used in this analysis, is presented in Table 16.9.

The data presented suggest that the water supply goal and target[3] adopted in the Millennium Declaration are likely to be achieved globally if a similar effort as compared to that undertaken in the last decade is continued until the year 2015. For certain subregions, however, the target may not be achieved, namely those in the African continent, as well as EMR-B (where coverage is already high and where half of the population are likely to experience an important risk reduction), EUR-B and EUR-C, under the assumption that past trends will continue.

**Table 16.8** Global projection of water supply and sanitation coverage

| | | *Access to improved water sources* | | | *Access to improved sanitation* | | |
|---|---|---|---|---|---|---|---|
| *Year* | *Total population (millions)* | *Population served (millions)* | *% served* | *Population not served (millions)* | *Population with access (millions)* | *% having access* | *Population without access (millions)* |
| 1990 | 5 255 | 4 072 | 77 | 1 183 | 2 582 | 49 | 2 673 |
| 2000 | 6 057 | 4 976 | 82 | 1 081 | 3 646 | 60 | 2 411 |
| 2010 | 6 826 | 5 894 | 86 | 932 | 4 739 | 69 | 2 087 |
| 2015 | 7 207 | 6 353 | 88 | 854 | 5 285 | 73 | 1 922 |
| 2020 | 7 579 | 6 802 | 90 | 777 | 5 831 | 77 | 1 748 |
| 2030 | 8 270 | 7 681 | 93 | 589 | 6 902 | 83 | 1 368 |

It is not always possible to see clear trends within scenarios. This is likely to be due to highly variable rates of population growth and movement of populations between scenarios. Greatest health gains are likely to be associated with movement of populations from scenario VI to better circumstances. AFR-D and AFR-E contain the highest proportion of population in scenario VI. The forecasts indicate that the situation is not likely to change dramatically over the next 30 years if the trends of the last decade continue.

SEAR-D and WPR-B present large proportions of their population with fairly good levels of coverage but relatively low proportions of people served with sanitation facilities (scenario Vb). AMR-A, EUR-A, and WPR-A have reached or will soon reach 100% coverage (scenario II). SEAR-B and AMR-B are projected to make good progress, tending from exposure scenarios Vb and VI to IV and II. AMR-D, in addition to developing a trend similar to the trend above is likely to make considerable progress towards scenario II. EUR-C should experience a large shift into scenario II (two large countries that were close to full coverage in 1990 will reach such status by 2010).

### *Sources of error/sensitivity analysis*

Factors such as water scarcity, competition for water resources and the cumulative effects of pollution of water resources are likely to both increase the cost of interventions and reduce their sustainability. This is due to pressures on both the quality and availability of water resources and would suggest that the projections might be optimistic estimates.

## Acknowledgements

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**Table 16.9** Projection of distribution of exposure by scenarios, 2000 to 2030[a]

| | *II (%)* | | | | *IV (%)* | | | | *Va (%)* | | | | *Vb (%)* | | | | *VI (%)* | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Year* | | | | *Year* | | | | *Year* | | | | *Year* | | | | *Year* | | | |
| *Subregion* | *2000* | *2010* | *2020* | *2030* | *2000* | *2010* | *2020* | *2030* | *2000* | *2010* | *2020* | *2030* | *2000* | *2010* | *2020* | *2030* | *2000* | *2010* | *2020* | *2030* |
| AFR-D[b] | 0 | 1 | 1 | 0 | 54 | 55 | 54 | 54 | 5 | 2 | 1 | 1 | 6 | 11 | 12 | 14 | 35 | 32 | 32 | 31 |
| AFR-E | 0 | 16 | 12 | 12 | 42 | 44 | 42 | 48 | 10 | 7 | 4 | 3 | 9 | 7 | 11 | 6 | 38 | 27 | 31 | 31 |
| AMR-A | 99.8 | 100 | 100 | 100 | 0.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.2 | 0 | 0 | 0 |
| AMR-B | 0 | 0 | 4 | 4 | 76 | 81 | 81 | 85 | 1 | 0 | 0 | 1 | 9 | 10 | 10 | 9 | 14 | 8 | 4 | 2 |
| AMR-D | 0 | 0 | 17 | 16 | 68 | 77 | 65 | 68 | 0 | 1 | 1 | 1 | 7 | 6 | 5 | 3 | 25 | 15 | 13 | 11 |
| EMR-B | 0 | 3 | 7 | 53 | 83 | 83 | 79 | 34 | 5 | 5 | 5 | 5 | 8 | 4 | 3 | 1 | 4 | 5 | 6 | 7 |
| EMR-D | 0 | 23 | 22 | 21 | 66 | 53 | 59 | 65 | 0 | 0 | 0 | 0 | 16 | 10 | 6 | 3 | 18 | 13 | 13 | 11 |
| EUR-A | 100 | 100 | 100 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| EUR-B | 0 | 7 | 7 | 6 | 79 | 72 | 73 | 74 | 8 | 6 | 6 | 5 | 1 | 1 | 1 | 1 | 12 | 13 | 14 | 14 |
| EUR-C | 0 | 74 | 72 | 70 | 94 | 23 | 24 | 25 | 5 | 2 | 2 | 2 | 0 | 0 | 0 | 0 | 1 | 1 | 2 | 3 |
| SEAR-B | 0 | 27 | 20 | 19 | 70 | 45 | 56 | 61 | 3 | 0 | 1 | 0 | 7 | 17 | 17 | 17 | 19 | 11 | 7 | 3 |
| SEAR-D | 0 | 0 | 0 | 0 | 35 | 39 | 47 | 54 | 0 | 0 | 0 | 0 | 53 | 58 | 53 | 46 | 12 | 2 | 0 | 0 |
| WPR-A | 100 | 100 | 100 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WPR-B | 0 | 0 | 0 | 0 | 42 | 49 | 60 | 67 | 1 | 0 | 1 | 1 | 33 | 31 | 29 | 26 | 24 | 19 | 14 | 8 |

[a] Results in percentage of regional population.

[b] Rounding of percentages may lead to sums slightly different from 100%.

Source: José Hueb, personal communication.

2000, and the five peer reviewers. We also wish to acknowledge the valuable support and contribution of the U.S. Environmental Protection Agency. This chapter has not been subjected to Agency review and therefore does not necessarily reflect the views of the Agency.

## Notes

1 The scenarios are equivalent to exposure categories used in other chapters in this book, in the sense that there is increasing risk across scenarios defined based on faecal–oral load. The term scenario is used here, as the shift from one level of faecal–oral load to another may occur due to changes in any of the multiple dimensions of exposure (water, sanitation and hygiene).

2 See the preface for an explanation of this term.

3 To halve the proportion of people not having access to water supply services by 2015 compared to 1990.

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