I

Groundwater and public health

G. Howard, J. Bartram, S. Pedley, O. Schmoll, I. Chorus and P. Berger

Water-related disease remains one of the major health concerns in the world. Diarrhoeal diseases, which are largely derived from poor water and sanitation, accounted for 1.8 million deaths in 2002 and contributed around 62 million Disability Adjusted Life Years per annum (WHO, 2004a). On a global scale, this places diarrhoeal disease as the sixth highest cause of mortality and third in the list of morbidity and it is estimated that 3.7 per cent of the global disease burden is derived from poor water, sanitation and hygiene (Prüss-Ustün et al., 2004). This health burden is primarily borne by the populations in developing countries and by children.

At 2002 estimates, roughly one-sixth of humanity (1.1 billion people) lack access to any form of improved water supply within 1 kilometre of their home, and approximately 40 per cent of humanity (2.6 billion people) lack access to some form of improved excreta disposal (WHO and UNICEF, 2004). These figures relate to the clear definitions provided in the updated Global Water Supply and Sanitation Assessment Report and are shown in Table 1.1 below.

If the quality of water or sanitation were taken into account, these numbers of people without access to water supplies and sanitation would increase even further.

Endemic and epidemic disease derived from poor water supply affects all nations. Outbreaks of waterborne disease continue to occur in both developed and developing
countries, leading to loss of life, avoidable disease and economic costs to individuals and communities. The improvement of water quality control strategies, in conjunction with improvements in excreta disposal and personal hygiene can be expected to deliver substantial health gains in the population.

Table 1.1. Definition of improved and unimproved water supply and sanitation facilities (WHO and UNICEF, 2000)

<table>
<thead>
<tr>
<th>Water supply</th>
<th>Sanitation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Improved</strong></td>
<td><strong>Unimproved</strong></td>
</tr>
<tr>
<td>Household connection</td>
<td>Unprotected well</td>
</tr>
<tr>
<td>Public standpipe</td>
<td>Unprotected spring</td>
</tr>
<tr>
<td>Boreholes</td>
<td>Vendor-provided water</td>
</tr>
<tr>
<td>Protected dug well</td>
<td>Bottled water</td>
</tr>
<tr>
<td>Protected spring</td>
<td>Tanker-truck provided water</td>
</tr>
<tr>
<td>Rainwater collection</td>
<td></td>
</tr>
</tbody>
</table>

This monograph provides information on strategies for the protection of groundwater sources used for drinking-water as a component of an integrated approach to drinking-water safety management (WHO, 2004b). The importance of source protection as the first stage of managing water quality has been an important component in both national and international efforts. In their *Guidelines for Drinking-water Quality*, WHO (2004b and previous editions) emphasize the need for effective source protection.

The focus of this monograph is the public health aspects of groundwater protection. It does not address environmental concerns, such as ecological protection. The control of some pollutants, whilst of little importance for health, may be very important to environmental protection. For guidance on these areas, readers should consult appropriate texts such as Chapman (1996).

1.1 GROUNDWATER AS A SOURCE OF DRINKING-WATER

Groundwater is the water contained beneath the surface in rocks and soil, and is the water that accumulates underground in aquifers. Groundwater constitutes 97 per cent of global freshwater and is an important source of drinking-water in many regions of the world. In many parts of the world groundwater sources are the single most important supply for the production of drinking-water, particularly in areas with limited or polluted surface water sources. For many communities it may be the only economically viable option. This is in part because groundwater is typically of more stable quality and better microbial quality than surface waters. Groundwaters often require little or no treatment to be suitable for drinking whereas surface waters generally need to be treated, often extensively. There are many examples of groundwater being distributed without
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It is vital therefore that the quality of groundwater is protected if public health is not to be compromised.

National statistics for the use of groundwater as a source of drinking-water are sparse, but the importance of this resource is highlighted by figures published in Europe and the USA. The proportion of groundwater in drinking-water supplies in some European countries is illustrated in Table 1.2 and for the USA in Table 1.3. The data show that reliance upon groundwater varies considerably between countries; for example, Norway takes only 13 per cent of its drinking-water from groundwater sources, whereas Austria and Denmark use groundwater resources almost exclusively for drinking-water supply. A global estimate of one-third of the world’s population depending on groundwater supply is given by Falkenmark (2005).

Table 1.2. Proportion of groundwater in drinking-water supplies in selected European countries (EEA, 1999; UNECE, 1999)

<table>
<thead>
<tr>
<th>Country</th>
<th>Proportion</th>
<th>Country</th>
<th>Proportion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>99%</td>
<td>Bulgaria</td>
<td>60%</td>
</tr>
<tr>
<td>Denmark</td>
<td>98%</td>
<td>Finland</td>
<td>57%</td>
</tr>
<tr>
<td>Hungary</td>
<td>95%</td>
<td>France</td>
<td>56%</td>
</tr>
<tr>
<td>Switzerland</td>
<td>83%</td>
<td>Greece</td>
<td>50%</td>
</tr>
<tr>
<td>Portugal</td>
<td>80%</td>
<td>Sweden</td>
<td>49%</td>
</tr>
<tr>
<td>Slovak Republic</td>
<td>80%</td>
<td>Czech Republic</td>
<td>43%</td>
</tr>
<tr>
<td>Italy</td>
<td>80%</td>
<td>United Kingdom</td>
<td>28%</td>
</tr>
<tr>
<td>Germany</td>
<td>72%</td>
<td>Spain</td>
<td>21%</td>
</tr>
<tr>
<td>Netherlands</td>
<td>68%</td>
<td>Norway</td>
<td>13%</td>
</tr>
</tbody>
</table>

The data from the USA demonstrates the importance of groundwater particularly for smaller supplies, reflecting the generally limited treatment requirements. However, this has implications for control of public health risks as the management and maintenance of smaller supplies is often weaker than for larger, utility operated supplies (Bartram, 1999).

Table 1.3. Proportion of groundwater in drinking-water supplies in the USA by size of supply (US EPA, 2004)

<table>
<thead>
<tr>
<th>Population served</th>
<th>Proportion groundwater</th>
<th>Proportion surface water</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;500</td>
<td>89%</td>
<td>11%</td>
</tr>
<tr>
<td>500-1000</td>
<td>78%</td>
<td>22%</td>
</tr>
<tr>
<td>1001-3300</td>
<td>70%</td>
<td>30%</td>
</tr>
<tr>
<td>3301-10 000</td>
<td>57%</td>
<td>43%</td>
</tr>
<tr>
<td>10 000-50 000</td>
<td>43%</td>
<td>57%</td>
</tr>
<tr>
<td>&gt;50 000</td>
<td>26%</td>
<td>74%</td>
</tr>
</tbody>
</table>

Within countries the usage of groundwater may also vary substantially, depending on the terrain and access to alternative water sources. For instance, in the USA it ranges from 25 per cent or less in Colorado and Kentucky to more than 95 per cent in Hawaii.
and Idaho. In rural areas of the USA, 96 per cent of domestic water comes from groundwater. In the United Kingdom, although the national average for groundwater usage is 28 per cent, the southern counties of England depend more heavily on groundwater than the northern counties, Wales and Scotland.

In Latin America, many of the continent’s largest cities – Mexico City, Mexico, Lima, Peru, Buenos Aires, Argentina and Santiago de Chile, Chile – obtain a significant proportion of their municipal water supply from groundwater. In India, China, Bangladesh, Thailand, Indonesia and Viet Nam more than 50 per cent of potable supplies are provided from groundwater. In Africa and Asia, most of the largest cities use surface water, but many millions of people in rural areas and low-income peri-urban communities are dependent on groundwater. These populations are most vulnerable to waterborne disease. Pedley and Howard (1997) estimate that as much as 80 per cent of the drinking-water used by these communities is abstracted from groundwater sources.

Where it is available, groundwater frequently has important advantages over surface water. It may be conveniently available close to where it is required, can be developed at comparatively low cost and in stages to keep pace with rising demand. Although small, simple surface water supplies can be achieved relatively cheaply and pumping groundwater from deep aquifers may create significant operating costs, overall the capital costs associated with groundwater development are usually lower than with large-scale surface water supplies. For the latter, large, short-term capital investments in storage reservoirs often produce large, step-wise increments in water availability and temporary excess capacity that is gradually overtaken by the continuing rising demand for water. An additional disadvantage in some circumstances is that surface water reservoirs may have multiple, sometimes conflicting functions – water supply, flood control, irrigation, hydroelectric power and recreation – and cannot always be operated for the optimum benefit of water supply.

Furthermore, aquifers are often well protected by layers of soil and sediment, which effectively filter rainwater as it percolates through them, thus removing particles, pathogenic microorganisms and many chemical constituents. Therefore it is generally assumed to be a relatively safe drinking-water source.

However, groundwater has been termed the ‘hidden sea’ – sea because of the large amount of it, and hidden because it is not visible, thus pollution pathways and processes are not readily perceived (Chapelle, 1997). This highlights a key issue in the use of aquifers as drinking-water source, showing that particular attention is needed to ascertain whether the general assumption of groundwater being safe to drink is valid in individual settings. As discussed below, understanding the source-pathway-receptor relationship in any particular setting is critical to determine whether pollution will occur.

Whilst there is a large volume of groundwater in this ‘hidden sea’, its replenishment occurs slowly – at rates varying between locations. Over-exploitation therefore readily occurs, bringing with it additional quality concerns.
1.2 THE PUBLIC HEALTH AND SOCIOECONOMIC CONTEXT OF GROUNDWATER PROTECTION

The use of groundwater as a source of drinking-water is often preferred because of its generally good microbial quality in its natural state. Nevertheless, it is readily contaminated and outbreaks of disease from contaminated groundwater sources are reported from countries at all levels of economic development. Some groundwaters naturally contain constituents of health concern: fluoride and arsenic in particular. However, understanding the impact of groundwater on public health is often difficult and the interpretation of health data complex. This is made more difficult as many water supplies that use groundwater are small and outbreaks or background levels of disease are unlikely to be detected, especially in countries with limited health surveillance. Furthermore, in outbreaks of infectious disease, it is often not possible to identify the cause of the outbreak and many risk factors are typically involved.

Throughout the world, there is evidence of contaminated groundwater leading to outbreaks of disease and contributing to background endemic disease in situations where groundwater sources used for drinking have become contaminated. However, diarrhoeal disease transmission is also commonly due to poor excreta disposal practices and the improvement of sanitation is a key intervention to reduce disease transmission (Esrey et al., 1991; Curtis et al., 2000). Furthermore, water that is of good quality at its source may be re-contaminated during withdrawal, transport and household storage. This may then require subsequent treatment and safe storage of water in the home (Sobsey, 2002).

Ensuring that water sources are microbially safe is important to reduce health burdens. However, a balance in investment must be maintained to ensure that other interventions, also important in reducing disease, are implemented. Diverting resources away from excreta disposal, improved hygiene practices in order to achieve very good quality water in sources may be counter-productive (Esrey, 1996). Balancing investment decisions for public health gain from water supply and sanitation investment is complex and does not simply reflect current knowledge (or lack of) regarding health benefits, but also the demands and priorities of the population (Briscoe, 1996).

Groundwater is generally of good microbial quality, but may become rapidly contaminated if protective measures at the point of abstraction are not implemented and well maintained. Further problems are caused by the creation of pathways that short-circuit the protective measures and natural layers offering greatest attenuation, for instance abandoned wells and leaking sewers. Pollution may also occur in areas of recharge, with persistent and mobile pollutants representing the principal risks.

The control of the microbial quality of drinking-water should be the first priority in all countries, given the immediate and potentially devastating consequences of waterborne infectious disease (WHO, 2004b). However, in some settings the control of chemical quality of groundwater may also be a priority, particularly in response to locally important natural constituents such as fluoride and arsenic. Furthermore, hazardous industrial chemicals and pesticides which can accumulate over time may potentially render a source unusable. The scale, impact and the often lack of feasible clean-up technologies for some chemical contamination in groundwater means that they should receive require priority for preventative and remedial strategies.
Groundwater also has a socioeconomic value. It is often a lower cost option than surface water as the treatment requirements are typically much lower. In many countries, groundwater is also more widely available for use in drinking-water supply. This may provide significant advantages to communities in obtaining affordable water supplies, which may have benefits in terms of promoting greater volumes of water used for hygiene and other purposes. The natural quality of groundwater also makes its use valued in industry, and it may provide environmental benefits through recharge of streams and rivers or for the growth of vegetation. These other benefits reinforce the need for its protection.

The actions taken to protect and conserve groundwater will also create costs to society, through lost opportunity costs for productive uses of land and increased production costs caused by pollution containment and treatment requirements. When developing protection plans and strategies, the cost of implementing such measures should be taken into consideration, as well as the cost of not protecting groundwater, in order for balanced decisions to be made.

1.3 GROUNDWATER QUANTITY

The interrelated issues of groundwater quality and quantity can best be addressed by management approaches encompassing entire groundwater recharge areas or groundwater catchments. These units are appropriate both for assessing pollution potential and for developing management approaches for protection and remediation. Excessive groundwater abstraction in relation to recharge will lead to depletion of the resource and competition between uses, e.g. between irrigation and drinking-water supply. Strong hydraulic gradients ensuing from abstraction can induce the formation of preferential flow paths, reducing the efficacy of attenuation processes, and thus lead to elevated concentrations of contaminants in groundwater. Furthermore, changes in groundwater levels induced by abstraction may change conditions in the subsurface environment substantially, e.g. redox conditions, and thus induce mobilization of natural or anthropogenic contaminants.

Groundwater quantity issues may have substantial impacts on human health. Lack of a safe water supply affects disease incidence for instance by restricting options for personal and household hygiene. Competing demands for groundwater, often for irrigation and sometimes for industry, may lead to shortage of groundwater for domestic use. In such situations it is important to ensure allocation of sufficient groundwater reserves for potable and domestic use and health authorities often play an important role in this. This monograph largely focuses on water quality issues, as these are of direct relevance to the provision of safe drinking-water. Quantity issues are therefore addressed in the context of their impact on groundwater quality.

This text is concerned with groundwater as a source of drinking-water supply. However, in many locations other uses, for example irrigation, account for the largest fraction of groundwater abstraction, and inter-sectoral collaboration may be needed to develop effective groundwater allocation schemes.
1.4 DISEASE DERIVED FROM GROUNDWATER USE

Groundwater contributes to local and global disease burdens through the transmission of infectious disease and from chemical hazards.

1.4.1 Infectious disease transmission through groundwater

The global incidence of waterborne disease is significant, though it can only be estimated since reliable data are not sufficiently available for direct assessment of disease cases (Prüss-Ustün et al., 2004). The contribution of groundwater to the global incidence of waterborne disease cannot be assessed easily, as there are many competing transmission routes; confounding from socioeconomic and behavioural factors is typically high; definitions of outcome vary; and, exposure-risk relationships are often unclear (Esrey et al., 1991; Payment and Hunter, 2001; Prüss and Havelaar, 2001). Many waterborne disease outbreaks could have been prevented by good understanding and management of groundwaters for health. Pathogen contamination has often been associated with simple deficiencies in sanitation but also with inadequate understanding of the processes of attenuation of disease agents in the subsurface.

The most comprehensive reports of waterborne disease outbreaks come from two countries, the USA and the United Kingdom, and some indications of the role of groundwater in the infectious diarrhoeal disease burden can be estimated in these countries (Craun, 1992; Hunter, 1997; Payment and Hunter, 2001; Craun et al., 2003; 2004).

Lee et al. (2002) identified that of 39 outbreaks of waterborne disease in the USA between 1999 and 2000, 17 were due to consumption of untreated groundwater, although approximately half of these outbreaks were reported from individual water supplies, which are not operated by a utility and served less than 15 connections or less than 25 persons. A further eight were reported in non-community supplies, which serve facilities such as schools, factories and restaurants.

A detailed analysis of the incidence of waterborne disease in the USA was published in the mid-1980s by Craun (1985), which is still relevant. In his summary of data from the period between 1971 and 1982, Craun reports that untreated or inadequately treated groundwater was responsible for 51 per cent of all waterborne disease outbreaks and 40 per cent of all waterborne illness. A recent analysis of public health data in the USA showed little change to the epidemiology of disease outbreaks (Craun et al., 1997). Between 1971 and 1994, 58 per cent of all waterborne outbreaks were caused by contaminated groundwater systems, although this is in part is due to the higher number of water supplies using groundwater than those using surface water.

Craun et al. (2003) report that for the period 1991-1998, 68 per cent of the outbreaks in public systems were associated with groundwater, an increase from previous reports (Craun, 1985; Craun et al., 1997). However, this apparent increase is likely to be due in part to the introduction of the USA Surface Water Treatment Rule in 1991, which requires 'conventional filtration' of most surface water supplies. In general it appears that waterborne outbreaks in the USA decreased after 1991, with the introduction of more stringent monitoring and treatment requirements.
Craun et al. (2004) provide a detailed discussion of waterborne outbreaks in relation to zoonotic organisms (organisms with an animal as well as human reservoir) between 1971 and 2000 in the USA. They note that 751 outbreaks were reported linked to drinking-water supplies during this period, the majority (648) being linked to community (year-round public service) water supplies. The aetiology was either known or suspected in 89 per cent of the outbreaks and zoonotic agents caused 118 outbreaks in community systems representing 38 per cent of outbreaks associated with these systems and 56 per cent of those where aetiology was identified. The data show that the majority of illnesses and deaths were caused by zoonotic agents in the reported waterborne outbreaks.

The zoonotic agents of greatest importance were *Giardia*, *Campylobacter*, *Cryptosporidium*, *Salmonella*, and *E. coli* in outbreaks caused by contaminated drinking-water. The majority of outbreaks caused by zoonotic bacteria (71 per cent) and *Cryptosporidium* (53 per cent) were reported in groundwater supplies. The use of contaminated, untreated or poorly treated groundwater was responsible for 49 per cent of outbreaks caused by *Campylobacter*, *Salmonella*, *E. coli*, and *Yersinia*. Groundwater that was contaminated, untreated or poorly treated contributed 18 per cent of all outbreaks caused by *Giardia* and *Cryptosporidium*.

Kukkula et al. (1997) describe an outbreak of waterborne viral gastroenteritis in the Finnish municipality of Noormarkku that affected some 1500-3000 people, i.e. between 25 and 50 per cent of the exposed population. Laboratory investigations confirmed that adenovirus, Norwalk-like virus and group A and C rotaviruses were the principal causative agents. The source of the outbreak was thought to be a groundwater well situated on the embankment of a river polluted by sewage discharges. In 1974 an outbreak of acute gastrointestinal illness at Richmond Heights in Florida, USA was traced to a supply well that was continuously contaminated with sewage from a nearby septic tank (Weissman et al., 1976). The main aetiological agent was thought to be *Shigella sonnei*. During the outbreak approximately 1200 cases were recorded from a population of 6500.

Outbreaks of cryptosporidiosis have also been linked to groundwater sources, despite being usually regarded as a surface water problem. A large outbreak of cryptosporidiosis occurred in 1998 in Brush Creek, Texas, USA from the use of untreated groundwater drawn from the Edwards Plateau karst aquifer (Bergmire-Sweat et al., 1999). There were 89 stool-confirmed cases and the estimated number of cases was between 1300 and 1500. This outbreak was associated with the consumption of water drawn from deep wells of over 30 m located more than 400 m from Brush Creek.

In 1997, epidemiological investigations traced an outbreak of cryptosporidiosis in the United Kingdom to water abstracted from a deep chalk borehole. Three hundred and forty five confirmed cases were recorded by the investigation team, who claimed this to be the largest outbreak linked to groundwater to have been reported (Willcocks et al., 1998). This incident has particular significance because the water used in the supply was drawn from a deep borehole and was filtered before distribution.

In the outbreak of *E. coli* O157:H7 and *Campylobacter* in Walkerton, Ontario in Canada in 2000, the original source of pathogens appears to have derived from contaminated surface water entering into a surface water body directly linked to an abstraction borehole (Health Canada, 2000). Although the series of events leading to the
outbreak indicate a failure in subsequent treatment and management of water quality, better protection of groundwater would have reduced the potential for such an outbreak. An outbreak of E. coli O157:H7 occurred among attendees at the Washington Country Fair, New York, USA and was shown to be caused by consuming water from a contaminated shallow well that had no chlorination (CDC, 1999). A total of 951 people reported having diarrhoea after attending the fair and stool cultures from 116 people yielded E. coli O157:H7. This outbreak resulted in hospitalization of 65 people, 11 children developed haemolytic syndrome and two people died.

In developing countries evidence of the role of groundwater in causing disease outbreaks is more limited, although there have been numerous studies into the impact of drinking-water, sanitation and hygiene on diarrhoeal disease. In part the limited data on groundwater related outbreaks reflects the often limited capacity of local health surveillance systems to identify causal factors and because it is common that several factors may be implicated in the spread of disease. However, the limited data on outbreaks specifically linked to groundwater may also reflect that improved groundwater sources are generally of relatively good quality. Diarrhoeal disease related directly to drinking-water is most likely to result from consumption of poorly protected or unimproved groundwater sources, untreated or poorly treated surface water, contamination of distribution systems and recontamination of water during transport. Pokhrel and Viraraghavan (2004) in a review of diarrhoeal disease in Nepal in relation to water and sanitation, cite examples from South Asia where contamination of groundwater supplies has led to outbreaks of disease.

A study of local populations in Kanpur, India recorded an overall incidence rate of waterborne disease of 80.1 per 1000 population (Trivedi et al., 1971). The communities in the study areas took water from shallow groundwater sources, analysis of which revealed that over 70 per cent of the wells were contaminated. Of the cases of waterborne disease investigated, the greatest proportion was of gastroenteritis, followed by dysentery.

In addition to outbreaks, there is some evidence of contaminated groundwater contributing to background levels of endemic diarrhoeal disease. For example, Nasinyama et al. (2000) showed that the use of protected springs in Kampala, Uganda which were in generally in poor condition was associated with higher rates of diarrhoea than the use of piped water supplies. Much of this disease burden is thought to occur in developing countries where the use of untreated water from shallow groundwater sources is common in both rural and peri-urban settlements (Pedley and Howard, 1997).

1.4.2 Chemical hazards

The risk to health from chemicals is typically lower than that from pathogens. The health effects of most, but not all, chemical hazards arise after prolonged exposure, and tend to be limited to specific geographical areas or particular water source types. Much remains to be understood about the epidemiology of diseases related to chemical hazards in water and the scale of disease burden remains uncertain. However, some data do exist. Craun et al. (2004) report that 11 per cent of waterborne outbreaks in the USA between 1971 and 2000 were associated with acute effects following ingestion of a chemical.
Ensuring that chemicals of health concern do not occur at significant concentrations in groundwaters implies understanding sources of pollution, aquifer vulnerability and specific attenuation processes as well as recognizing the importance of naturally-occurring chemicals of health concern. In groundwater, however, there are two contaminants in particular that represent particular hazards of concern: fluoride and arsenic.

Fluoride affects bone development and in excess leads to dental or, in extreme form, skeletal fluorosis. The latter is a painful debilitating disease that causes physical impairment. However, too little fluoride has also been associated with dental caries and other dental ill-health (WHO, 2004b). Drinking-water is the principal route of exposure to fluoride in most settings, although burning of high fluoride coal is a significant route of exposure in parts of China (Gu et al., 1990).

Arsenic causes concern given the widespread occurrence in shallow groundwaters in Bangladesh, West Bengal, India and in groundwater in several other countries. The scale of arsenic contamination is most severe in the shallow groundwater of Bangladesh. At present, the total population exposed to elevated arsenic concentrations in drinking-water in Bangladesh remains uncertain, but is thought to be somewhere between 35 and 77 million and has been described as the largest recorded poisoning in history (Smith et al., 2000; BGS and DPHE, 2001). Problems are also noted in countries as diverse as Mexico, Canada, Hungary and Ghana, although the source of arsenic and control strategies available vary. The true scale of the public health impact of arsenic in groundwater remains uncertain and the epidemiology is not fully understood.

In the case of Bangladesh, the lack of country-wide case-controlled studies makes estimating prevalence of arsenicosis difficult. In a recent evaluation of data collected by the DPHE-Unicef arsenic mitigation programmes, Rosenboom et al. (2004) found a prevalence rate of arsenicosis (keratosis, melanosis and de-pigmentation) of 0.78 per 1000 population exposed to elevated arsenic (above 50 µg/l) in 15 heavily affected Upazilas (an administrative unit in Bangladesh). These authors note, however, that the data were difficult to interpret and that exposure had been relatively short and therefore these numbers could increase. The lack of a national cancer prevalence study makes estimations outside small cross-section studies problematic.

Increasing numbers of countries in Asia are now identifying arsenic contamination of groundwater (including Cambodia, China, Laos, Myanmar, Nepal, Pakistan and Viet Nam). In India, increasing numbers of areas are being identified as arsenic affected beyond West Bengal (School of Environmental Studies, Jadavpur University, 2004). This demonstrates that arsenic is an important contaminant for public health and concern is growing.

Other chemical contaminants of concern in groundwater may also lead to health problems. These include nitrate, uranium and selenium. Of these, nitrate is of concern as it is associated with an acute health effect (methaemoglobinaemia or infantile cyanosis). The scale of the health burden derived from nitrate remains uncertain although it has been suggested to cause significant health problems in some low-income countries where levels in groundwater reach extremely high values (Melian et al., 1999). Nitrate is also of concern given that it is stable once in groundwater with reasonably high oxygen content,
where it will not degrade. Thus it may accumulate to a long-term water resource problem that is expensive and difficult to remediate and whose effect may not be noticed until concentrations become critical.

1.5 GROUNDWATER IN THE CONTEXT OF INTERNATIONAL ACTIVITIES TO REDUCE WATER-RELATED DISEASE

The International Drinking Water Supply and Sanitation Decade (IDWSSD; 1980-1990) provided a sustained focus on the need for concerted efforts to accelerate activities to increase global access to safe water supply and to sanitation. The Rio Earth Summit (1992) placed water both as resource and as water supply on the priority agenda and the World Summit on Sustainable Development in 2002 also placed safe drinking-water as a key component of sustainable development. In September 2000, 189 UN Member States adopted the Millennium Development Goals (MDGs). Target 10 of the MDGs is to halve by 2015 the proportion of people without sustainable access to safe drinking-water and basic sanitation; the baseline for this target has been set as 1990. Other important initiatives have included a Protocol on Water and Health to the 1992 Convention on Use of Transboundary Watercourses and International Lakes (Box 1.1).

Box 1.1. The WHO-UNECE Protocol on Water and Health (UNECE and WHO, 1999)

The WHO-UNECE Protocol on Water and Health to the 1992 Convention on the Protection and Use of Transboundary Watercourses and International Lakes is an international legal instrument on the prevention, control and reduction of water-related diseases in Europe.

A major product of the Third European Ministerial Conference on Environment and Health (1999), the Protocol was signed at the Conference by 35 countries and represents the first major international legal approach for controlling water-related disease. It has become legally binding for the 16 countries that have ratified it in 2005. By adopting the Protocol, the signatories agreed to take all appropriate measures towards achieving:
- adequate supplies of wholesome drinking-water;
- adequate sanitation of a standard which sufficiently protects human health and the environment;
- effective protection of water resources used as sources of drinking-water and their related water ecosystems from pollution from other causes;
- adequate safeguards for human health against water-related diseases;
- effective systems for monitoring and responding to outbreaks or incidents of water-related diseases.
The Global Environmental Monitoring System Water programme, launched in 1977 by UNEP in collaboration with UNESCO, WHO and WMO, has the overall objective of observing and assessing global water quality issues in rivers, lakes and groundwater by collecting together and interpreting data from national monitoring networks. A first assessment of freshwater quality published in 1989 (Meybeck et al., 1989) included discussion of links between water quality and health. The programme was reviewed and evaluated in 2001 with a view to enhancing its ability to contribute to inter-agency global programmes, including the Global International Waters Assessment and the UN-wide World Water Assessment Programme.

Recently, the World Bank has established a groundwater management advisory team (GW-MATE) to develop capacity and capability in groundwater resource management and quality protection through World Bank programmes and projects and through the activities of the Global Water Partnerships regional networks.

WHO's activities in support of safe drinking-water span across the range of its functions as a specialized agency of the UN system (Box 1.2).

**Box 1.2. WHO activities related to safe drinking-water**

*Evidence and information:* Burden of disease estimates (at global level and guidance on their conduct at other levels); and cost-effectiveness water interventions (generically at global level and guidance on their conduct at other levels).

*Status and trends:* Assessing coverage with access to improved sources of drinking-water, and to safe drinking-water (with UNICEF through the Joint Monitoring Programme).

*Tools for good practice:* Evidence-based guidance on effective (and ineffective) technologies, strategies and policies for health protection through water management.

*Normative guidelines:* Evidence-based and health-centred norms developed to assist development of effective national and regional regulations and standards.

*Country cooperation:* Intensive links to individual countries through its network of six regional offices, regional environment centres and country offices.

*Research and testing:* Encouraging and orienting research; developing and encouraging the application of protocols to increase harmonization, exchange and use of data. Publication with IWA of the Journal of Water and Health (http://www.iwapublishing.com/template.cfm?name=iwapwaterhealth).

*Tools for disease reductions:* Focussing especially on settings such as healthy cities, healthy villages, healthy schools.
1.6 GROUNDWATER IN THE WHO GUIDELINES FOR DRINKING-WATER QUALITY

Since 1958 WHO has published at about ten year intervals several editions of *International Standards for Drinking-water* and subsequently *Guidelines for Drinking-water Quality*. The third edition of the Guidelines, published in 2004, includes a substantial update of the approach towards the control of microbial hazards in particular based on a preventive management approach. In preparing the third edition of the Guidelines a series of state-of-the-art reviews was prepared on aspects of water quality management and human health (Box 1.3) of which *Protecting Groundwater for Health* is one.

In the overall context of the *Guidelines for Drinking-water Quality* (GDWQ), this monograph serves two purposes: it provides the background information on potential groundwater contamination as well as approaches to protection and remediation that were taken into account in developing the third edition of the GDWQ. Further, *Protecting Groundwater for Health* supplements it by providing comprehensive information on: assessing the potential for contamination of groundwater resources, prioritizing hazards and selecting management approaches appropriate to the specific socioeconomic and institutional conditions.

**Box 1.3. State of the art reviews supporting the third edition of WHO Guidelines for Drinking-water Quality (selected titles)**

- Water Safety Plans: Managing Drinking-water Quality from Catchment to Consumer (Davison et al., 2005)
- Water Treatment and Pathogen Control: Process Efficiency in Achieving Safe Drinking-water (LeChevallier and Au, 2004)
- Assessing Microbial Safety of Drinking-water: Improving Approaches and Methods (Dufour et al., 2003)
- Rapid Assessment of Drinking-water Quality: A Handbook for Implementation (Howard et al., 2003)
- Domestic Water Quantity, Service Level and Health (Howard and Bartram, 2003)
- Managing Water in the Home: Accelerated Health Gains from Improved Water Supply (Sobsey, 2002)
- Water Quality: Guidelines, Standards and Health: Assessment of Risk and Risk Management for Water-related Infectious Disease (Fewtrell and Bartram, 2001)
- Chemical Safety of Drinking-water: Assessing Priorities for Risk Management (in preparation)
A central approach of the third edition of the GDWQ is the development of a reliable preventive safety management approach: a Framework for Safe Drinking-water, the three key requirements of which are described in Box 1.4. This includes the introduction of Water Safety Plans (WSPs) as a management tool for avoidance and control of groundwater contamination. These are described in Chapter 16 of this book.

### Box 1.4. The three key requirements of WHO’s Framework for Safe Drinking-water (WHO, 2004b)

1. **Health-based targets** based on an evaluation of health concerns.
2. Development of a **Water Safety Plan (WSP)** that includes:
   - *System assessment* to determine whether the water supply (from source through treatment to the point of consumption) as a whole can deliver water of a quality that meets the health based targets.
   - *Operational monitoring* of the control measures in the drinking-water supply that are of particular importance in securing drinking-water safety.
   - *Management plans* documenting the system assessment and monitoring plans and describing actions to be taken in normal operating and incident conditions, including upgrading, documentation and communication.
3. A system of **independent surveillance** that verifies that the above are operating properly.

This approach meets the need for developing an understanding of the key steps in the supply chain at which pollution may be introduced or prevented, increased or reduced. Effective management implies identifying these, ideally through a quantitative system assessment. The framework also includes identification of the appropriate measures to ensure that processes are operating within the bounds necessary to ensure safety. For drinking-water supply from groundwaters these controls may extend into the recharge area but may also relate to more immediate source protection measures, such as wellhead protection. Some of the measures to verify safe operation of processes relevant to groundwater safety may be amenable to sophisticated approaches such as on-line monitoring of levels (e.g. of landfill effluents). Others (such as the ongoing integrity of a well plinth) are best approached through periodic inspection regimes.

### 1.7 REFERENCES


Protecting Groundwater for Health

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