
3. Hazards in drinking-water supply and waste management

3.1 Microbial risks: waterborne infectious disease

From a public health point of view, the reliable supply of safe drinking-water is vital for daily life. Unfortunately, the same water that sustains life can also be the bearer of dangerous contaminants in the form of bacteria, viruses and protozoans. These include bacteria such as toxigenic *Escherichia coli* and *Campylobacter*, viruses like *Norovirus* and *Hepatitis E*, and protozoans like *Giardia* and *Cryptosporidium*. The risk of infection and disease and the public health burden is determined by the severity of illnesses that are caused by the pathogens, the extent of the exposure, their infectivity, and the physical condition and susceptibility of the exposed population.

3.1.1 Microorganisms in water

Natural bodies of water such as lakes and rivers and groundwaters normally contain nutrients; certain microorganisms (bacteria, viruses, etc.) have evolved to take advantage of this environment. Fortunately, most of these microorganisms do not cause disease in humans, that is they are not pathogenic. In addition to microorganisms that live on nutrients in the water, still more come from runoff from soil in the vicinity. But once again, the majority of the microorganisms from soil are not harmful.

However, it is common for sewage to be discharged into these waters, without adequate treatment. Many microorganisms in sewage pose a real threat to health. Wastes from domestic and wild animals can also pose a danger. Other sources and routes of exposure may also be significant; in addition to ingestion, inhalation of aerosol droplets and contact with contaminated water can also be sources of infection (WHO 2004a).

Humans may be infected by these pathogens by drinking contaminated water or by eating uncooked shellfish that have concentrated harmful organisms they have extracted from contaminated water. Foods that have been irrigated with untreated sewage, fertilized with untreated excreta or processed with contaminated water are also an indirect source of risk. Microorganisms may seep through some soils for long distances until they reach a body of surface water or groundwater. Leaking septic tanks and inadequate latrines may contaminate nearby drinking-water sources. Some soils, such as sandstone, are effective at filtering microorganisms, but coarser and fractured soils

may allow transport of pathogenic organisms for long distances and depths.

A further cause of contamination of drinking-water is through the improper storage of water in household storage tanks and cisterns, and in smaller containers after it has been drawn. This is a common source of pathogens in drinking-water in developing countries.

3.1.2 Which microorganisms are important?

The pathogenic microorganisms from human and animal waste that are found in contaminated drinking-water include bacteria, viruses and protozoans, and many of the illnesses that they cause can be fatal. Some of the important water-borne pathogenic bacteria include several salmonellae organisms such as the typhoid bacterium, *Vibrio cholerae* bacillus, *Shigella* spp., pathogenic and enterohaemorrhagic *E. coli*, and *Yersinia enterocolitica*. Some notable pathogenic viruses in water include *Hepatitis A* and *Hepatitis E* virus, *Norovirus*, *Sapovirus* and *Rotavirus*. Notable pathogenic protozoans in water include *Giardia intestinalis*, *Entamoeba histolytica* (the cause of amoebiasis), and *Cryptosporidium parvum*. Some helminthes that cause disease from water contact include *Dracunculus medinensis* and *Schistosoma* spp.

3.1.3 Estimating levels of water quality and sewage contamination

The WHO Guidelines for Drinking-water Quality focus on *E. coli* (preferred) and thermotolerant coliform bacteria, which are present in large quantities in the intestines of warm-blooded animals, as the best indicators of the sanitary quality of water supplies. However, they alone are not necessarily sufficient indicators for viruses and protozoa. *E. coli* are relatively easily disinfected, but viruses and protozoa are usually much more resistant to chlorine and (especially) chloramines. The latter are in fact weak disinfectants. *E. coli* are well known to public health and plumbing professionals as a sign of recent contamination of water with human or animal waste. Analysis by culture methods may require 24 to 48 hours per test. *E. coli* normally only survive in water for a few days, so measuring levels of *E. coli* under standard conditions is a way of estimating the level of recent human or animal faecal contamination. Total coliform bacteria measurements are used in some countries as conservative indicators of the sanitary condition of the drinking-water; however, they are not direct indicators of sanitary contamination, especially in tropical countries, where many bacteria of no sanitary significance occur in almost all untreated supplies.

3.1.4 Microbial growth in plumbing: heterotrophs, *Legionella* and *Pseudomonas*

Heterotrophs

Microorganisms grow in drinking-water distribution systems, especially in the absence of a residual disinfectant. Most of these are heterotrophs that require an external source of carbon, and they grow in water, on particulates and on

surfaces in contact with water as biofilms, and also on foods. They can also include a broad spectrum of opportunistic pathogen microorganisms such as *Aeromonas*, *Flavobacterium*, *Serratia*, *Pseudomonas* and *Klebsiella*, but there is no evidence in the general public of an association of any of these organisms with gastrointestinal infection through ingestion of drinking-water (WHO 2004a); there may be concerns with some severely immunocompromised persons and hospital environments (Bartram et al. 2003). They are found in all waters without residual disinfectant, including bottled waters, and on carbon filters and other treatment devices and surfaces. Most heterotrophs are not harmful to healthy persons, but they can be a nuisance by generating tastes and odours or discoloration of water supplies. The principal determinants of growth of heterotrophs are lack of disinfectant residual, warm temperature, availability of nutrients including organic carbon, and stagnation. They are measured by aggregate heterotrophic plate count (HPC) tests that detect a wide range of organisms, including many bacteria and fungi. High counts are more likely to be indicative of biofilms and lack of cleanliness in the system and availability of nutrients. In the absence of indicators of sanitary significance (e.g. *E. coli*), HPC organisms in themselves are not indicative of faecal contamination.

Legionella

Legionella are among the exceptions to harmless growth organisms in distributed water, and they are not measured by HPC tests. *Legionella* can grow to significant numbers in warm waters, hot water heaters, hot tubs, hot water lines and shower heads, and probably in the plumbing systems of large buildings, and in cooling towers for air conditioner heat exchangers. Special precautions are required to prevent and control *Legionella* in hospitals and health care facilities, because aerosols from showers, spas and cooling systems are a route of infection and those facilities contain high-risk populations. *Legionella* grow well in water at temperatures in the range of about 25 °C to 50 °C. Preventive and remedial controls are essential, especially in hospitals and health care facilities (Surman-Lee 2006). The WHO Guidelines for Drinking-water Quality indicates that the water temperature should be maintained outside the range of 25–50 °C, at which *Legionella* proliferates (WHO 2004a); however, hot water temperatures above 50 °C may also present a scalding risk to young children and the elderly (see section 3.3).

Pseudomonas aeruginosa

Pseudomonas aeruginosa microorganisms also grow in piped plumbing and distribution systems and on devices under the conditions cited above. They can cause a range of infections but rarely cause serious illness in healthy individuals. They are a significant problem in hospital environments where the organism can colonize damaged sites such as burn and surgical wounds, the respiratory tracts

of susceptible people and physically damaged eyes, and they have caused skin infections in hot tubs and spas. Cleaning of contact lenses with contaminated solution can cause a type of keratitis. Ingestion of drinking-water is not an important source of infection (WHO 2004a).

3.2 Chemical risks

Since the end of the 19th century the main health focus for drinking-water supply has been on microbial risks. Microbial contamination remains the most significant, imminent and large-scale manageable risk associated with drinking-water when water is not properly managed. Chemical contamination of drinking-water can result from natural or human-related contamination of surface water or groundwater, or contamination that occurs during the treatment of water (disinfection by-products), or delivery through mains or household water (corrosion).

The number of potentially harmful chemical contaminants (if present at sufficient concentrations) identified in drinking-water in small amounts has been increasing rapidly over the last twenty years due to the development of analytical methods capable of detecting levels in parts per billion and parts per trillion. These chemicals are usually present at extremely low concentrations when detected. Water is just one source and usually not the most important source of exposure to most of these chemicals, except for disinfection by-products. A few of these contaminants have been shown to cause adverse effects in humans when ingested via highly contaminated water. Some of the more common contaminants detected, with their mode of occurrence and health effects under some exposure conditions, are: arsenic (natural; cancer), fluoride (natural; dental and crippling skeletal fluorosis), lead (corrosion of lead pipe; neurological effects), pesticides (agricultural use and spills; variable effects), nitrate and nitrite (agricultural and sewage; infant deaths), radon (natural geology to indoor air and some groundwaters; cancers), sulfates (natural; causing temporary diarrhoea to non-residents). Arsenic, fluoride and nitrate/nitrite are probably the most important examples that have shown demonstrable health effects from consumption of contaminated water.

Some groups, including young children and the immunocompromised, may have higher than average risk of the effects of some chemical exposures in the environment compared to the general population. Examples include the effect of aluminium on dialysis patients when inadequately treated dialysis water is used; the impact of lead poisoning on pregnant women and infants, usually as a result of exposure to lead paint dust; and the effects of arsenic on people with compromised nutritional status.

Arsenic is widely distributed in small quantities in waters around the world. However, thirty years ago in Bangladesh millions of shallow surface wells were drilled to reduce the risk of gastrointestinal diseases from highly polluted

surface water. Unfortunately, the groundwater from many of these shallow tube wells was contaminated with arsenic and this was not determined before the wells were put into service. It has been estimated that over 40 million people in Bangladesh are exposed to potentially risky levels of arsenic in water. The WHO guideline value for arsenic is 10 parts per billion; however, some countries use 50 parts per billion as an interim goal due the difficulty and cost of removing arsenic from drinking-water.

Fluoride is another natural water component that has caused serious consequences when it is present in excessive amounts. At recommended values it has beneficial effects by reducing tooth decay (guideline value is 1.5 milligrams per litre, but national regulators should also take into account climatic conditions, fluoride intake from other sources and total water consumed). At slightly higher consumption levels fluoride can cause discoloration of tooth enamel, and at even higher levels (greater than about 14 milligrams per day) serious adverse skeletal effects occur.

Nitrate and **nitrite** in excess are a particular risk to infants, causing methaemoglobinaemia, which may result in morbidity and death from short exposures. The WHO guidelines are 50 milligrams per litre for nitrate and 3 milligrams per litre for nitrite, and the sum of the ratios of each to its guideline value should not exceed 1 (WHO 2004a). Nitrate and nitrite are usually present in water contaminated with sewage, septic tank effluent or agricultural runoff. Combined exposure to nitrate or nitrite and gastrointestinal disease-causing microorganisms seems to cause the greatest risk of methaemoglobinaemia.

Epidemiological studies of environmental contaminants are usually driven by concerns arising from episodes of exposure or evidence of chronic exposure. However, attempts to understand the epidemiology of chemical contamination of drinking-water reveal a number of complex issues that make such studies difficult to carry out. These issues include:

- the fact that drinking-water is seldom the principal source of exposure, except for arsenic and fluoride in some cases;
- the wide variation in the amount of contamination from non-drinking-water sources;
- difficulty in measuring dietary concentrations;
- difficulty in accurately defining the duration and magnitude of human exposure;
- the relative impact of other factors besides chemicals that may contribute to similar health risks.

A poor assessment of relative risks sometimes makes it difficult for officials to make good public health decisions. They should rely on recognized national and international health authorities and make use of solid background information

such as the WHO Guidelines for Drinking-water Quality as guides for these matters (WHO 2004a).

Drinking-water is drawn from an environment that changes constantly as a community develops. Therefore, it is increasingly important that there is constant awareness of developing sources of potential contamination from industry, waste disposal or agricultural practices, or changes in urbanization patterns. Medical authorities, environmental epidemiologists, toxicologists, chemists, engineers and exposure analysts need to effectively communicate and work collaboratively to help risk managers determine which environmental hazards are real, to help regulators make sensible and realistic standards and to help policy-makers make the best environmental policy and water management decisions. The WHO Guidelines for Drinking-water Quality provide comprehensive and up-to-date guidance to decision-makers by providing consensus recommendations developed by international experts from all of those disciplines.

3.3 Other risks

3.3.1 Hot water and scalding

Burns from hot tap water can result in severe injuries to young children and the elderly. Almost all hot water burns in children occur in the bathroom. The average temperature of hot water systems in Australia is 65 °C. Water at this temperature can inflict a severe burn on a child in less than half a second. In many industrialized countries, the average hot water temperature is 60 °C, which will cause a severe burn in about five seconds.

While parents can help reduce the risk by checking bath temperatures and by supervising children, the obvious answer is to minimize the risk by reducing the temperature of the water in the hot water system to below 55 °C (but not below 50 °C, which would increase *Legionella* risk), depending on the specifications of the system that has been installed. An alternative is to install thermostatically controlled mixing valves on the bath taps. Other alternative strategies to prevent accidents with children are the installation of a child-resistant hot water tap (with a push and turn movement similar to that used in the caps of medicine bottles) or the provision of a childproof tap cover. Tap covers are only suitable for certain kinds of taps.

Whenever any maintenance or scheduled work is carried out overnight, procedures must be in place to ensure that occupants are notified and aware of the dangers. There have been instances when pasteurization (temporarily raising the temperature of the hot water system above normal levels) in homes for the aged has had fatal consequences. The Institute of Plumbing and Heating Engineering in the United Kingdom of Great Britain and Northern Ireland recommends maximum outlet temperatures as follows: bidet 38 °C; shower 41 °C;

washbasin 41 °C; bath 44 °C; and supervised bath 46 °C (see sections 3.1.4 and 14.3.1) (IPHE 2005).

Some plumbers have argued that reducing water temperature is not a simple matter. The following potential disadvantages must be taken into account:

- The cost of storage of larger quantities of lower temperature hot water may be higher than that of smaller quantities of hotter water.
- The water may not be hot enough for other purposes, such as washing kitchen dishes.
- Storage of tepid water may introduce a risk of bacterial growth (*Legionella*, *Mycobacterium avium* and *Pseudomonas aeruginosa*).

The ideal solution is to maintain a reservoir of relatively hot water, but to ensure that high-temperature water cannot be accessed in shower or bath taps. This can be done with a thermostatically controlled mixing valve at the bath or shower.

3.3.2 Damage to buildings and land

Flowing water can exert significant force and under some circumstances this force can result in damage to buildings and to land. Plumbers should be aware of the potential damage to building structures that can be caused by water hammer. Installation of water hammer arresters and antioscillation valves will reduce this risk. Damage to foundations and other structures can be caused by uncontrolled water and wastewater runoff.

3.3.3 Corrosion

All water is corrosive in some circumstances, but excessive corrosion is a serious economic and potential health problem. It may lead to structural failures and deterioration of chemical and microbiological quality, including exceedance of guideline values for lead, copper and iron. Corrosion is partial dissolution of any (especially metal) materials in the plumbing system. It can be caused by interactive water quality factors including pH, insufficient or excess alkalinity, temperature and galvanic action. Corrective actions are sometimes complex and may involve management of calcium, carbonate and bicarbonate, dissolved oxygen, and especially maintaining the appropriate pH, which should usually be in the approximate range of 7 to 8.5 to minimize corrosion.

3.3.4 Incrustation

Water containing excessive amounts of bicarbonates, carbonates or iron has a tendency to deposit minerals on the pipe surface. These minerals are solid and difficult to remove without mechanical cleaning, which is costly. This mineral deposition reduces the internal volume of the pipe and thus reduces the flow

capacity; sometimes this leads to total blockage. In addition, this irregular surface can become a locus for biofilms and can harbour microorganisms, shielding them from contact with disinfectant. It can also cause excessive disinfectant demand.