Fawell, J. (2007): Chemical contaminats of concern for drinking water. In: Lozán, J. L., H. Grassl, P. Hupfer, L.Menzel & C.-D. Schönwiese. Global Change: Enough water for all? Wissenschaftliche Auswertungen, Hamburg. 384 S. Online: www.klima-warnsignale.uni-hamburg.de

2.8 Chemical contaminants of concern for drinking water

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SUMMARY: *While pathogens remain the most important contaminants in drinking water, some chemicals occur in drinking water that are also a significant cause of disease when present at elevated concentrations. There is also an increased perception that many chemicals only found in trace quantities, if at all, are a significant cause of disease. However, only arsenic, fluoride, nitrate in combination with microbial infection/ contamination and possibly selenium have been shown to cause adverse health effects in humans through drinking water. WHO provides guideline values for many contaminants against which safe levels can be judged and provides advice on how to assess the potential risks of concentrations in excess of guideline values. WHO also proposes the use of water safety plans to provide a risk assessment/risk management approach to ensuring safe drinking water that also includes identifying and assessing risks from chemical contaminants.*

While microbiological contaminants in drinking water are considered to be of primary importance, there are a number of chemical contaminants that are of concern for health and there is also often a perception that chemicals are very important, even when this is not actually the case. One of the major differences between chemical and microbial contaminants is that while chemicals are generally associated with adverse health effects only after an extended period of exposure, even a very short exposure to waterborne pathogens can give rise to disease.

While the most important chemical contaminants from a human health perspective are those generally associated with effects arising from long-term exposure and those which can be found in both surface and groundwater, there are occasions in which there are accidental spills of large quantities of chemical contaminants to surface waters. These are a particular issue for rivers that have drinking water intakes downstream of industrial complexes or mining activity. In this case the primary requirement is to determine whether the concentrations of the spilled contaminants are sufficiently high to cause immediate injury and what action(s) can be taken either to treat the water or to avoid abstraction of the contaminant by closing intakes for the period when the contaminant is passing. WHO provides advice on the use of the guidelines in emergency situations such as accidental spills (WHO 2004).

WHO in their Guidelines for Drinking-water Quality (WHO 2004) has introduced the concept of Drinking Water Safety Plans as a means of ensuring that a supply is capable of providing safe water. A key part of this process is identifying hazards in the catchment, assessing the risks to drinking water and the health of drinking water consumers and developing risk management procedures, including plans for dealing with accidental spills and emergencies. As another part of this process guideline values have been determined for a number of the most important and most common chemical contaminants found in drinking water or which may reach drinking water. In addition WHO has developed a protocol to assist in determining which chemicals could pose a risk to drinking water supplies (WHO 2006a). From a global perspective, some of the most important and most commonly encountered chemicals are discussed here but other sources consider a wider range of substances (WHO 2004, FAWELL & STANFIELD 2000, FAWELL & NIEUWENHUIJSEN 2003).

Naturally occurring chemicals

As water percolates through rock strata or through soil it can dissolve or leach chemical components. These can be inorganic compounds or ions that are frequently found in drinking water but usually at widely varying concentrations. They can also be organic compounds that derive from the breakdown of plant material. The third source is algae in surface water that can give rise to a range of toxins and other products. However, the potential effects on health and the risks to health vary significantly between the different contaminants.

Arsenic is found in many countries, usually in groundwater, in specific areas, where it is leached from arsenic rich sedimentary deposits. However, in some regions it is found in significantly elevated concentrations that have been shown to give rise to serious adverse health effects in those individuals drinking contaminated water over extended periods of time (WHO 2006b, IPCS 2001). High concentrations have been found in drinking water from wells in many parts of the developed and developing world, but most seriously in Bangladesh and Bengal, South America and parts of the Far East, particularly parts of China. In Bangladesh, arsenic is associated with tube wells but the concentration in a particular well can be difficult to predict due to variations in the aquifer and the depth of wells.

Arsenic is associated with a range of adverse effects including hyperkeratosis of the skin and peripheral vascular disease. However, the greatest concern is that of cancer of the skin, lung, bladder and probably the liver. Indeed arsenic is the only substance that is causally associated with human cancer as a consequence of long-term exposure through drinking water. There is considerable controversy over the assessment of the dose response for arsenic

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carcinogenicity and therefore the risks associated with low concentrations. The WHO guideline value is currently 10 µg/litre (WHO 2004) but this is designated provisional because of uncertainties over the dose response and is based on the practical limit of achievability by treatment. However, treatment for small supplies requires careful operation and in many circumstances even this concentration may not be achievable. As a consequence it is very important to take into account local circumstances and the benefits of water that contains arsenic but is microbiologically safe. Currently theoretical models used to estimate risk have a great deal of uncertainty and it remains unclear whether exposure to concentrations of up to 50 µg/litre will result in a detectable increase in cancer cases. This is further complicated by the fact that there is evidence from the epidemiology that local factors such as genetic differences in metabolism and of nutritional status may affect arsenic toxicity. In addition, higher intakes of water above the WHO default value of 2 litres per person per day and local food staples such as soups or stews that are left to simmer for long periods concentrating the arsenic from the water as it evaporates can contribute to a significant increase in intake from water. As a consequence of the uncertainties, there is considerable research activity in this area to try and resolve these questions.

In some countries **fluoride** is added to drinking water to help prevent the formation of dental caries; this is recognised as being protective of public health. Fluoride is also commonly added to dental products in many countries. However, fluoride can be naturally present at high concentrations in drinking water in significant of areas of the world, which is a major cause of serious adverse health effects in affected regions (WHO 2004, 2006c). High intakes of fluoride can result in dental fluorosis, which in its more severe form is an unsightly brown mottling of the teeth; milder forms of fluorosis can only be detected by trained professionals. However, high intakes of fluoride over an extended period of time can give rise to the much more serious condition of skeletal fluorosis, which is a crippling disability that has a major public health and socio-economic impact, affecting millions of people in various regions of Africa, China and India (IPCS 2002). A WHO expert group concluded that there is clear evidence from India and China that skeletal fluorosis and increased risk of bone fractures occur at a total intake of 14 mg fluoride per day and evidence suggestive of an increased risk of effects on bone at intakes above 6 mg fluoride per day (IPCS 2002). Although the problem is found in many parts of the world, drinking water concentrations can exceed 10 mg/litre in parts of Africa, the Indian sub-continent and the Far East. However, it should be noted that there are other sources of fluoride such as high fluoride coal in China and brick-tea in various parts of the world. The presence of dental fluorosis can be used as one of the first indicators of high fluoride intake and should trigger an investigation of the source or sources of fluoride. WHO has produced a monograph on fluoride, which describes geographical areas in which naturally high fluoride can be found in drinking water, some of the treatments that can be applied at a local level and provides a decision tree to assist in determining suitable actions (WHO 2006d). The WHO guideline value for fluoride in drinking water is 1.5 mg/litre based on an intake of 2 litres of drinking water per day and a combination of practicality both for beneficial use and for naturally occurring fluoride, and minimising the risk of dental fluorosis (WHO 2004). However, WHO emphasise the importance of considering local circumstances and total intake in setting standards. It is, therefore important to consider the actual intakes of drinking water and it is also important to ensure that the problem is not as a consequence of exposure from other sources that may also require intervention.

Selenium is an essential trace element with a required intake of about 100 µg/d and person. When ingested in amounts of more than a few 100 µg/d, it can cause damage to hair and nails, and cause damage to the liver. In some rare circumstances naturally-occurring concentrations of selenium in groundwater may be sufficiently high to cause health problems, although other sources of selenium are probably also important (WHO (2004).

Blue-green algae or ***Cyanobacteria***, are a natural part of the microscopic flora of water bodies found in many countries in most parts of the world. They can form substantial and rapid growths in still or slow-flowing waters when the conditions are right and these can be seen as dense paint-like accumulations with a range of colours (see. *Fig. 2.8-1*). These organisms can produce a number of natural by-products, including muco- and lipopolysaccharides and potentially a range of different toxins. They can also produce geosmin and methyl isoborneol, which are of no specific concern for health but which can cause unpleasant tastes and odours at very low concentrations. There are a number of toxins that can be produced and these broadly fall into two main categories, hepatotoxins that affect the liver and neurotoxins affecting the nervous system. The main hepatotoxins are the microcystins, of which microcystin-LR is the most common, and cylindrospermopsin. The neurotoxins appear to be less commonly encountered but include anatoxin-a and saxitoxin, which is the same agent that causes paralytic shellfish poisoning in marine waters. The only toxin for which WHO has set a guideline value is microcystin-LR (1.0 µg/litre). Data on human populations are limited but there is evidence of effects in some specific incidents. Analysis is difficult and potentially expensive and treatment of drinking water may also be difficult. The recommended approach to managing the risks from these compounds is to prevent the formation of the blooms by managing surface waters. More detailed consideration of this problem and remedial measures is given in the WHO monograph on the subject (CHORUS & BARTRAM 1999).

Chemicals from Agriculture

Agriculture is a significant user of water and various agricultural practices can contribute to the contamination of drinking water sources. The primary concern from this sector is that of nitrate, which is usually associated with shallow wells in agricultural areas although high nitrate levels can also be found in some surface waters. Nitrate can give rise to methaemoglobinaemia or blue-baby syndrome in bottle-fed infants. However, more recent data (AVERY 1999) has shown that simultaneous microbial contamination of the drinking water has a significant impact in increasing the risk of blue-baby syndrome. It is, therefore, important to ensure that water used for infants is also microbiologically safe. WHO has developed a guideline value of 50 mg/litre (as nitrate) to protect bottle-fed infants but have indicated that between 50 and 100 mg/litre the water can be used as long as it is microbiologically safe and there is increased surveillance for the occurrence of methaemoglobinaemia in infants(WHO 2006e). It is also important that consideration is taken of the possible presence of nitrite in the drinking water because nitrite is a more potent methaemoglobinaemic agent than nitrate and the two must be considered together (WHO 2004). Badly sited and leaking septic tanks or pit latrines can also be a significant source of nitrate contamination of groundwater and so siting of wells and latrines needs to be carefully

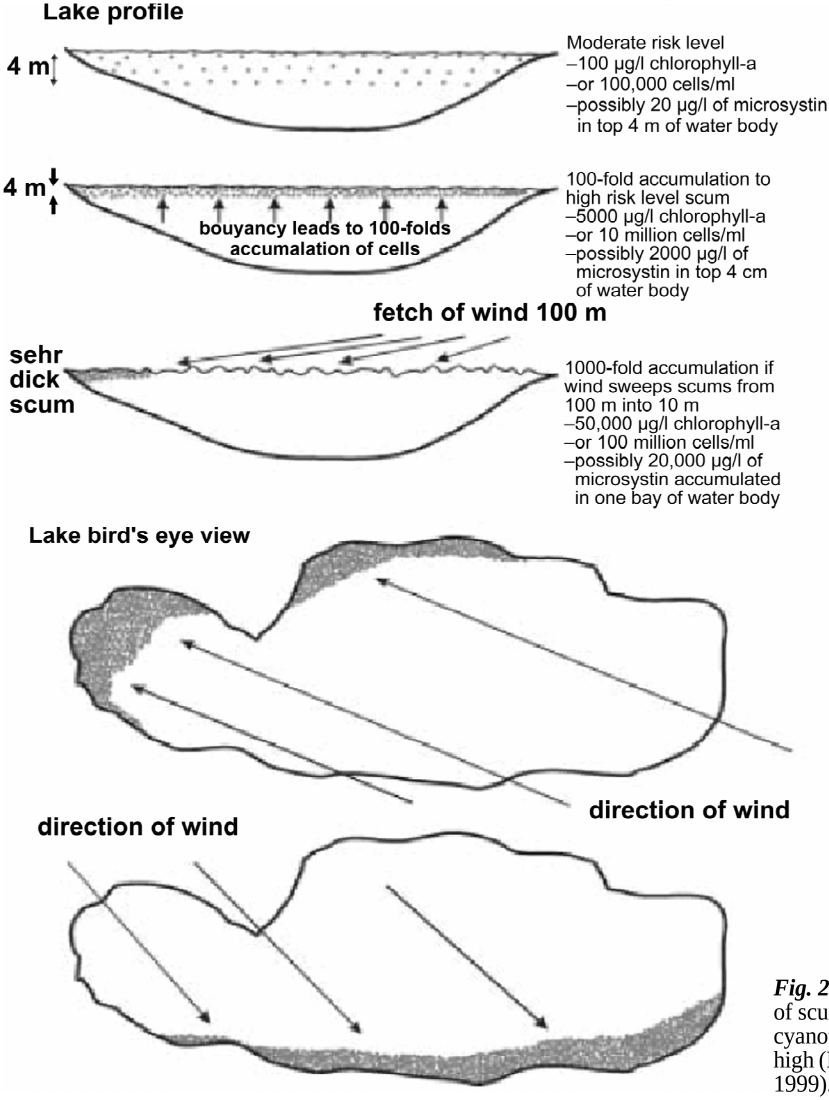

Fig. 2.8-1: Schematic illustration of scum formation changing the cyanotoxin risk from moderate to high (From CHORUS & BARTRAM 1999).

planned. Protection of wells from surface water run-off and ensuring that manure stores are kept away from wells are also important protective steps.

Pesticides are often cited as a significant concern in drinking water but the concentrations found are usually small and evidence of actual health problems associated with exposure from drinking water is lacking. However, serious local contamination can occur and it is important to minimise the potential for contamination of water by pesticides by ensuring sensible use near drinking water sources and wells, including mixing pesticides away from wells and water courses. The comments with regard to well protection also apply to pesticides. In addition there is considerable variation in the pesticides used in different countries and it is therefore important to determine which pesticides are actually used before implementing regional pesticide abatement programmes.

Contaminants from industry and hazardous waste sites

There is a wide range of possible contaminants that can arise from industrial activity and illegal or careless disposal. The most common of are oils and gasoline, which are widely used and often carelessly handled. While WHO has considered these under the heading of petroleum products no formal guidelines have been set for the complex mixtures that can occur (WHO 2006f). However, health-based guideline values have been set for the key compound and human carcinogen benzene and the BTEX compounds (toluene, ethylbenzene and xylenes), which are relatively water-soluble. WHO has published a guideline value for benzene in drinking-water of 10 µg/litre, corresponding theoretically to an additional lifespan risk of 10^{-5} to contract cancer by exposure to benzene via drinking-water (WHO 2004). The primary problem associated with BTX and similar substances in petroleum products is that of taste and odour, which can render drinking water unpalatable and unacceptable to consumers at levels much lower than those that could cause adverse health effects (WHO 2004). As with agricultural contaminants preventing contamination is vital and this can be achieved by relatively simple means.

An additional problem that can occur is that of contamination of groundwater by **chlorinated solvents**. WHO has established guidelines for these substances that are almost entirely found in groundwater because they readily volatilise from surface water (WHO 2003, 2004). The primary cause of contamination from these types of substances is poor handling and allowing used solvent to be spilt or poured onto the ground. Disposal or illegal disposal of waste solvent in pits has also been identified as a significant cause of groundwater pollution. Although there are no data to confirm health effects at low concentrations normally found in drinking water, they are possible at high concentrations.

Contaminants arising from treatment or from materials in contact with water

Concern has been expressed about the unwanted **disinfection by-products** (DBPs) of chlorination arising from the reaction of chlorine with naturally occurring organic matter. WHO has considered the health effects from DBPs in detail and emphasises that disinfection should never be compromised in trying to reduce such by-products because of the demonstrably greater public health benefits from chlorination compared to the possible low risks of adverse effects from unwanted by-products of chlorination (WHO 2004, IPCS 2000). These include groups of substances such as trihalomethanes and the haloacetic acids. While there has been considerable research on the potential health effects of long-term exposure to these substances there is still only equivocal evidence of a small increase in cancer risk. Where there are larger treatment systems, removing the precursors by oxidative treatment and subsequent filtration over active carbon before disinfection is the best possible way to prevent by-product formation.

In some countries **lead** and **copper** were/are widely used for plumbing in buildings and where the water is very hard or aggressive, high concentrations of these metals can leach into the drinking water, particularly after standing in the pipe for several hours. However, concentrations can vary widely even between adjacent buildings due to the variations in the pipework. This is potentially a problem for young children and WHO has set a guideline value of 10 µg/litre for lead based on bottle-fed infants and of 2 mg/litre for copper based on gastrointestinal effects (WHO 2004). In general, the best approach for lead is to replace the pipes. If this does not seem affordable, central treatment for corrosion control to reduce metal solvency, or simply flushing the pipes for a short time after extended periods in which the water has been standing in the pipes may be used to reduce weekly mean levels close to 10 µg/litre (lead) or distinctly less than 2 mg/litre (copper). The flushed water can be used for bathing or other household uses other than drinking or cooking.

Discussion

WHO has changed the way in which it regards all contaminants and emphasises the need to take a preventative approach rather than a reactive approach to contamination of drinking water wherever possible. This means identifying the problems and providing, often simple, solutions to prevent contamination. This approach can be applied to all water supplies and is referred to as the Water Safety Plan Approach (WHO 2004) ♦