



Water and human health

SDK125_1 Introducing health sciences: a case study approach

Water and human health

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Contents

- [Introduction](#)
- [Learning outcomes](#)
- [1 Water as a global resource](#)
- [2 The global water cycle](#)
- [3 The distribution of water and its use by people](#)
 - [3.1 Water distribution and usage issues](#)
 - [3.2 The impact of climate change on global freshwater resources](#)
- [4 Chemical pollution of water](#)
 - [4.1 Levels of toxic substances](#)
 - [4.2 DDT: a classic case in ecotoxicology](#)
 - [4.3 Mercury](#)
 - [4.4 Nitrogen: a developing threat to health](#)
 - [4.5 Endocrine disruptors](#)
 - [4.6 Postscript to Section 4](#)
- [Conclusion](#)
- [6 Self-assessment questions](#)
- [Keep on learning](#)
- [References](#)
- [Acknowledgements](#)

Introduction

This course examines why water shortages are predicted as a result of the world's growing population and the importance of access to clean and safe drinking water in public health. It looks at the distribution of water throughout the world and problems with contamination, topics of wide general interest.

This OpenLearn course provides a sample of Level 1 study in [Science](#).

Learning outcomes

After studying this course, you should be able to:

- define and use in context, or recognise definitions and applications of, each of the terms printed in bold in the text
- identify some of the reasons why clean, fresh water is an increasingly scarce resource for many people in the world
- explain what is meant by the bioaccumulation of xenobiotic chemicals and identify the implications that this has for what people can safely eat
- distinguish between the effects on human health of high and low levels of environmental pollution by nitrogen compounds5 explain what is meant by an endocrine disruptor.

1 Water as a global resource

We shall not finally defeat AIDS, tuberculosis, malaria or any of the other infectious diseases that plague the developing world until we have also won the battle for safe drinking-water, sanitation and basic health care.

(Kofi Annan, United Nations Secretary-General (2005) The International Decade for Action 2003–2015)

Freshwater is a natural resource that is vital for human survival and health. The Earth is a very wet planet, but only 2.53% of its water is fresh; the rest is seawater (UNESCO, 2003). There is currently much concern about the capacity of the Earth's freshwater resources to sustain human life and health in the near future. One estimate suggests that, if current trends continue, by 2050, when the global human population will reach almost nine billion people, seven billion people in 60 countries will be short of water unless action is taken (UNESCO, 2003). Half the human population will be short of water by 2025. (*Note: 1 billion = 1000 million.*)

SAQ 1

Can you suggest some reasons why such dire predictions are being made?

[View answer - SAQ 1](#)

As well as being concerned about the *quantity* of water available for humans, governments and international agencies are much concerned with its *quality*. Naturally occurring water is never pure, but contains a wide variety of dissolved substances, some of which are harmful to health. You will return to health issues related to the pollution of water by chemicals in [Section 4](#).

If predictions about a shortage of water for half the human population in 2025 seem alarming but far away, it is important to point out that, for many people, a water crisis is already a daily experience. As you will see later, many people in the world already face the severe adverse consequences for their health of having insufficient water and water that is also polluted. This is particularly true in Africa ([Figure 1](#)).

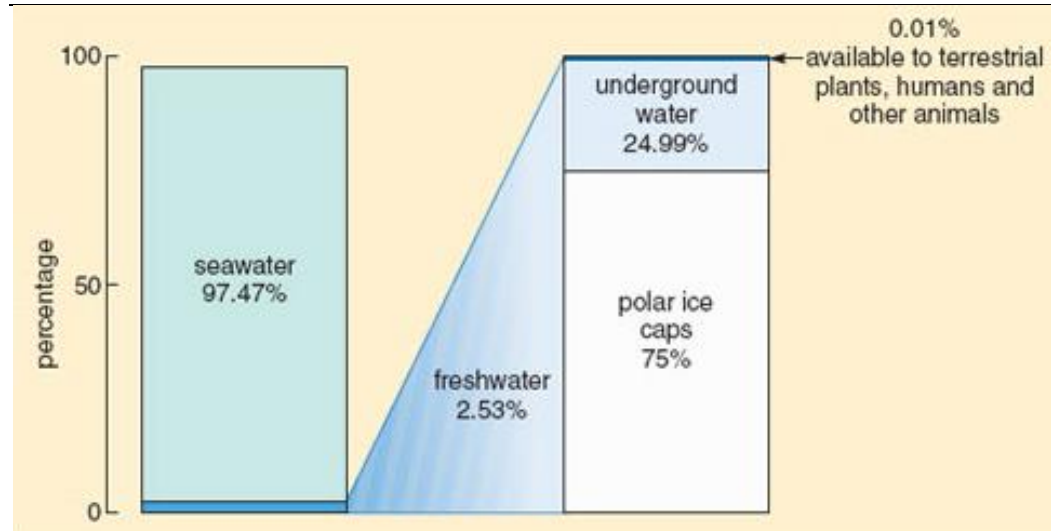


(Source: Global Environment Teaching, East Africa) *Global Environmental Teachings*, University of Wisconsin, Stevens Point

Figure 1 Water for domestic use has to be carried long distances every day in many parts of Africa, mainly by women and girls

A global water crisis is already apparent to those who look beyond humans and consider what is happening to other species. Planet Earth is at the beginning of a mass extinction event that is eliminating species at a faster rate than at any time in the history of the planet. This is the sixth mass extinction event in Earth's history; the fifth saw the extinction of the dinosaurs, around 70 million years ago. While much media attention is focused on the destruction of tropical forests around the world, it is in fact biodiversity in the world's freshwater habitats that is declining the fastest. You will return to this in [Section 4](#).

Planet Earth contains an enormous amount of water, but only a tiny fraction of it is available as freshwater to plants and animals, including humans, that live on land. As [Figure 2](#) shows, only about 0.01% of the world's total freshwater is readily available to terrestrial life.



(Source: based on data quoted in Lannoo et al., 2006)

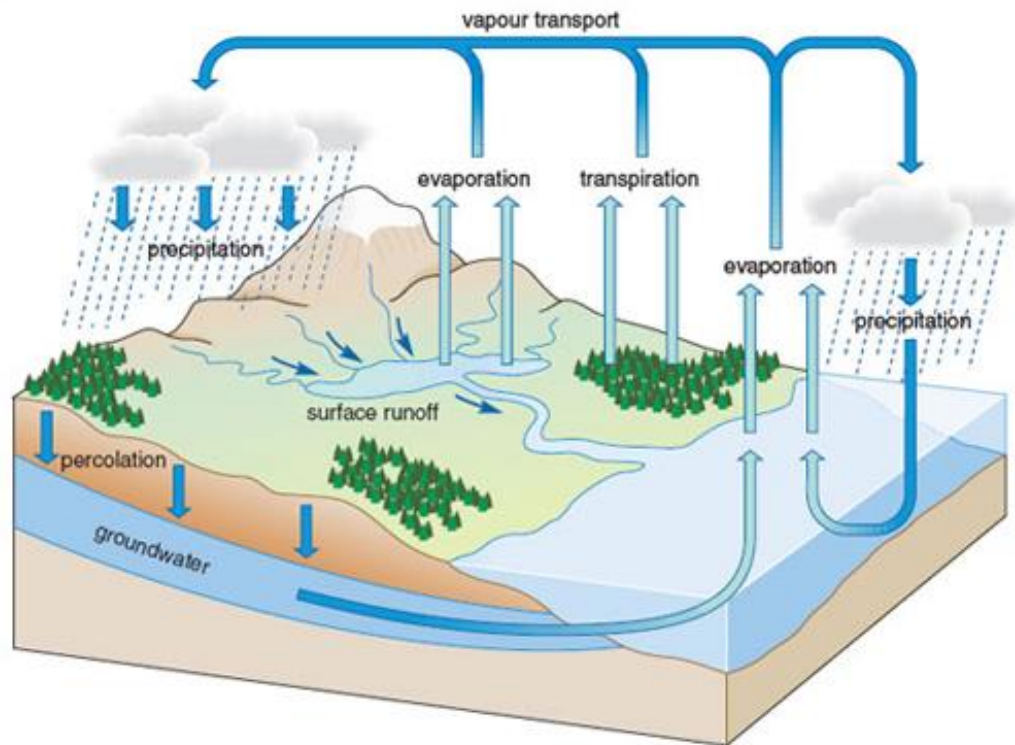
Figure 2 The distribution of the world's water resources

Here are some more facts about the world's freshwater resources to bear in mind as you study this course (Lannoo et al., 2006):

- Freshwater is unevenly distributed throughout the world, e.g. Canada has 30 times as much freshwater available to each of its citizens as China.
- Freshwater is being contaminated by saltwater influxes (tidal waves, rising sea levels), human waste and other by-products of human activity (e.g. industrial chemicals, acid rain), as well as agricultural fertilisers, pesticides and herbicides.
- Since 1950, the number of people on Earth has increased from 2.5 to 6.5 billion, and the per capita use of freshwater (i.e. the amount each person uses annually) has tripled. By 2050 the human population is predicted to reach 8.9 billion; per capita water use is also expected to continue to increase.
- More than 60% of all freshwater used in the world is diverted for agriculture.

2 The global water cycle

The flow of water through the land, the atmosphere and the sea is shown in [Figure 3](#).



(Source: based on Houghton, 2004, p. 155) Houghton, J. (2004) *Global Warming* (3rd edn), Cambridge University Press

Figure 3 The global water cycle

The route by which most water enters the atmosphere is evaporation from the sea. Much smaller amounts of water enter the atmosphere from the land and from rivers and lakes.

Water vapour in the atmosphere condenses into clouds and falls as precipitation (rain, hail or snow). The distribution of rainfall across the planet is very uneven, with some regions receiving rain all year round and some receiving none at all ([Figure 4](#)). Some of the water that falls on the land runs into streams and thence into lakes, rivers and the sea; some of it evaporates back into the atmosphere and a lot of it percolates deep into the ground, where it becomes groundwater. Groundwater, extracted by means of wells, is an important source of water for people, especially in those parts of the world where rainwater is insufficient to meet their needs. Percolation through the ground purifies water by filtration so that water that emerges from the ground at natural springs is typically very free of microbes.

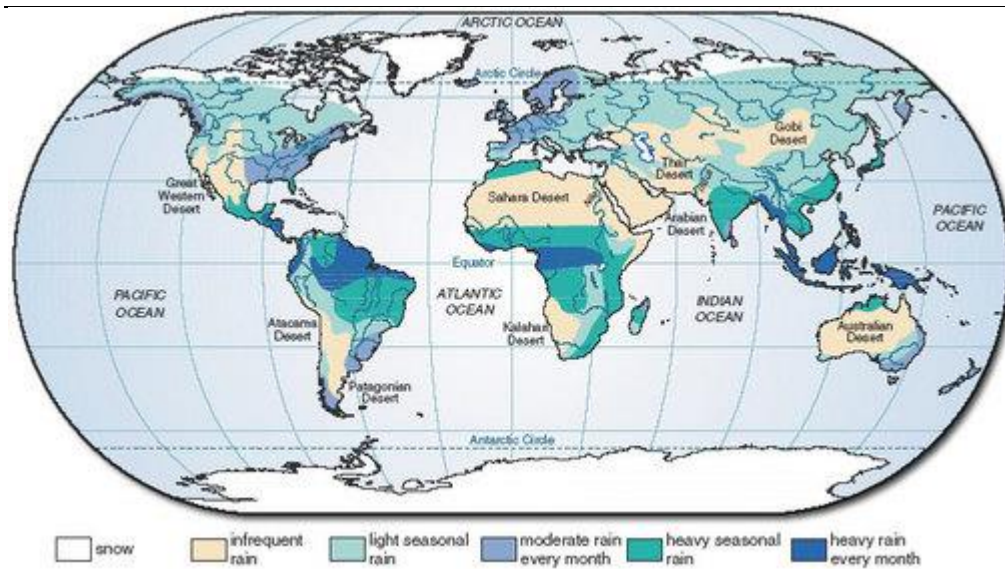


Figure 4 Map showing world rainfall

Transpiration is the release of water vapour by plants (Figure 3). Plants take in carbon dioxide from the atmosphere and release oxygen. To maintain a flow of nutrients through their stems and leaves they take up water in their roots and release it as water vapour through tiny holes in their leaves, called stomata, through which they also take in carbon dioxide. A recent study suggests that, because carbon dioxide levels in the atmosphere are rising through the burning of fossil fuels, plants don't need to keep their stomata as wide open as they used to in order to obtain the carbon dioxide they need. As a consequence plants are now releasing less water into the atmosphere than they did in the past (Gedney et al., 2006; Matthews, 2006). This represents a very subtle consequence of climate change that affects the global water cycle and makes the important point that the global ecosystem is very complex, and that a change in one component can have wide-ranging and unexpected consequences.

An important component of the water cycle, not shown in Figure 3, is human intervention in the form of sanitation systems. Water-borne human waste is collected in sewers, treated in sewage plants and returned, as cleaner water, to the water cycle, into rivers or the sea. The primary function of sewage treatment is to break down faeces and remove harmful microbes from the water. Sewage plants also have a role to play in removing harmful chemicals from water. In heavily populated parts of the world, water passing through sanitation systems represents a substantial proportion of the water flow in rivers. The River Lea, which runs from Hertfordshire in England into the River Thames, would probably cease to flow for much of the year were it not for the output from sewage plants (Brown, 2002).

The population in many of the world's megacities is growing so fast that the development of effective sewage systems is not keeping pace. In cities such as Karachi, in Pakistan, the water supply, mostly from groundwater, is heavily polluted by untreated sewage and contains high levels of bacteria (Rahman et al., 1997).

3 The distribution of water and its use by people

3.1 Water distribution and usage issues

People in many parts of the world currently face a chronic shortage of water. This is a developing crisis that is expected to get worse. As you read in [Section 1](#), several factors underlie this dire prediction. In addition, climate change is expected to cause major changes in the distribution of freshwater. The uneven distribution of freshwater across the world is illustrated in [Table 1](#).

Table 1 Distribution of the world's human population and available freshwater across six continents

Continent	Proportion of world's human population/%	Proportion of world's available freshwater/%
North and Central America	8	15
South America	6	26
Europe	13	8
Africa	13	11
Asia	60	36
Australia and Oceania	1	5

(Source: data derived from UNESCO, 2003, Figure 1, p. 9)

SAQ 2

From the data in [Table 1](#), which continent is facing the greatest water crisis?

[View answer - SAQ 2](#)

SAQ 3

Compare the data in [Table 1](#) with the world rainfall map in [Figure 4](#). Is water availability in different regions reflected in the pattern of rainfall?

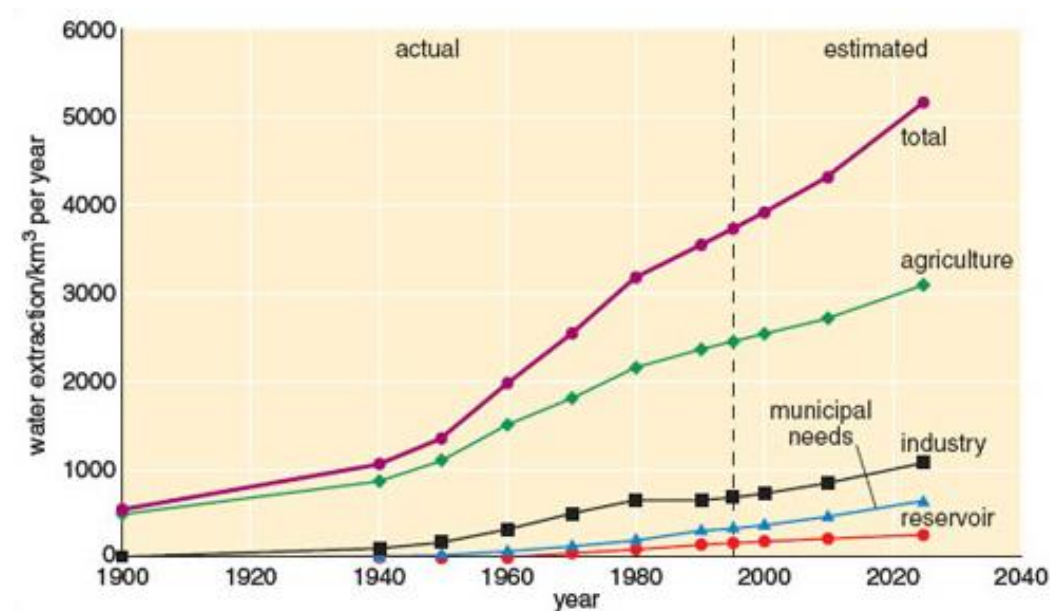
[View answer - SAQ 3](#)

SAQ 4

Which region does not fit this pattern?

[View answer - SAQ 4](#)

People use water for a variety of purposes. As well as water for drinking, people use water to wash in, for sanitation, to irrigate the land for crops, to give to livestock, as a source of food (fishing), for transport and for recreation. The major categories of water use, on a global scale, are summarised in [Figure 5](#), which shows that water use increased up to 1995 and how it is predicted to continue to increase up to 2025.



(Source: Houghton, 2004, Figure 7.6, p. 155) Houghton, J. (2004) *Global Warming* (3rd edn), Cambridge University Press

Figure 5 Graph showing the amount of water extracted globally from natural reserves (rivers, lakes and groundwater) and used for four use categories. Water extraction is measured in cubic kilometres (km³) per year. Data from 1900 to 1995 are actual figures; from 1995 to 2025 they are estimated

SAQ 5

What is the most significant use of water worldwide?

[View answer - SAQ 5](#)

SAQ 6

Which of the factors discussed in [Section 1](#) account for the fact that water extraction is increasing?

[View answer - SAQ 6](#)

Water use in agriculture is of two kinds: irrigation of crops and watering of livestock. Many methods of crop irrigation are wasteful of water in that much of it is lost into the air by evaporation before it is taken up by crops. Livestock use even more water. [Table 2](#) compares the amounts of water required to produce various major food

products. Notice how ‘expensive’ it is to produce beef and lamb in terms of water requirements.

Table 2: Volume of water required to produce 1 kilogram (kg) of specific food products

Product	Water required/litres
fresh meat – beef	15 000
fresh meat – lamb	10 000
poultry meat	6000
palm oil	2000
cereals	1500
citrus fruit	1000
pulses, roots and tubers	1000

(Source: data derived from UNESCO, 2003, Figure 1, p. 17)

The supply of clean water is affected by how people dispose of their waste water. People living in areas where there is no sanitation system for the disposal of waste water have little choice but to throw it away into a river or onto the ground. Each litre of water disposed of in this way pollutes an average of eight litres of freshwater, and the UN estimates that the global human population pollutes 12 000 km³ of water annually in this way. Unless there is major investment in sanitation systems, this figure will have increased to 18 000 km³ by 2050 (UNESCO, 2003).

3.2 The impact of climate change on global freshwater resources

The availability of freshwater will be significantly altered in a future world affected by climate change (Houghton, 2004). In some regions, water availability will decrease; in others it will increase. Precise predictions about the extent and exact location of such changes cannot be made because they are based on climate models, the accuracy of which is uncertain. However, there is wide agreement that probable changes will include:

- More rain in northern high latitudes in winter and in the monsoon regions of south east Asia in summer.
- Less rain in southern Europe, Central America, southern Africa and Australia in summer.
- Greater water flows in rivers that are fed by glaciers.
- Overall, higher temperatures in all regions, which will lead to greater evaporation so that, even in regions where rainfall does not decrease, water availability will be reduced.

- Rising sea levels, which will lead to flooding of low-lying coastal regions, including major flood plains and river deltas, many of which are currently densely populated; for example, the Bengal delta in Bangladesh contains 8.5 million people (Hecht, 2006) (see [Figure 6](#)).

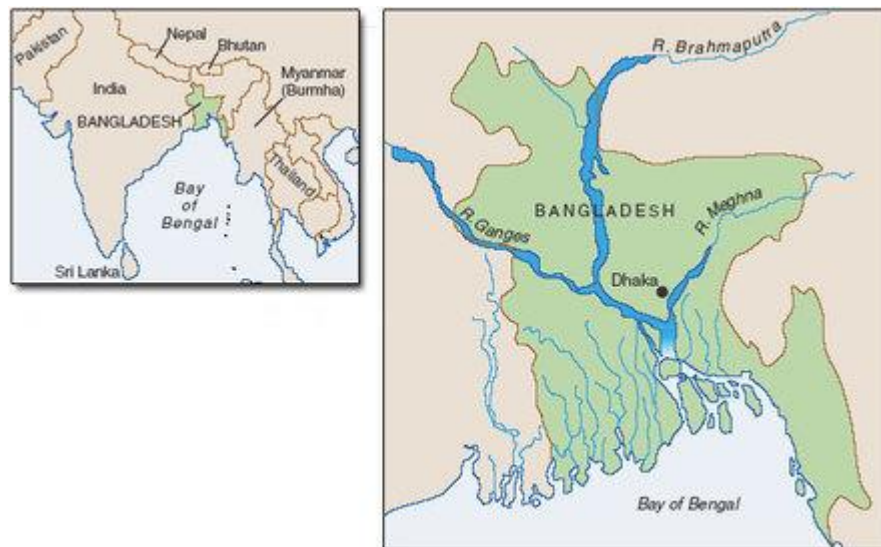


Figure 6 Map of Bangladesh showing the extensive delta formed by the Rivers Ganges, Brahmaputra and Meghna

The impact of Hurricane Katrina on the Mississippi delta in southern USA in 2005 revealed some of the adverse effects of human activities on river deltas. Control of water flow higher up-river reduces the amount of sediment reaching a delta, causing the land to subside. This is exacerbated by extraction of groundwater within the delta. Rising sea levels, resulting from climate change, may then threaten to inundate the lowered delta, especially during very severe weather (Hecht, 2006). In the Mississippi delta, the situation was exacerbated by inadequate maintenance of flood barriers.

As a result of the changes listed above, some regions will experience a greater frequency of flooding, while others will experience more frequent and more severe droughts. These changes will affect human health directly, as well as indirectly by disrupting agriculture and the supply of food.

The impending water crisis is bringing about a major change in the way that the water extraction industry approaches its task (Gleick, 2003). In the past, the emphasis was on finding more effective ways of extracting water from natural resources; now the emphasis is on finding more efficient ways to use it. For example, in California considerable reductions in water use have been achieved. More efficient ways of irrigating farmland have been developed that decrease the amount of water lost by evaporation to the air. Domestic use of water has been reduced by the introduction of new designs of toilets, showers, washing machines and dishwashers. For example, domestic consumption of water to dispose of sewage in the USA has been reduced by 75% over 20 years by changes in toilet design. Similar reductions in domestic water use have been achieved in Australia, Japan and Europe (Gleick, 2003).

4 Chemical pollution of water

4.1 Levels of toxic substances

Toxic substances are a feature of the natural world; many plants contain chemical compounds that make them anything from mildly distasteful to lethally poisonous to animals that might eat them. Some animals are equipped to deal with dangerous plants in their environment and possess detoxification mechanisms that break down harmful compounds. Humans, for example, rely on their liver to neutralise the harmful effects of alcohol. During human cultural evolution, cooking techniques have developed that destroy toxic chemicals in plants. Examples include nerve poisons in the lentils from which dahl is made in India, and cyanide in cassava, a staple crop in Africa and South America. There are limits, however, to what the liver and cooking can achieve and the environment contains a huge array of chemical compounds, some of them of human manufacture, that are harmful to human health and survival. The latter are said to be **xenobiotic** (zen-oh-bye-ot-ik). Literally meaning ‘alien to nature’, in the context of this course this word refers to chemicals ‘of human origin’.

Water is said to be polluted, or contaminated, whenever any harmful or undesirable change in its physical, chemical or biological quality results from the release into it of synthetic or naturally occurring chemicals, radioactivity or **organic** matter. (Organic means arising from the bodies of plants, animals or other organisms.) Pollution often refers to the results of human activity but there are significant natural causes of contamination, such as volcanic eruptions, which release a variety of chemicals, and tsunamis, which mix salty seawater with freshwater. Much of the groundwater obtained from boreholes in parts of Bangladesh and West Bengal is contaminated with naturally occurring arsenic, released from rocks deep underground.

Contamination can occur at many points in the global water cycle depicted in [Figure 3](#). Most familiarly, pollutants can be released into rivers or into the sea, but they can also be released into groundwater by pollution of the soil. Some pollutants enter the water cycle from the atmosphere; for example, acid rain is caused by the mixing of water vapour with gaseous pollutants such as sulfur dioxide, released by burning fossil fuels, and a variety of nitrogen compounds from agricultural fertilisers (see [Section 4.4](#)).

Pollution may be acute or chronic. *Acute pollution* events refer to the sudden release of large quantities of a contaminant, usually leading to very obvious harmful effects. An example is provided by the accidental release of a large quantity of aluminium sulfate, a substance used in water treatment, into the water supply of Camelford, in Cornwall in July 1988, leading to severe loss of mental function in a large number of people (Altmann et al., 1999). *Chronic pollution* refers to the slow and persistent contamination of water through the sustained release of a pollutant and is, in many ways, a more serious concern, for three reasons. Chronic pollution may go undetected for a long time; it is generally more difficult to rectify than an acute pollution event;

chronic pollution is also serious because, unlike most acute pollution events, it is often not confined, as the Camelford tragedy was, to a small area.

One of the most toxic of xenobiotic pollutants, dioxin, formed by the burning of plastics and certain fertilisers, has become ubiquitous (found everywhere) and can be detected in virtually every person that has been tested for it throughout the world (Sargent, 2005).

As a result of the risks arising from pollution, the water supply in high-income countries is carefully monitored to ensure that levels of contaminants do not exceed specified concentrations that are considered to be safe. The determination of safe levels is quite a complex process that involves the science of **toxicology** (the study of toxins and their effects on living organisms). This involves exposing animals to a toxic compound to determine its lethal dose. Among the animals used for toxicological testing of water-borne chemicals are tadpoles of the African clawed frog (*Xenopus laevis*) ([Figure 7](#)). *Xenopus* is widely used for this purpose as it breeds readily in captivity and produces huge numbers of tadpoles. Frogs and amphibians are regarded as particularly sensitive indicators of environmental damage.



(Photo: Ronn Altig) Ronn Altig, University of California, Berkeley

Figure 7 The tadpole of *Xenopus laevis*

There is growing recognition that determining the lethal dose of a compound in *Xenopus* tadpoles in a laboratory is not very helpful in trying to determine if that compound poses a threat to human health.

SAQ 11

Why do you suppose this is?

[View answer - SAQ 11](#)

Another approach to the study of pollution is the science of **ecotoxicology**, which is the study of the fate of contaminants in the natural environment and of their effects on

plants, animals and **ecosystems**. (Ecosystems are recognisable assemblages of plants and animals, such as woodland, grassland, rivers, etc., in which a distinct set of plants and animals live together and interact with one another.) This asks, not how much of a compound does it take to kill a tadpole, but what is the effect on a tadpole of the compound at the kind of concentration that occurs in the wild?

Much environmental damage has been done in Scandinavia by acid rain caused by industrial pollution from the industrial north of Britain, swept across the North Sea by the prevailing wind. For example, populations of frogs and newts have declined widely and disappeared altogether in some localities. If frog tadpoles are reared in water that is acidified to the same level as Scandinavian pond water, they do not die. Rather, they become lethargic and feed less than tadpoles in non-acidified water (Griffiths et al., 1994). They do not grow as fast as healthy tadpoles; they later become under-sized frogs and they do not survive to breed.

The result is the same as if tadpoles dropped dead when exposed to acid water; the frog population declines. By focusing on often very subtle, non-lethal effects of pollutants, ecotoxicologists provide a more complete and precise assessment of how pollutants affect wildlife than can be derived by determining their lethal dose. If it seems odd to you that scientists study the possible human health effects of xenobiotic chemicals by looking at their effects on tadpoles, bear in mind that it would be impossible, for ethical reasons, to test the effects of such chemicals on humans directly.

Bioaccumulation

When chemical contaminants enter the body of a person, they circulate around the body in the blood. Different contaminants have different chemical properties and specific contaminants tend to accumulate in specific parts of the body, called target tissues, or in substances produced in the body such as breast milk (Table 3).

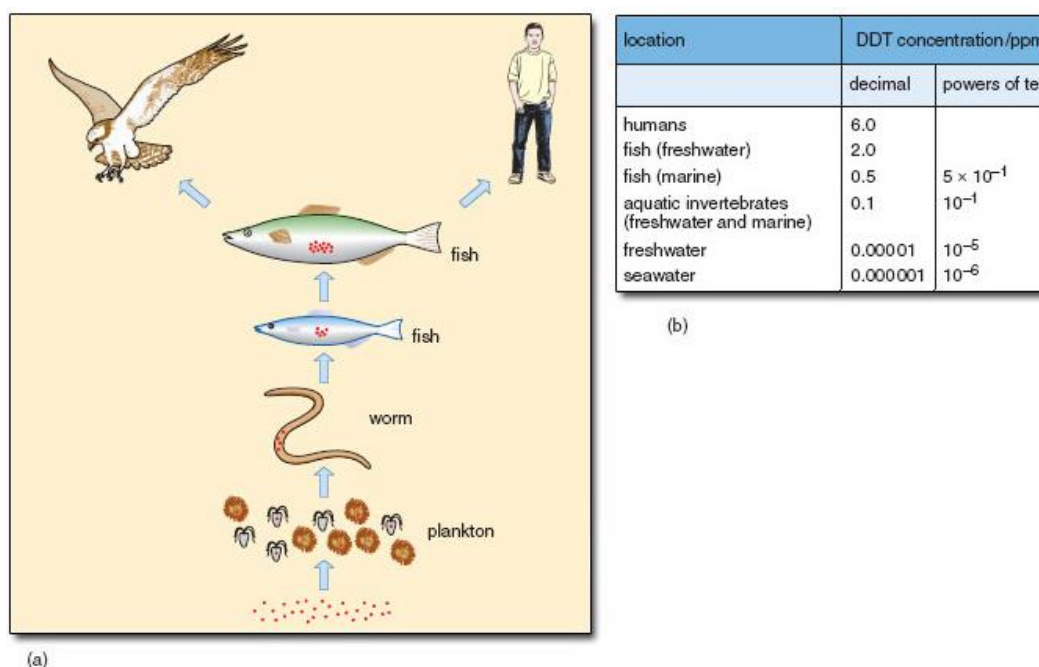
Table 3: Some common pollutants and their target tissues

Pollutant	Target tissues or substances
lead	bone, teeth, nervous tissue
mercury	nervous tissue, particularly the brain
organochlorine pesticides, polychlorinated biphenyls (PCBs)	fatty tissue, breast milk
asbestos	lungs

(Source: data derived from Connell et al., 1999, Table 4.1, p. 55)

The affinity of specific pollutants for specific target tissues is related to a very important aspect of ecotoxicology, called **bioaccumulation**. This refers to the fact that, having been released into the environment, a pollutant is not randomly or evenly

dispersed, but becomes concentrated into particular components of ecosystems. For example, DDT is accumulated in the fat reserves of birds, where it can reach quite high levels. (DDT, dichloro-diphenyl-trichloroethane, was the first widely used synthetic pesticide and has been used to kill agricultural and domestic insect pests since 1939; see [Section 4.2](#).) This has two important effects. In the affected bird it means that, if it uses its fat reserves to provide energy for some specific activity, such as reproduction or migration, a large dose of DDT is released into its blood over a short time. Every time a predator eats such a bird, it too receives a large dose which, in turn, is stored in its fat. The consequence of bioaccumulation is that contaminants that may be quite safe to wildlife, or humans, when encountered at the kind of concentrations at which they are released into water, can become concentrated at particular points in the food-chain at levels that are not safe ([Figure 8](#)).



(Source: data derived from Freedman, 1989)

Figure 8 (a) Diagram showing bioaccumulation of a chemical contaminant in an aquatic food chain. (b) Concentrations of DDT (in ppm, parts per million) in different parts of the environment

4.2 DDT: a classic case in ecotoxicology

DDT is very effective in controlling pests, being very toxic to insects, and is cheap to produce. Its effectiveness is enhanced because it is very persistent, remaining active in the environment for a long time. This increases its value as an insecticide to farmers because one application lasts a long time, but is also a major reason why it poses a threat to wildlife and to human health. Although the agricultural use of DDT was banned in most developed countries 30 years ago, it can still be detected in samples taken from the soil, from water and from the bodies of animals; it is also detectable in people.

Concern about the widespread effects of DDT led to it being banned in most developed countries in the 1960s and 1970s, but it is still used extensively in many developing countries, not least because it is very effective at controlling disease-carrying insects. DDT is credited with having eliminated malaria from Europe and the USA. The WHO has recently agreed that the human health benefits of using DDT in malaria areas outweigh the environmental risks, and it is a front-line weapon against the mosquitoes that carry malaria. Efforts are being made, however, to reduce the quantities used; for example, DDT-impregnated bed nets are increasingly being used instead of spraying ([Figure 9](#)).



(Photo: WHO/TDR/Martel) WHO/TDR/Martel

Figure 9 Insecticide-treated bed nets have to be re-treated regularly. Communal ‘dipping’ sessions, here in Viet Nam, encourage community participation and have reduced the incidence of malaria by up to 50% in some areas

The harmful effects of DDT on wildlife were first detected in 1947 when dramatic declines in a number of birds of prey, particularly the peregrine falcon, were noted in Britain. Similar declines were detected in the USA, especially among birds, such as

ospreys, that eat fish. By the early 1960s the link between such declines and DDT had been worked out.

SAQ 12

Why are birds like ospreys and peregrine falcons at particular risk?

[View answer - SAQ 12](#)

The most severely poisoned birds died; those that did not die produced eggs with shells so thin that they collapsed under the weight of the parents in the nest. The use of the breeding birds' fat reserves during egg production released large amounts of DDT, affecting the deposition of calcium in egg shells. This is an example of a phenomenon called endocrine disruption ([see Section 4.5](#)).

DDT has been suggested as a causal factor for a number of human health problems. Detailed studies have ruled out a suggested link between DDT and breast cancer, but it is still strongly suspected to be linked to pancreatic cancer, neuropsychological dysfunction and some reproductive problems (Beard, 2006).

DDT is only one of a vast array of pesticides that is now in use. In 1995, 2.6 million metric tons of active pesticide ingredients, worth \$38 billion, were used around the world (WRI, 1999). 85% of this was used in agriculture, much of which produces crops in developing countries, such as cotton, bananas, coffee, vegetables and flowers, that are exported to developed countries. In 2000, an estimated 3.75 million metric tons were manufactured worldwide; on current trends, global pesticide production is predicted to reach 6.55 million metric tons in 2025 and 10.1 million in 2050 (Tilman et al., 2001).

4.3 Mercury

Mercury is a naturally occurring metal which, in its pure form, is not particularly toxic. Under normal conditions of temperature and pressure, it is a silvery-white liquid which readily transforms into a vapour. When vaporised, it enters the atmosphere, remains there for a long time, and is circulated globally (WHO, 2005b). Through chemical reaction and precipitation it enters freshwater lakes and rivers, where it accumulates in the sediments at the bottom. Here it is transformed by bacteria into a variety of mercury compounds, particularly methyl mercury (chemical formula: CH_3Hg^+) which is highly toxic. From freshwater sediments methyl mercury is taken up by small organisms and enters aquatic food chains, accumulating in the fat of animals and, by bioaccumulation, reaching high levels in animals towards the top of the food chain, such as larger fish and fish-eating birds (Zahir et al., 2005).

The realisation that mercury compounds pose a serious threat to human health began with an unfolding tragedy in Minamata Bay, Japan, beginning in the mid-1950s (Connell et al., 1999). As is often the case, the first evidence that something was amiss came from observations of animals. Birds flew erratically and sometimes fell

into the sea; children were able to catch usually evasive octopuses with their bare hands; cats had convulsions and died. It was not until the 1960s that many local people became overtly ill. They had convulsions, began to stagger about and salivated excessively; deaths began to occur, including newly born children. The source of the problem was a chemical factory that was discharging its waste into Minamata Bay. This waste included large amounts of methyl mercury, estimated at 600 tons between 1932 and 1970. The animals and the people were suffering from mercury poisoning, now sometimes called 'Minamata disease'.

The principal sources of atmospheric mercury are the burning of fossil fuels in power stations and of domestic and industrial wastes in incinerators. Mercury compounds are also released directly to the land in many fungicides (chemicals used to protect crops from fungal diseases) (Clean Air Network, 1999). Mercury compounds have been used as an ingredient of some cosmetics, and even some vaccines. A compound of mercury called thiomersal in the UK (or thimerosal in the USA) has been used as a preservative in vaccines since 1931. In the late 1990s, some safety concerns about thiomersal led to its gradual withdrawal from some of the vaccines in which it had been an ingredient (note: it was never used in the measles, mumps and rubella MMR vaccine in the UK), but a WHO expert committee concluded that there is no evidence of any toxicity and it remains in use (GACVS, 2006).

The effects of mercury compounds on wildlife and on people

Mercury compounds have no effect on plants, but adverse effects have been demonstrated in a wide range of animals, including fish and amphibians (Boening, 2000). Very high levels of mercury have been found in the livers of American alligators in the severely polluted Everglades of Florida; these can be as much as 400 times greater than levels in alligators born and reared in alligator farms (Linder and Grillitsch, 2000).

SAQ 13

By what process would such high levels of mercury arise in alligators?

[View answer - SAQ 13](#)

Methyl mercury pollution is implicated in the near extinction of populations of stream-living salamanders in Acadia National Park, Maine (Bank et al., 2006).

The most important effect that mercury compounds have on people is on children born to women exposed to high levels during pregnancy (WHO, 2004). In extreme cases they have seizures and cerebral palsy; they may also be born blind or deaf. In less extreme cases, they have reduced intelligence, poor memory and attention deficit disorder. Mercury compounds have no detectable effect on the mother, but can be

detected in her hair, and mercury levels in maternal hair are strongly related to the severity of post-birth effects in children (Cohen et al., 2005).

Infants can also be exposed to mercury compounds via breast-milk. In some fishing communities the concentration of mercury in children's hair is correlated with the duration of breast-feeding. Reports of high mercury levels in mothers and children mostly come from regions where people eat a lot of fish; for example, high levels of blood mercury have been detected in people in the USA who identify themselves as Asians, Pacific Islanders or Native Americans (Hightower et al., 2006). The unsaturated fats that occur in fish have beneficial consequences for human health and people are encouraged to eat fish in many countries. Currently, the US government encourages the eating of fish in the general population, but discourages it in women of childbearing age because of the risk posed to unborn children by mercury compounds (Cohen et al., 2005). Around the Faeroe Islands especially high levels of mercury have been found in pilot whales and, as a consequence, pregnant women are encouraged to avoid eating whale meat (Booth and Zeller, 2005).

Mercury compounds represent a major threat to human health in the future. Mercury emissions from power stations and other sources are not controlled in most countries. For example, at the time of writing in 2006 they were not covered by US Clean Air legislation (Clean Air Network, 1999). The rate of emissions has been increasing; there was a 10% increase in the USA from 2001 to 2002, and, in countries such as China and India, whose rapidly expanding economies are heavily dependent on fossil fuels, emissions are predicted to increase even faster (Booth and Zeller, 2005). The effects of mercury pollution will be global; because mercury can be dispersed as a vapour it can be deposited anywhere in the world.

Current inaction over mercury contrasts strongly with what has happened in relation to another toxic metal, lead. Lead is recognised as a very important toxin for children (WHO, 2004). Like mercury, it has serious effects on the developing nervous system, causing impaired brain function, leading, for example, to attention deficit disorder. In many high-income countries, the most obvious sources of lead have been eliminated; lead is no longer used for water pipes and has been removed from petrol and paint. Lead has long been subject to a surveillance programme in the USA, but no such programme yet exists for mercury (Schweiger, 2005).

4.4 Nitrogen: a developing threat to health

A great deal of attention, by governments and the media, is focused on the environmental threat posed by carbon dioxide (CO₂) emissions and on the urgent need to reduce them. Mainly due to the burning of fossil fuels, the level of CO₂ in the atmosphere has increased by some 36% since pre-industrial times. According to recent estimates (IPCC, 2007), this increase has contributed more than 50% of the global warming attributed to human activities. The rest is due to enhanced atmospheric concentrations of a number of other 'greenhouse' gases, including nitrous oxide (N₂O). Molecule for molecule, N₂O is nearly 300 times more powerful as a greenhouse gas than CO₂ and levels of the gas are rising rapidly, largely due to

the widespread use of nitrogen fertilisers in agriculture; some of the nitrogen ends up in the air as N_2O . However, the amount of N_2O in the atmosphere is still very low, and the observed increase (up 18% above pre-industrial level) has contributed just 5% to global warming *so far*.

Nitrogen exists in the environment in huge quantities; as nitrogen gas (N_2) it makes up 78% by volume of the Earth's atmosphere. As an element, nitrogen is an inert gas; that is, it is unreactive, is of little use to animals or plants and does no harm to them. It is when nitrogen becomes incorporated into compounds with other elements (notably oxygen or hydrogen) that it becomes reactive and can be harmful. In a natural environment, like that which existed before the industrial revolution, reactive compounds of nitrogen are produced naturally, in relatively small quantities. For example, lightning converts nitrogen in the atmosphere into compounds called *nitrates* that enter the soil in rain. Bacteria that occur in nodules on the roots of certain plants, known as nitrogen-fixing bacteria, also convert nitrogen gas into nitrogen compounds which enter the soil, providing a natural fertiliser.

The situation changed during the industrial revolution, with the burning of fossil fuels on a large scale, releasing various nitrogen compounds into the atmosphere in large quantities. More recently, the industrial production of nitrogen fertilisers has released into the environment a number of other, reactive nitrogen compounds. These are listed, with their effects, in [Table 4](#) in [Box 1](#).

Box 1: (Enrichment) Reactive compounds of nitrogen and their environmental effects

There are many compounds of nitrogen and they have a variety of effects on the environment. [Table 4](#) lists a selection. The chemical formulae are included for completeness.

Table 4 Some compounds of nitrogen and their environmental effects

Compound	Chemical formulae	Environmental effects
nitrate ion	NO_3^-	acid rain, eutrophication of water [‡]
nitric acid	HNO_3	acid rain, eutrophication of water
nitrogen dioxide	NO_2	smog, acid rain, eutrophication of water
nitrous acid	HNO_2	smog, acid rain
nitric oxide	NO	smog, acid rain
nitrous oxide	N_2O	greenhouse gas, destruction of ozone in the stratosphere
ammonia/ammonium ion	$\text{NH}_3/\text{NH}_4^+$	smog, eutrophication of water, aerosols [§]

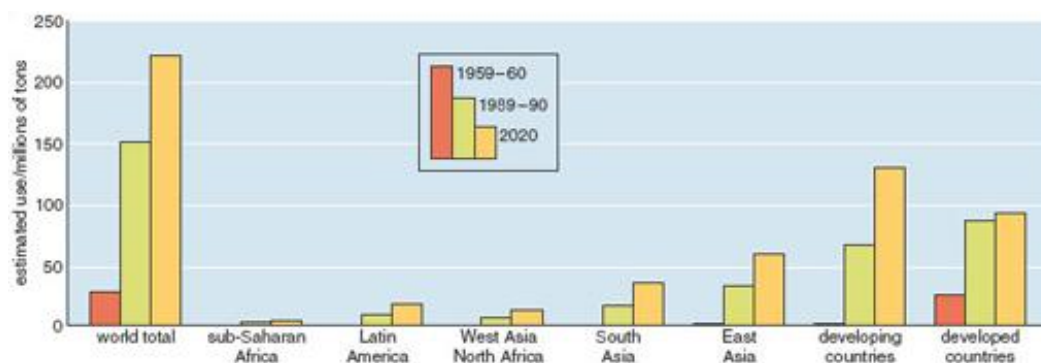
Water and human health

‡The term ‘eutrophication of water’ refers to the effect of high levels of nitrogen compounds in water; these include a reduction in biodiversity as the water becomes choked with algae.

§‘Aerosols’ refer to the formation of tiny particles, suspended in the atmosphere.

(Source: Hooper, 2006, p. 42)

The major source of nitrogen compounds in the environment is now the increasing use of fertilisers to enhance crop yields, driven largely by the need to feed the large proportion of the world's human population that is undernourished. This is a trend that is expected to continue ([Figure 10](#)).



(Source: Bumb and Baanante, 1996, Table 1) Bumb, B. and Baanante, C. (1996) ‘Trends in Fertilizer Use and Projections to 2020’, Brief no 38, International Food Policy Research Institute

Figure 10 Estimated growth in fertiliser use, 1959–2020

Other sources of nitrogen being added to the environment are urine and manure from livestock, industrial emissions and human waste. As a result of all this release of nitrogen compounds, the natural cycle of nitrogen in the environment has become swamped by what is called the ‘nitrogen cascade’ (Galloway et al., 2003). In the natural nitrogen cycle ([Figure 11](#)), *de-nitrifying* bacteria convert nitrogen compounds back into atmospheric nitrogen, but these are now unable to cope with the massive quantities currently being released into the environment. As a result, levels of nitrogen compounds are building up in soil, in the atmosphere and in water.

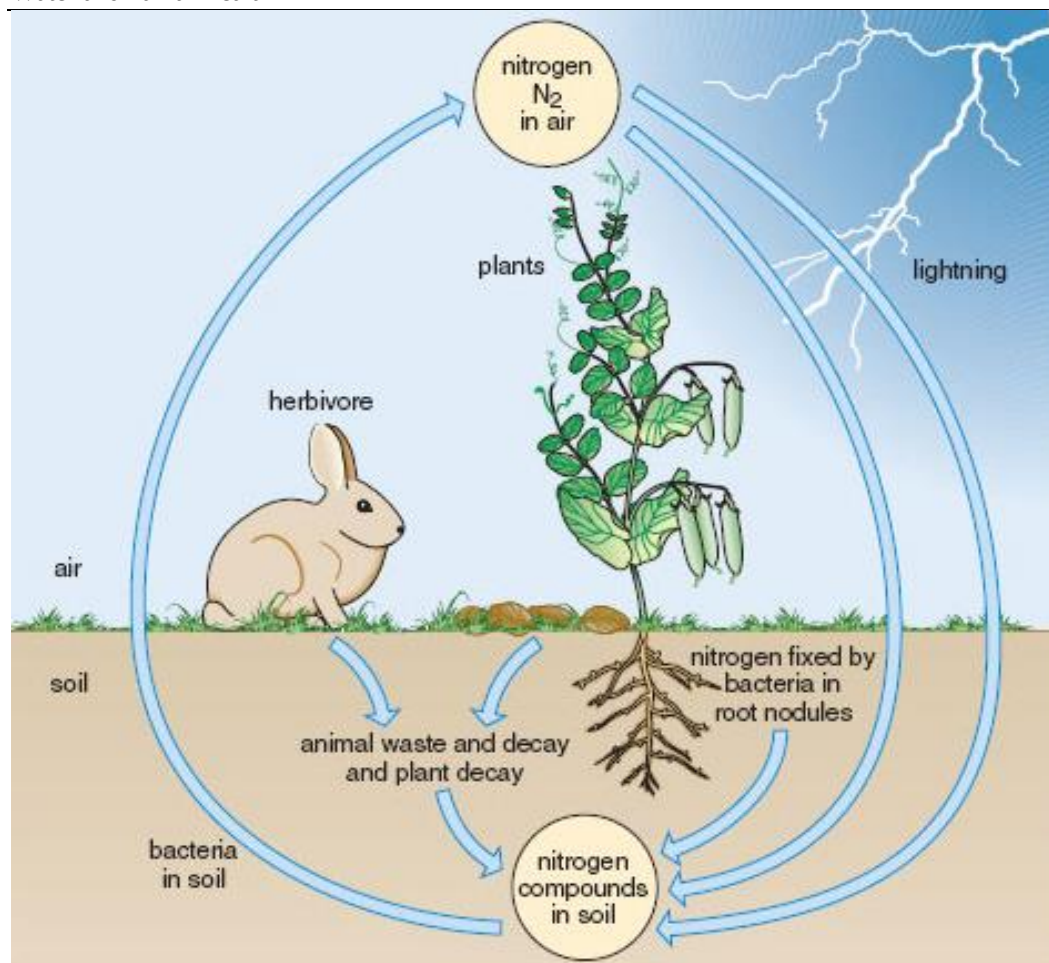


Figure 11 The natural (pre-industrial) nitrogen cycle

Effects on humans

The most well-known effect of nitrates on human health is methaemoglobinaemia (met-heem-oh-gloh-bin-eem-ia) or ‘blue baby syndrome’. If large quantities of nitrogen compounds are ingested in drinking water, the ability of the blood to carry oxygen is impaired, causing headache, fatigue, breathing difficulties, diarrhoea and vomiting and, in extreme cases, loss of consciousness and death. This syndrome is quite common in parts of the USA, and the Netherlands, where nitrogen levels are very high. Safety levels for nitrogen compounds in drinking water are set with a view to preventing methaemoglobinaemia in infants, an acute condition, and do not take into account the possible chronic health effects, for adults as well as children, of ingesting nitrogen compounds at low levels over a long period.

Nitrogen compounds are thought to be linked to asthma in some localities. Fresno, in the San Joaquin Valley of California, is notorious for its smog and has the third highest asthma rate in the USA. Fresno is the centre of a major milk-producing region and dairy farms release large amounts of nitrogen in the form of ammonia which forms particulates in the air (Hooper, 2006). The increased use of nitrogen compounds

in agriculture is also indirectly implicated in the marked increase in the incidence of asthma in many developed countries. Crops grown in nitrogen-enriched soils grow profusely and their flowers release very large amounts of pollen into the air (Townsend et al., 2003).

The most serious health consequences for humans from nitrogen pollution may well arise indirectly through its effects on the environment. For example, high levels of nitrogen in water cause the formation of algal bloom (Figure 12), exceptional growths of plant-like organisms, called algae, often combined with bacteria, which ‘choke’ lakes, rivers and streams. These blooms may contain a type of bacteria, called cyanobacteria, which produce toxins, killing water life and posing a threat to people. Algal blooms can kill the fish stocks on which many people may be dependent for food and it can take many years to clear them and restore the natural water ecology.



(Photo: Michael Marten/Science Photo Library) Michael Marten/Science Photo Library

Figure 12 An algal bloom in a woodland pond. The pond has been turned green by the growth of algae, which covers the surface and prevents light and oxygen reaching plants and animals underneath

4.5 Endocrine disruptors

Then he was a she...

(Lou Reed, American rock singer)

In 1996, a book called *Our Stolen Future* was published, bringing to public attention a debate that had been simmering among biologists for some time. Written by Theo Colborn and two colleagues at the World Wildlife Fund (WWF), this book presented the hypothesis that certain industrial chemicals, commonly found as environmental pollutants, are threatening human health by disrupting the body's hormonal system.

These chemicals, variously called **endocrine disruptors** (end-oh-krin), hormone mimics or, in the media, ‘gender benders’, could be playing a role in a range of problems, from reproductive and developmental abnormalities, to defects of the nervous system, to cancer. This disturbing hypothesis was based on studies of both wild and laboratory animals, for which there was a steady accumulation of evidence that certain xenobiotic chemicals were disrupting normal development and reproduction. One of the most common examples of endocrine disruption involves, to varying extents, the feminisation of males. There seem to be no endocrine disruptors that masculinise females, but several disrupt the normal functioning of the female reproductive system (US Environmental Protection Agency, 1997).

While it is now widely accepted that endocrine disruptors are having serious effects on a variety of wild animals, there is considerable debate among biologists as to whether human health and reproduction are being affected. If they are, it represents a possible cost of living in the modern ‘human zoo’.

Endocrine disruptors get their name because they interact with the endocrine (hormonal) system in the body. The **endocrine system** consists primarily of a number of endocrine glands (also known as ductless glands) that each secrete one or more hormones directly into the bloodstream. A **hormone** is a substance produced by an endocrine gland that is carried by the bloodstream to other organs or tissues where it acts to alter their structure or function.

An important effect of some hormones is to regulate behaviour. This is true of the ‘flight or fight’ hormone epinephrine (formerly known as adrenalin) which, secreted by the suprarenal glands in response to danger and other alarming stimuli, activates the body and facilitates a rapid response. It is less true of sex hormones, such as oestrogen or testosterone, which have little immediate effect on behaviour, but which have a profound, long-term, *organising* effect on the body. Thus, the level of testosterone determines the timing of adolescence in boys, for example. This organising effect is important in the context of endocrine disruption because it means that, if an organism's endocrine system is disrupted early in life, it can have profound consequences that can affect it throughout its life.

Fundamental to understanding how hormones and endocrine disruptors work is the concept of a receptor. A **receptor** is a large, specialised molecular structure embedded in the membrane that forms the outer layer of a cell ([Figure 13](#)). It consists primarily of proteins that have affinity for a specific hormone, drug or other natural or synthetic chemical. For example, cells in the mammary glands of mammals have receptors on their surface with a special affinity for the hormone oestrogen, which is secreted primarily by the ovaries. When oestrogen comes into contact with an oestrogen receptor on a cell, it initiates a change within that cell. By this mechanism, oestrogen controls mammary development at adolescence and function during reproduction. Mammary glands are said to be ‘target organs’ of oestrogen. This ‘special affinity’ involves a process called binding, in which a specific part of a hormone molecule becomes attached to part of the corresponding receptor on the surface of the target cell, triggering a change within the target cell. Because of the specificity of this

relationship, the process of binding is often likened to a key being inserted into a lock (Figure 13).

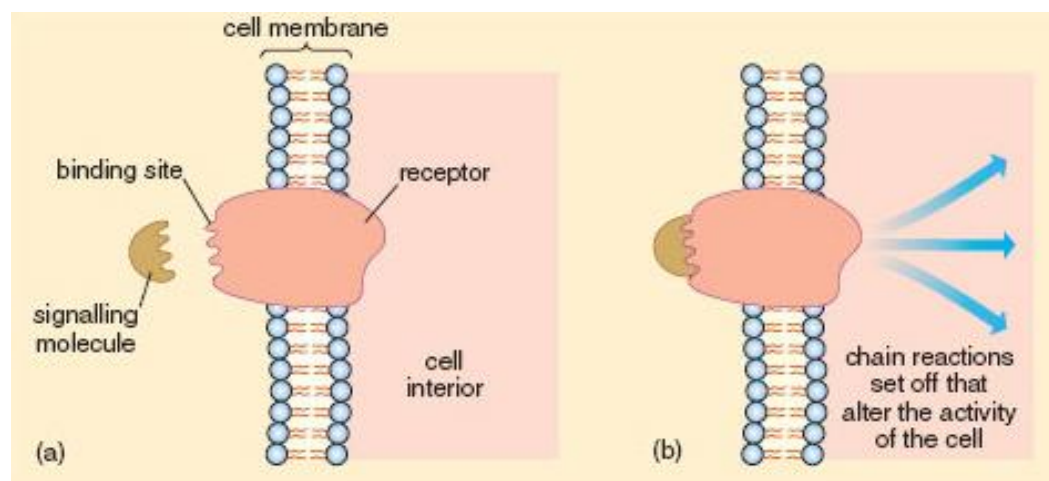


Figure 13 The 'lock and key' interaction between a signalling molecule (e.g. a hormone) and its specific receptor

Endocrine disruptors work because, although they are not hormones and often bear no obvious similarity to hormones, they happen to have in their molecular structure features that mimic the 'key' section of specific hormone molecules. Thus a substance that is not a hormone has the ability to 'unlock the lock' on target organs and thus behave as if the relevant hormone had become bound to them.

Before going on to examine endocrine disruptors in more detail, it is important to mention a related issue, the presence in the environment of real hormones. Women taking the contraceptive pill excrete substantial amounts of modified versions of human reproductive hormones, such as oestrogen, in their urine. Artificial hormones are not broken down in sewage treatment plants and so appear, sometimes in quite high concentrations, in sewage outflows into rivers. At a number of sites in the UK, male fish have been found to be feminised close to sewage outflows (Tyler et al., 1998).

It is important to emphasise that animals are very sensitive to very small variations in reproductive hormones. This is illustrated by work carried out by an American biologist, Fred vom Saal, who works on rodents (vom Saal and Bronson, 1978, vom Saal et al., 1999). Rodents have large litters and, during their development within their mother, embryos are lined up in the uterus in a row. In this row a male embryo may find itself between another two males, between two females, or between one of each. Vom Saal developed techniques to determine the exact position of each embryo prior to birth and to detect small variations in the behaviour of the young rodents that those embryos became as they grew up. He found that the behaviour of individuals was affected by their position in the uterus, as measured by variations in aggressive and sexual behaviour. Male rodents that had been between another two males in the uterus are more aggressive and sexually active than those that had been between two females. This effect is due to the fact that, even as embryos, young mammals secrete

tiny quantities of sex hormones. This example gives credence to the hypothesis that very small amounts of hormone, or of hormone mimics, can influence animals as they develop.

The evidence for endocrine disruption in wildlife

During the 1970s and 1980s, biologists found alligators in Florida with reduced penis size and low fertility. About the same time Western gulls in the USA were found with abnormal mating behaviour and reproductive organs. These anomalies were linked to high levels of PCBs (polychlorinated biphenyls), DDT and dioxin in the local environment. Around the same time, reproductive abnormalities were found in fish living in British rivers close to sewage outfalls. Such findings stimulated ecotoxicologists to start looking closely at a range of xenobiotic chemicals and their possible endocrine-disrupting effects.

For example, atrazine is the most widely used herbicide in the world; 30 000 tons of it are sprayed onto farmland in the USA each year. It can be detected at quite high levels in streams and rivers that collect run-off from farmland and has been detected at high levels in rain. In a laboratory study, tadpoles of the African clawed frog (*Xenopus laevis*) were reared in water containing atrazine at concentrations similar to those found in natural water bodies in the USA. The tadpoles grew, developed and metamorphosed into frogs, at which point they were examined in detail. Many of them were hermaphrodites, meaning that their gonads (testes and ovaries) contained both egg- and sperm-producing tissues. Many of those that were unequivocally male had a poorly developed larynx, the means by which males produce mating calls. Males that were allowed to develop to adult age showed a ten-fold decrease in testosterone level compared with untreated males (Hayes et al., 2002a, b).

The evidence for endocrine disruption in humans

Establishing a link between endocrine disruptors and human health is complicated by the fact that experiments of the kind conducted on animals are out of the question. It would be wholly unethical to administer DDT to people, for example, to see what effects it had on them. Studies on humans are thus limited to establishing a correlation between the presence of a xenobiotic chemical in the environment and some kind of health problem.

For example, the Aamjiwnaang are a community of Native Americans who live next to a major chemical complex in Ontario, Canada. Over the years, the ratio of boys and girls born in this community has been changing, from equal numbers in the period 1984–88 to 46 boys and 86 girls in 1999–2003. High levels of phthalates and hexachlorobenzene, both known to have endocrine-disrupting properties, have been found in the local soil (Mackenzie et al., 2005). Such data are suggestive of a causal link between endocrine-disrupting chemicals and a changed sex ratio, but do not provide conclusive proof for such a link. There may be other reasons why the sex ratio has changed.

By 2006, over 50 chemical compounds had been identified as endocrine disruptors. Many of these are long-lived compounds that can persist in the environment for many years without being degraded, and which can bioaccumulate in body tissues. They include several herbicides (e.g. atrazine), fungicides and insecticides (e.g. DDT); industrial chemicals and by-products such as PCBs and dioxin; and a number of compounds found in plastics, such as phthalates and styrenes, that are used to package foods and drinks (WRI, 1999). Levels of endocrine disruptors are especially high in heavily urbanised areas of the world.

4.6 Postscript to Section 4

This section has considered a small number of chemical pollutants of water and has examined what is known about their harmful effects on animals, humans and the environment. You should be aware of a number of important general points that arise from what you have read. First, there is an enormous variety of chemical pollutants; you have read about only a few. Secondly, the evidence that chemical pollutants are potentially harmful is often more convincing from studies of animals than it is from studies of human health. Thirdly, you have read mostly about amphibians; much is known about the harmful effects of chemical pollutants on other animals, but they have been the focus here because of their role as ‘canaries’, possibly providing early warning of environmental problems. Finally, while much is known about the harmful effects of chemical pollutants on wildlife and people, this body of knowledge pales into insignificance in comparison with what is not known.

Conclusion

- Freshwater is a finite and limited resource on Earth and, increasingly, much of it is polluted, by both pathogenic microbes and chemical contaminants.
- Human demand for freshwater is increasing; in particular, water is required to irrigate crops to feed the rapidly expanding human population.
- Water cycles globally, through the oceans, the atmosphere and freshwater river systems. At certain points in the cycle, water is purified, both naturally and by treatment plants.
- Freshwater is very unevenly distributed in the world, such that a large proportion of the world's human population has insufficient water for growing crops, for drinking and for sanitation.
- Climate change is altering the global distribution of water, causing droughts in some regions, flooding in others.
- The chemical and physical properties of water are such that, over the range of temperatures that occur on Earth, it supports a rich diversity of plants and animals.
- An enormous variety of chemical compounds, produced by human activities, pollute natural water bodies, causing both acute and chronic pollution.
- Evidence for the effect of chemical pollution is provided by ecotoxicology, the study of the impact of xenobiotic chemicals on wildlife in natural situations.
- As chemical pollutants pass through natural food chains, bioaccumulation causes high levels to build up at certain points, e.g. in the fat reserves of predatory fish and birds. As a result, these animals and their offspring can be exposed to a very high dose.
- DDT is an effective insecticide that is toxic to wildlife, but is also a vital means for combating malaria.
- Levels of mercury compounds in the environment are increasing; they are a threat to wildlife and to people who eat a lot of fish, and especially to their children.
- Levels of nitrogen compounds in the environment are increasing very rapidly. These are toxic to humans at high levels but, more importantly, at lower levels they cause widespread environmental changes, especially eutrophication of water.
- A large number of xenobiotic chemicals, called endocrine disruptors, cause major disruption to the reproductive development of freshwater animals; their possible effects on humans are uncertain.

Water is a natural resource that is vital to human health. It is also a resource that is undergoing a major crisis; its capacity to support plant and animal life is rapidly being destroyed by human activities. The message of this course is that human health and the health of the natural environment are intimately linked to one another.

‘Perhaps the time has come to cease calling it the “environmentalist view”, as though it were a lobbying effort outside the mainstream of human activity, and start calling it the real-world view.’

E. O. Wilson (American biologist and environmental campaigner)

6 Self-assessment questions

Question 1

Give three reasons why many people in the world face an increasingly severe shortage of fresh, safe water.

[View answer - Question 1](#)

Question 2

In some parts of the world, people are advised to limit the amount of certain kinds of fish that they eat; why is this?

[View answer - Question 2](#)

Question 3

Describe how, as levels of nitrogen compounds increase in the environment, their effects on human health change.

[View answer - Question 3](#)

Question 4

What does it mean to say that a particular xenobiotic chemical is an endocrine disruptor?

[View answer - Question 4](#)

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SAQ 1

Answer

They arise because people are using water at an increasing rate, the human population is expanding, and predicted patterns of climate change are expected to reduce water availability in many parts of the world, while increasing it in others.

[Back](#)

SAQ 2

Answer

Asia. It contains nearly two thirds of the world's human population, but only one third of its available freshwater.

[Back](#)

SAQ 3

Answer

Generally, yes, it is. The regions of highest water availability (Asia, South America) have high rainfall. The region with the lowest water availability (Australia) has low rainfall.

[Back](#)

SAQ 4

Answer

Africa has high rainfall ([Figure 4](#)), but rather low water availability ([Table 1](#)).

The reason for this is that rainfall in Africa is concentrated near the Equator, but is low in southern Africa, where many people live.

[Back](#)

SAQ 5

Answer

Agriculture: in 2025 it will account for 60% of all the water extracted from natural water resources (just over 3000 km³ in the total of just over 5000 km³).

[Back](#)

SAQ 6

Answer

Increasing human population and increasing per capita use of water.

[Back](#)

SAQ 11

Answer

For a start, there is the question of whether *Xenopus* is more or less sensitive to the compound than humans. Furthermore, the lethal dose approach is a measurement only of mortality, and provides no information about morbidity.

[Back](#)

SAQ 12

Answer

Peregrines and ospreys prey on mammals and fish and so occupy a position at the top of food chains, in which DDT-affected insects occupy a low level, so that, through bioaccumulation, they build up DDT in high concentrations in their body fat.

[Back](#)

SAQ 13

Answer

Bioaccumulation. Alligators are large, predatory animals that feed on fish.

[Back](#)

Question 1

Answer

The human population of the world is increasing rapidly; per capita use of freshwater is increasing; climate change is altering the distribution of freshwater, making it more scarce in some regions, such as southern Africa. You might also have answered, correctly, that an increasing proportion of water supplies are polluted, by pathogens and by xenobiotic chemicals, as a result of increasing urbanisation and industrialisation.

[Back](#)

Question 2

Answer

Large, predatory fish occupy a position at the top of food chains in which, by bioaccumulation, they can contain high levels of xenobiotic chemicals, such as methyl mercury, which may be harmful to human health, particularly during fetal development.

[Back](#)

Question 3

Answer

At lower levels, nitrogen compounds cause deterioration, by eutrophication, of natural water bodies, which can promote the formation of algal blooms. This can have indirect effects on human health by depleting fish stocks on which some communities depend. At higher levels, they can have a direct impact on human health, for example, by causing 'blue baby syndrome' and also asthma in some localities.

[Back](#)

Question 4

Answer

An endocrine disruptor is a chemical compound which, though not itself a hormone, has a molecular structure that enables it to mimic the effect of a hormone in an animal. The commonest examples of endocrine disruptors are those that mimic female hormones and feminise male animals (e.g. fish).

[Back](#)