WATER QUALITY

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Contents

Summary

Access to uncontaminated water may be argued as being the most important requirement for healthy human societies. Water is an abundant substance but it is also a vulnerable resource because only a very small fraction of the Earth's water is present in readily available forms such as groundwater or in rivers and lakes. In addition, these forms of water are susceptible to contamination resulting from human activity. Activities resulting in contamination include domestic water use, agriculture and aquaculture, recreational uses, industrial uses and transport activities. The resulting contamination may be classified into two main forms, being microbiological or chemical in origin. Water related infections arise primarily from pathogenic microorganisms excreted in faeces and their classification and methods of detection and enumeration are fundamental to our understanding of their transmission modes as well as remediation strategies. Historically, chemical pollution has been associated with the introduction of oxygen-demanding chemicals into water bodies. This continues to be a primary pollution issue, but such pollution may also be accompanied by toxic substances such as organic micro-pollutants and heavy metals as well as pollution from nutrients. Chemical speciation of heavy metals is an important issue in understanding the bioavailability of toxic substances, as is knowledge of their transport and removal mechanisms. The use of toxicity tests as tools for understanding pollutant impacts in aqueous systems including test organism and test components selection are considered in a concluding section.

1. Introduction

Since water is so familiar to us, it is easy to forget what an extraordinarily unusual chemical it is. Water can be described as the most important of all chemical substances. Along with energy from sunlight, the presence of water is the essential requirement for all life to exist. In its liquid form, the pure substance has no colour, no taste and no odour. It is a covalently bonded molecule, but the charge distribution within water is uneven and it is therefore polar and an excellent solvent for all kinds of substances. Uniquely for a chemical compound, its solid form is less dense that the liquid and it has a remarkably high specific heat capacity. It is an abundant substance that covers 70 percent of the Earth's surface, and yet it must be regarded as a vulnerable resource. Only 3 percent of the Earth's water is freshwater and the vast majority of this is locked in icecaps and glaciers. The most familiar and accessible form of water in rivers and freshwater lakes comprises only about 0.01 percent of the Earth's water.

It is against this background, and with population growth and climate change (see *Greenhouse Gases and Global Warming*) throughout the world, that there has come an increasing need for sustainable water and waste management programmes. The demand for water has never been greater and as with all other resources, there are problems of scarcity and allocation between competing interests. Scarcity is particularly acute in arid and semi-arid areas, and there are conflicts between domestic, industrial and agricultural users, between urban and rural demand and between human activity and ecological conservation needs.

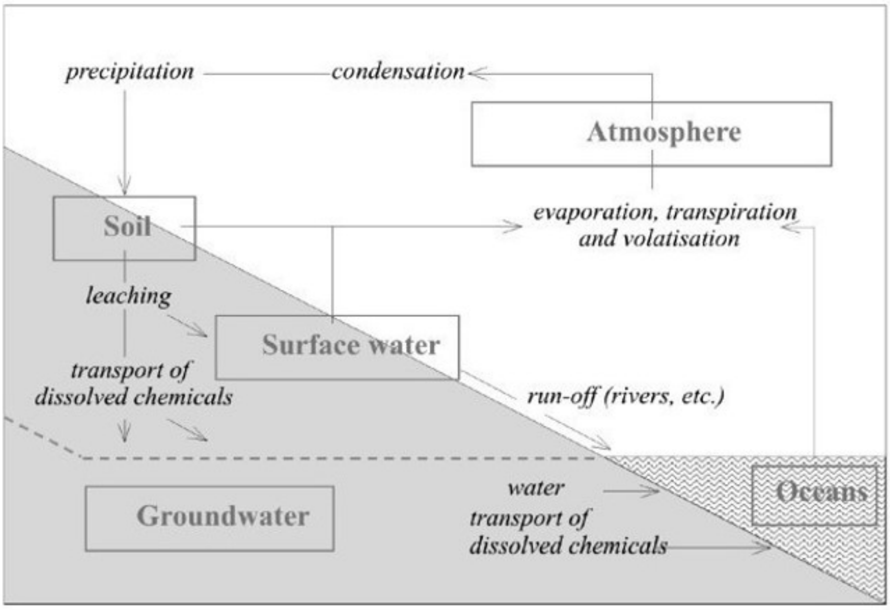

Figure 1. A simplified hydrologic cycle

The hydrologic cycle represents a series of processes and describes the movement of water resources through environmental compartments and also forms the basis for the transport of materials (including pollutants) through the environment. The main processes involved in the cycle are shown in Figure 1.

In order to sustain and manage the world's water resources, an understanding of the natural processes occurring within the hydrologic cycle is required. Such knowledge must include information about compartments of the cycle such as lakes and groundwater, as well as the pathways between such compartments. The impacts of human activity are not processes occurring in isolation from the hydrologic cycle. Rather, the effects of human activity can be seen as being superimposed upon a baseline of this naturally complex system. Knowledge of the processes within this system is required before prediction, assessment and remediation of human impacts can be undertaken.

2. Water Resources

2.1 Surface Waters

Surface waters include flowing water (*e.g.* rivers, streams, or canals) or standing water (*e.g.* lakes, ponds or reservoirs). Sources contributing to these water bodies include rain falling directly onto the water surface, surface runoff, inter-flow from water logged soil and water table discharge from aquifers with a high water table.

Rivers are a most valuable freshwater resource for man. They provide supplies of drinking water and food, navigation routes, water for industrial municipal and irrigation use. They also provide a means of disposal of waste as well as providing recreational value. Rivers are water bodies which flow through and drain a specific surface area known as a catchment area, river basin or watershed. They are complex systems in which both lateral and vertical mixing take place in addition to the unidirectional flow which ranges between 0.1-1.0 m s^{-1}. Water spends a short period of the hydrologic cycle in rivers compared with other compartments of the cycle. Typically, a 500 kilometers river with an average flow rate of 0.5 m s^{-1} might have a retention time of around 12 days. During its flow through the catchment area, the natural composition of water may change greatly. Catchment areas containing more readily dissolvable material such as chalk will result in elevations in dissolved major ions such as calcium. In addition to the climate, natural geology and geography of the catchment, the water quality will also be altered by the extent of human development of the catchment. Although the nature of the catchment dictates the properties of the surface waters therein, the catchment itself cannot be considered in isolation. Pollutants in the form of particles and gases may be transported from one catchment area to another. This highlights the importance of the hydrologic cycle and its role in the natural transport of pollutants.

Lakes provide similar freshwater resources to those provided by rivers. They are features that may exist for days or thousands of years and may arise from a range of geological processes. All lakes may be characterised by their very low average flow velocities, which are often multidirectional. As a result of this, the retention time of lake waters can be very long indeed, possibly thousands of years. In contrast to rivers, lakes may undergo periods of the year where the water is not vertically fully mixed, caused by thermal stratification. This natural phenomenon may exacerbate problems caused by man's activity (see *Thermal Pollution of Water, Eutrophication and Algal Blooms*). Since lakes receive water from faster moving water, capable of carrying more material, the process of sedimentation is an important and constant feature in lakes. This process allows an historical record of events within the lake and its catchment to be made through analysis of sediment composition. Since pollutants are often associated with sediment particles, the build up of sediments may also lead to the build up of pollutants. This means that polluting chemicals such as nutrients or heavy metals, which have built up in the bottom sediments, can remain problematic long after original source of the contaminant from an incoming source has been removed.

Reservoirs are water bodies contained by dams or embankments and which are modified and managed for human use (e.g. drinking or industrial water supply, flood control, recreation etc.). Although natural lakes and reservoirs share many characteristics, reservoirs, by definition, are the result of human activity and as such are likely to be as much if not more vulnerable to pollution threats than corresponding natural lakes.

2.2 Subsurface Water (Groundwater)

A number of processes control the water deposited on the surface of the Earth through precipitation. Some is lost through direct evaporation from the surface and transpiration by vegetation and some is retained in the upper soil as interstitial water, held by molecular attraction of the soil particles and by capillary forces (see *Soil Chemistry*). The remainder percolates through an unsaturated zone, also called "zone of aeration", to the zone of saturation to an underground layer called an aquifer and becomes groundwater. There are two types of aquifer: a "confined aquifer", confined above as well as below, by a relatively impermeable stratum where the water flows under pressure; and an "unconfined aquifer" in which the water may flow with a free surface, or "water table".

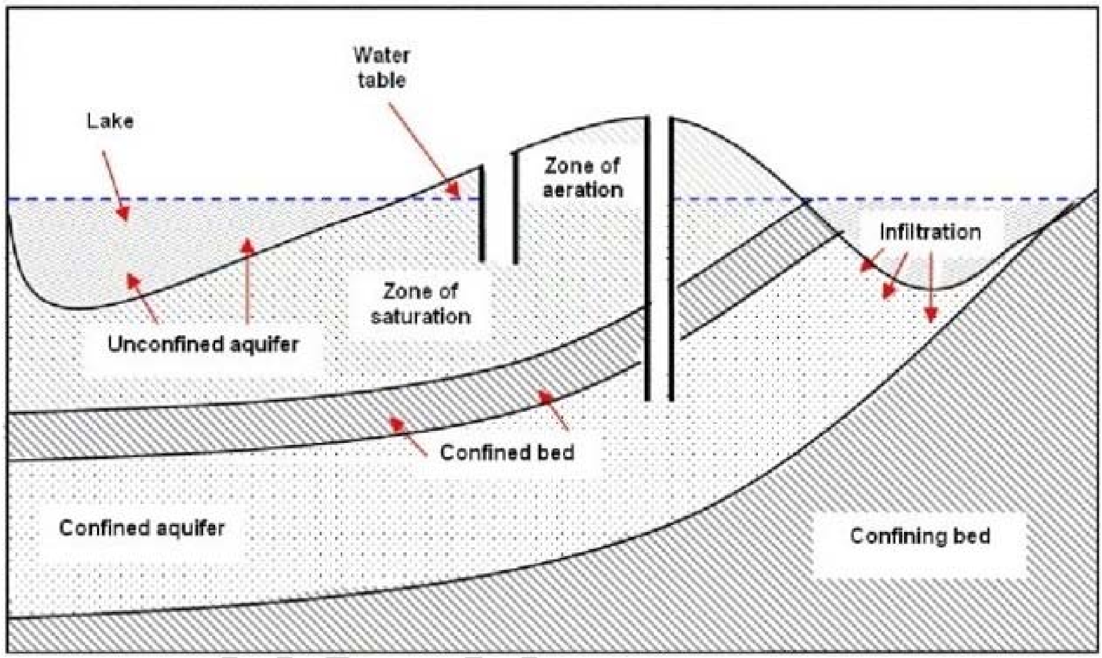

Figure 2. Schematic representation of subsurface water distribution

Groundwater accounts for only a small portion of the world's total water but it is a major source of freshwater for human use. The characteristics and quality of groundwaters may differ greatly from those of surface waters even when they originate from the same source. This is due to the variety of physical and geochemical processes which affect them. As water percolates through soil and rock, to become groundwater, it may dissolve minerals from the medium through which it passes, increasing its ionic strength. Oxygen levels will be low in groundwater due to the lack of contact with the atmosphere. Microbial concentrations will be greatly reduced by filtration through the soil substrate, both affecting the biological activities in this phase.

Composition of groundwater is affected by both geological and climatic conditions. important chemical components are dissolved salts, iron, manganese, arsenic, radionuclides and trace metals (see *Speciation of Heavy Metals and Radioisotopes*). The rate of percolation has a significant effect on the quality of the water. Slow percolation in dry, arid regions may cause high salinity in the water. On the other hand, excessive hardness may be found in humid climates as a result of weathering of sedimentary rocks and dissolution of calcium and magnesium-containing minerals.

3. Categories of Water Use

3.1 Domestic

Domestic water use includes drinking, cooking, washing, cleaning, toilet flushing and gardening. These account for 40-60 percent of most urban water supplies. Office uses, leisure, services, car washes etc. account for the remainder. Up to 70 percent of domestic water supply is discharged into the sewer system and where flush toilets are used, approximately a third of this is flushed down toilets. There are major differences in the availability of water for domestic use between developed and developing countries both in urban and rural situations. Where piped water supply is available, domestic supplies generally provide potable water. This should comprise of an adequate and continuous supply of water of a satisfactory chemical, bacteriological and aesthetic quality. This water should be safe (does not contain pathogens or harmful chemicals), palatable (no unpleasant taste), colourless and odourless, reasonably soft (for washing), non-corrosive (protect pipes and tanks) and contain low organic content (to avoid biological growth).

Guidelines and directives for potable water are provided by a number of national and international organisations. These include:

- World Health Organisation guidelines for drinking water quality
  Volume 1: Recommendations (1993)
  Volume 2: Health criteria and other supporting information (1997)
  Volume 3: Surveillance and control of community cupplies. (1997)

These provide advisory only guideline values with world-wide applications.

- European Commission directive on water intended for human consumption (1998). Directive 98/93. EC Official Journal L330/41.

These apply to the member states of the European Community only, and should have been adopted into national laws by 2003.

- United States Environmental Protection Agency (USEPA) National Primary Drinking Water Regulations, as specified in the 1996 amendments to the safe Drinking Water Act.

The USEPA regulations set mandatory ‘maximum contamination levels’ (MCLs) and non mandatory advisory ‘secondary levels ‘ (SMCLs) or ‘maximum contaminant level goals (MCLGs).

Bottled water: The use of bottled water for drinking is enjoying an increasing popularity. Bottled water can originate from a variety of sources and are grouped into a number of types. These are: (i) Artesian water: extracted from wells which tap confined aquifers, (ii) Spring water: extracted from a water flow which originates in an underground source, (iii) Purified water: artificially purified water through technologies such as distillation, deionisation and reverse osmosis and (iv) Mineral water: originate from an underground source and is defined by the level of naturally dissolved solids (minerals) which should be higher than 250 mg L^{-1}. The microbiological and chemical quality of bottled water is regulated by the appropriate food standard agencies (United States Food and Drugs Administration [US FDA], United Kingdom Food Standards Agency [UK-FSA] and European Food Standards Agency [E-FSA] etc). The standards applied may differ from, but are greatly influenced by those applied to drinking water.

3.2 Agriculture and Aquaculture

Agricultural use includes water supplies to farm and market gardens. The productivity of the agricultural sector in arid and semi-arid areas is highly dependent on regular irrigation. Even in areas with higher levels of rainfall, supplemental irrigation is often necessary. Important factors affecting the levels of consumption include the type of crop chosen as well as the climatic conditions, season and local weather. The land application method of irrigation water often has an effect on the risk of infection, salinity of the soil as well as on the quantities of water required.

Aquaculture is the farming of products cultivated within water, and includes fish farming and algal culture. There are various contaminants that may be hazardous to fish life. These include suspended matter, substances which exert oxygen demand and raised temperature, both of which can lower the dissolved oxygen (DO) below the level which can support fish life, high or low pH, increased salinity and toxic waste.

3.3 Recreational Use

Much recreational activity around the world, such as the development of recreational and scenic parkland depends on the availability of suitable water resources. The quality standards for recreational usage of reclaimed wastewater will generally depend on the amount of direct contact between the public and the water.

Contact recreational water: Water of this type is used for whole-body immersion recreation – including bathing, swimming and water-skiing – in which there is prolonged, intimate contact with the water and considerable risk of ingestion or bodily contact with pollutants in sufficient quantities to pose a significant health hazard. The quality standards for this type of recreational water are higher than for non-contact applications. Water used for primary contact recreation should be aesthetically enjoyable and reasonably free from pathogenic organisms. Clarity is important for recreational waters for reasons of safety and visual appeal. Aquatic plant growth such as algae should also be absent or low in acceptable contact recreational waters. In bathing and swimming waters, the acceptable range of pH is 6.5 to 8.3 because the lachrymal fluid of the human eye is approximately 7, and large deviations of pH may result in eye irritation. The chemical characteristics of primary contact water should indicate the water to be non-toxic on ingestion and non-irritating to the skin, mucous membranes, eyes and ears.

Limited contact recreational water: The uses of such waters include boating, fishing and other non-body immersion activities incidental to shoreline usage. The water quality criteria for such limited body contact (or secondary contact) usage are less restrictive than those for primary contact.

Non-contact recreational water: Certain water quality criteria have been established to protect the biota and provide conditions conducive to the growth and propagation of fish in waters that are purely scenic.

EU guideline values for recreational water are based on pathogen presence and aesthetic appearance of water. In 1986, the US EPA recommended that *E. coli* be used in place of faecal-coliform bacteria in state recreational water-quality standards as an indicator of faecal contamination. Details of WHO guidelines on water quality can be viewed at www.who.int/water_sanitation_heath.

3.4 Environmental Conservation

Water demand exists for the preservation and benefit of fish and wildlife, protection of wetland and marshes, ponds, streams, and estuary areas. Environmental conservation activities and sustainable management of water resources may sometimes conflict with the demand for water abstraction and requirements for wastewater discharge.

3.5 Transport

Rivers and canals are regularly used for navigation and transport. Water flow through them has to be kept constant throughout the year. This exerts competing demand particularly during dry seasons. In addition, contamination from boats such as fuel spillage and toilet discharge can affect other water uses.

3.6 Industrial Use

Industry is an extensive user of water for a range of processes and, as such, is a major source of particular types of polluted effluent. Industrial use can often be met by treated wastewater and, thus, water reclamation and reuse has an important part in industrial practice. Water quality parameters affecting use will depend on the type of process. This will often relate to hardness, salinity, pH and organic content, which will affect pipes and boilers. Industry is both a high consumer of water and high pollution discharger particularly in reference to potentially toxic chemicals.

4. Microbiological Quality Parameters

4.1 Water Related Infections and Microbial Pollution

Microbial contamination of the water environment is associated with a range of human and animal infections caused primarily by pathogenic microorganisms excreted in faeces. These water-related infections can be broadly categorised according to their mode of transmission described for the first time in 1972 in the Bradley classification of water related diseases.

Water-bourne: This category includes infections which are caused by the ingestion of infectious agents present in contaminated drinking water causing diarrhoea and other conditions (examples include hepatitis A, polio, cholera, shigella, amoebic dysentery, cryptosporidium and others). The most common route of transmission is the faecal–oral route. With this route of transmission the infections are often transmitted through contaminated food and lack of hygiene as well through drinking water.

Water wash/hygiene related: This category includes infections which are effected by the availability or rather the lack of availability of water, for washing, bathing and cleaning, leading to poor hygiene. These include skin and eye infections as well as faecal-oral transmission related to a lack of hygiene.

Water based/contact: This category includes infections, which are caused by the infectious agent penetration of the skin on contact with water. These are infections cause by parasitic helminths (worms) whose life cycle includes aquatic intermediate hosts. The most important in this category is schistosomiasis (bilharzia).

Water related vector: This category includes infections transmitted by insect vectors, which breed in water or bite in the vicinity of water bodies. Infections arising from these vectors include malaria, filariaisis, river blindness (oncocerciasis) and mosquito borne viruses such as yellow fever and Japanese encephalitis. Most are independent of microbiological water quality.

4.2 Environmental Classification of Excreta-Related Infections

A summary of the main commonly excreted pathogens and their associated diseases, classified according to their mode of infection, latency, persistence of pathogens in the environment and the infective dose for humans is provided in Table 1 below.

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Biographical Sketches

Hemda Garelick has worked at London School of Hygiene and Tropical Medicine, and at Middlesex University. She has a long-standing interest in public health, with particular focuses on health and hygiene aspects of water and sanitation systems. Dr Garelick's research has included areas of environmental microbiology and bio-remediation. This involves the investigation of health aspects of, and risk from, microbial pollution in particular, the fate of antibiotic resistant microorganisms in the environment and in food. Other research projects investigated both chemical and microbial pollution of water with emphasis on levels and distribution of indicator and pathogenic micro-organisms in urban waters and sediment.

Huw Jones worked at King's College, London, UK on the effects of heavy metal contamination on nitrogen fixation in agricultural soils. At Middlesex University, Dr Jones investigated the uses of macroinvertebrate tissues and developed novel field biomonitoring techniques to assess organic micropollutant impacts in urban fresh waters. Since then, he has worked with British Airports Authority at London's Heathrow Airport on the development of reed-bed systems for treatment of runway run-off and on similar systems for road runoff in UK. Other research interests include investigations of risk associated with lead, barium and bismuth in the crystal glass industry and the biokinetics of aluminium in the human body.