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Chapter 3
Water quality and health

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Introduction

During the last decade, it has become commonplace to speak of the links between water quantity and water quality. As population has continued to rise throughout most of the world, it has become increasingly difficult to provide an adequate supply of water for all uses. While in a few highly arid regions, such as the Sahel and the Arabian peninsula, this is the result of naturally scarce supplies, in most countries the crux of the problem lies with water quality rather than water quantity.

In the industrialized countries, industrial effluents and agricultural chemicals have contaminated surface waters, posing a threat to aquatic life and necessitating costly treatment before fresh water can be tapped as a source for municipal and industrial supply. Similarly, ground water resources, once considered better protected from anthropogenic contamination, have become widely polluted with chemicals, many of which are known or suspected carcinogens.

In the developing world, chemicals are being introduced at an ever-increasing rate; however, traditional water-related disease, particularly the enteric and diarrheal pathogens, remain the primary health concern. Diarrheal disease is the leading cause of morbidity in the world, responsible for the deaths of three million young children each year.[1] In Latin America, a recent outbreak of cholera, last seen in the western hemisphere over a century ago, suggests that in some regions progress in controlling the microbiologic contamination of drinking water has been completely inadequate. Yet while still grappling with the most basic water quality issues, the less-developed countries are at the same time having to face the water quality problems posed by industrialization and chemically reliant agriculture.

The water quality challenges that the world currently faces are enormous. This chapter aims to provide an overview of global water quality in relation to human health by presenting an inventory and some examples of specific water quality problems. Subsequently, emerging issues and trends are described, and in the last section approaches to water quality management in both the industrialized and developing worlds are presented and discussed.

Water quality problems

Background. The quality of natural waters varies both temporally and spatially, making it difficult to compare water quality across broad geographic regions or time-scales. For instance, dissolved oxygen concentration, an important parameter for aquatic life, varies inversely with temperature and so changes continuously as the temperature of the atmosphere changes. Water quality in rivers may change substantially on a seasonal basis in response to contaminant inputs that are carried by runoff, such as metals and petroleum products associated with urban stormwater runoff, and chemicals leached from agricultural fields. Over longer time periods, water quality will vary in response to natural events, both catastrophic changes such as volcanic explosions and gradual changes such as the maturation of lakes. There are also vast differences among natural waterbodies depending on their location, their origin, and the surrounding climate. For instance, some water sources have naturally high concentrations of radionuclides, which make them unsuitable for most human uses.

To some extent, water quality concerns are specific to the type of waterbody, i.e., river, lake, or underground aquifer. Eutrophication and sedimentation are problems that affect only surface waters. Lakes a[nd] reservoirs are more prone to long-term acidification than are rivers, wh[ile] the latter are more susceptible to sudden pulses of high acidity due to th[eir] lower buffering capacity. In some regions, ground water is better pr[o]tected from sewage pollution yet more susceptible to contamination fro[m] fertilizers and agricultural chemicals.

The adequacy of water quality for human use, however, depends n[ot] only upon the absolute concentrations of given parameters but also upo[n] how the water will be used. The highest quality water is required fo[r] drinking. Beyond that, water of progressively lesser quality is require[d] for swimming and recreational use, industrial use, and irrigation. Th[e] water quality needs of aquatic life vary; however, aquatic species ar[e] frequently more sensitive to organic and chemical pollution than ar[e] human beings.

Worldwide, natural processes still dominate the chemistry of natural waters. In only a few cases has anthropogenic pollution been truly global in scale; these include increases in lead, DDT, and atmospheric CO_2. On a local, and increasingly on a regional scale, however, human influences have begun to dominate the quality of natural waters.[2] For centuries surface waters have been used as receptacles for human waste because the natural processes of waterbodies – sedimentation, aeration, mixing, bacterial processing – help to break down and to return wastes to the natural environment. But the ever-increasing human population and its growing wasteload have clearly overtaxed the natural recycling capabilities of many waterways. In areas of eastern Europe, for example, rapid and uncontrolled industrialization has resulted in grossly polluted waterways. According to a recent report released by the government of Czechoslovakia, 70% of all surface waters in the country are heavily polluted and 30% are not capable of sustaining fish.[3]

Anthropogenic pollution may be categorized as emanating from either municipal, industrial, or agricultural sources. Municipal waste is composed primarily of human excreta and generally contains few or no chemical contaminants but may carry numerous pathogenic microorganisms. Industrial wastes vary tremendously depending upon the type of industry or processing activity, and may contain a wide variety of both organic and inorganic chemicals. Agricultural pollution is comprised of the excess phosphorus and nitrogen present in fertilizers, which pollute ground water and accelerate the eutrophication of surface waters, as well as numerous different organic pesticides.

A further distinction is often made between "point" and "non-point" sources of pollution. Both municipal and most industrial effluents are labeled point sources because they are emitted from one specific and identifiable place (e.g., a sewage or industrial outfall). Agricultural pollution, on the other hand, enters waterways in a diffuse manner as chemicals percolate into ground water or are washed from the soil into nearby surface waters. Other examples of non-point sources include runoff from mining operations, uncollected sewage (particularly in rural areas), and urban stormwater runoff. The distinction between point and non-point sources is particularly relevant from a management perspective because it is much more difficult both to identify and to measure the impact of diffuse sources. Finally, pollutants may be categorized not by their source but by their chemical, physical, and biological characteristics – such as bacteria, metals, and organic chemicals. The next several sections of this chapter describe the major classes of water quality pollutants, the threats they pose to human health, their sources, and what is known about their extent.

Microbiologic contamination and water-related disease. For more than half a century, water-related disease has been of minor consequence in the industrialized world, yet globally microbiologic contamination remains the most pressing water quality concern. Estimates of the global occurrence of waterborne disease are highly uncertain, but on the order of 250 million new cases of waterborne disease are reported each year, resulting in roughly 10 million deaths. Seventy-five per cent of these cases occur in tropical countries, where both climatic conditions and the poor state of water supply and sanitation infrastructure combine to spread disease.[4]

Microbiologic diseases associated with water are not necessarily waterborne, but are more properly classified among four different categories (see Table 3.1). The term "waterborne" includes those diseases in which water is the passive agent for transmission, and generally refers to those pathogens that are passed from excreta to water and then subsequently ingested. Most important in this category are the waterborne enteric and diarrheal diseases. The diarrheal diseases are the result of so many different etiologies that the pathogenic agents are often not identified, but can be roughly grouped into those diseases caused by bacteria (e.g., *Vibrio cholera*), those caused by parasites (e.g., *Giardia lamblia*), and those caused by viruses (e.g., Norwalk, rotaviruses).

Water-washed, or water-hygiene, diseases result from unsanitary conditions and can be avoided through the use of additional water for washing. This category includes the eye and louse-borne diseases (e.g., trachoma, typhus) as well as many of the diarrheal diseases which may be passed directly from person to person without first passing into water supplies.

Water-based diseases are passed through means other than ingestion by hosts that either live in water or require water for part of their life-cycle. Among the most common diseases in this category are schistosomiasis which is contracted from dermal contact with infected snails, and guinea worm disease (dracunculiasis). Finally, water-vector diseases are spread by insects that either breed in or bite near water.

The principal pathway for the transmission of waterborne disease is through the contamination of drinking water supplies with pathogen-carrying animal or human excreta, and the subsequent ingestion of pathogens by uninfected people (fecal–oral transmission). Typhoid fever and cholera were the first diseases identified as waterborne, and cholera remains one of the more important diseases in this class. The first cholera pandemic spread all the way to the Americas from South Asia in 1817, and up until the mid-19th century, cholera outbreaks occurred repeatedly in the U.S. In 1970 the disease leaped across a vast expanse of unaffected territory to reach western Africa, where it rapidly invaded several countries. Today, cholera remains endemic in Asia and Africa, and in January of 1991 cholera arrived in Peru, making its reappearance in the western hemisphere for the first time in this century. Since then the disease has traveled to several other Latin American countries, claiming nearly 4,000 lives within a year. Water transmission has played a key role in the epi-

TABLE 3.1 Classifications of water-related infections

Category	Infection	Pathogenic agent
1. Fecal–oral (waterborne or water-washed)	Diarrheas and dysentries	
	Amoebiasis	P
	Campylobacter interitis	B
	Cholera	B
	E. coli diarrhea	B
	Giardiasis	P
	Rotavirus diarrhea	V
	Salmonellosis	B
	Shigellosis (bacillary dysentry)	B
	Enteric fevers	
	Typhoid	B
	Paratyphoid	B
	Poliomyelitis	V
	Ascariasis (giant roundworm)	H
	Trichuriasis (whipworm)	H
	Strongyloidiasis	H
	Taenia solium taeniasis (pork tapeworm)	H
2. Water-washed:		
Skin and eye infections	Infectious skin diseases	M
	Infectious eye diseases	M
Other	Louse-borne typhus	R
	Louse-borne relapsing fever	S
3. Water-based:		
Penetrating skin	Schistosomiasis	H
Ingested	Dracunculiasis (guinea worm)	H
	Clonorchiasis	H
	Others	H
4. Water-related insect vector:	Trypanosomiasis (sleeping sickness)	P
Biting near water	Filariasis	H
Breeding in water	Malaria	P
	Onchocerciasis (river blindness)	H
	Mosquito-borne viruses	
	Yellow fever	V
	Dengue	V
	Others	V

Source: Adapted from R.G. Feachem, 1984, Infections related to water and excreta: The health dimension of the decade, in P.G. Bourne (ed.) *Water and Sanitation*, Academic Press, Inc., Orlando, pp. 21–47.

B, bacterium; P, protozoan; S, spirochete; M, miscellaneous; H, helminth; R, rickettsia; V, virus.

demic, especially in the slums of Lima and other Peruvian cities where most of the deaths have occurred.[5]

Although over 30 species of parasites infect the human intestine, only seven have global distributions or serious pathologies: amoebiasis, giardiasis, *Taenia solium* taeniasis, ascariasis, hookworm, trichuriasis and strongyloidiasis.[6] Globally, *Giardia* is the most common animal parasite of human beings and the most common cause of waterborne disease; its distribution is increasing because of its resistance to chlorine.[7] Global morbidity due to whipworms (trichuriasis) is estimated at roughly 100,000 annually, with 500 million people infected. In some regions, including Cameroon, the Caribbean, and Malaysia, whipworm infection rates are reported to be more than 90%. The parasite responsible for amoebiasis, *Entamoeba histolytica*, is estimated to infect as many as 500 million people worldwide, and it remains a major health problem in China, Mexico, eastern South America, western and southern Africa, and all of south-east Asia. *Ascaris* is estimated to infect 1 billion people worldwide.[8]

One of the more unusual waterborne diseases is Legionnaire's disease, first diagnosed in July of 1976 when an outbreak of acute respiratory illness occurred during an American Legion convention in Philadelphia, causing 221 cases of illness and 34 deaths. Infection is believed to have occurred through the inhalation of bacteria in aerosolized, contaminated water. Unlike most pathogens, *Legionella* does not have an animal host reservoir but is a common inhabitant of natural waters. More important from a health standpoint is its resistance to chlorine, which allows it to survive and multiply in water treated to meet U.S. and European drinking standards.[9]

Waterborne diseases can be controlled directly through improved water quality. In the early part of the 19th century, Europe and North America made dramatic improvements in public health through the protection and treatment of water supplies, ultimately bringing both cholera and typhoid under control. Currently, in the developed countries the microbial pathogens of greatest concern are those that demonstrate resistance to chlorine, including hepatitis A, *Giardia lamblia*, and *Cryptosporidium*. During the current century, the incidence of waterborne disease in the U.S. population has declined from roughly eight cases per 100,000 person-years during the period 1920–1940 to four cases in the period 1971–1980.[10] Although outbreaks of waterborne disease still occur with some frequency, such outbreaks are now limited to small water systems and consequently affect many fewer people. In 1989–1990, waterborne outbreaks in the U.S. caused 4,288 cases of illness and four deaths. Among these outbreaks giardiasis was the most common.[11]

Of the water-based diseases, schistosomiasis and dracunculiasis are the most widespread. Schistosomiasis currently infects 200 million people and puts another 400 million at risk in more than 70 countries. In many regions, the disease is spreading and intensifying due to new irrigation projects, which create a favorable environment for the host snails. In the Nile delta, the parasite quickly spread throughout the river region following the construction of the high dam at Aswan and related irrigation projects, resulting in infection rates of up to 100%. In Sudan the construction of the Sennâr dam in 1924 has had similar results. In the newly irrigated region of Gezira, the prevalence in children of two carrying parasites (*S. haematobium* and *S. mansoni*) increased from less than 5% to more than 45% and 77%, respectively. In West Africa, the construction of the Akosombo dam and Lake Volta resulted in infection rates in children rising from less than 10% to more than 90% within a year of the reservoir's filling.[12]

Dracunculiasis, or guinea worm disease, is caused by the ingestion of water containing a species of crustacean that is infected with guinea worm larvae (*Dracunculus medinensis*). Upon maturation, adult worms emerge through the skin and release new larvae into water. An extremely debilitating disease, guinea worm remains a major public health concern in Africa and South Asia, despite remarkable progress in controlling the vector. The total number of cases worldwide in 1990 was estimated at less than 3 million, compared to 5–10 million in the mid-1980s. Twelve countries in Africa and South Asia now account for more than 98% of the cases worldwide.[13]

Guinea worm disease is one of the few diseases that can be controlled completely through the provision of safe drinking water, and most searchers acknowledge that it could be eradicated from the globe witl the next decade. Control measures include protecting sources of wa from guinea worm larvae, filtration of drinking water to remove bc larvae and infected crustaceans, and boiling or chlorination of drinki water to destroy larvae. In Africa, the most dramatic evidence of succe comes from the Côte D'Ivoire, which has implemented an aggressi rural water supply and education program. In 1966, the country report more than 67,000 cases of guinea worm disease. By 1976, this had fall to 4,971 cases, and by 1990 to 1,360 cases, despite the fact that reportir and surveillance had become much more thorough. The Republic Gambia has had similar success and may actually have succeeded i eliminating the disease. Overall, there remain ten "core" African cour tries with high levels of infection.[14]

Water-vector diseases form a slightly different class because they ar not directly attributable to water quality, although in many cases it is th large-scale development of water resources for urban and agricultural us that has created favorable conditions for host insects. Of the disease transmitted by water-related insect vectors, malaria is unquestionably th most important. More than 2 billion people, or 40% of the world's popu lation, remain exposed to malaria risk in approximately 100 countries Malaria is one of the most important killers of children under 5 years o age, accounting for 20%–30% of childhood deaths. Nine per cent of those exposed live in areas with intense transmission and no fully implemented control programs, while 32% live in regions where malaria was once controlled but has now re-emerged. The global incidence of malaria is estimated to be on the order of 120 million clinical cases each year, with roughly 300 million people carrying the parasite. Half of all cases recorded come from India and Brazil, and about one-fourth of reported cases originate from Thailand, Sri Lanka, Afghanistan, Vietnam, China, and Myanmar. Summarizing the malaria situation globally, however, tends to mask the great variations that exist between and within countries. In India, for example, 2 million cases were reported in 1989, but 55% of these cases came from only three states: Gujarat, Orissa, and Madhya Pradesh. In the Americas, where malaria incidence increased dramatically from 270,000 cases in 1974 to 1.1 million in 1989, 52% of the cases are from Brazil. Within Brazil, the Amazon region recorded 97% of all cases, the majority coming from only three states; even within these states cases are concentrated in particular villages.[15] Aside from malaria, mosquitos may transmit several other diseases, such as yellow fever, dengue fever, filariasis, and dozens of lesser-known maladies.

Several water-related vector diseases are transmitted by flies. African trypanosomiasis, or sleeping sickness, is a very deadly disease that is transmitted by the African tsetse fly. In 36 affected countries, 50 million people are at risk and 25,000 new cases are reported each year. During the last decade, severe outbreaks have occurred in Sudan and Uganda, but the extent of the disease, like many others, is poorly documented. American trypanosomiasis (Chagas disease) affects 18 million people in Latin America, and transmission has recently intensified as a result of the proliferation of slums in urban areas.[16] Onchocerciasis, or river blindness, affects seven West African countries, causing approximately 70,000 cases of blindness or impaired vision. After 15 years of vector control, however, the disease is no longer considered a major public health problem.[17]

The actual degree of disease and suffering caused by water-related disease in the developing world is unknown. Most illnesses go undiagnosed and unreported, while epidemiological and microbiological studies have been conducted for only a handful of these diseases. The wide variety of disease-carrying bacteria, parasites, and insects that exist in tropical regions, combined with the relatively poor state of health care and water supply, suggest that these long-standing water quality problems will not be easily overcome. The continuing costs in human life and suffering clearly make these diseases one of the foremost global problems of any kind.

Nitrates. Nitrate is one of the many forms of nitrogen that occur in the environment. Although nitrogen is an essential element for all forms of life, increasing concentrations of nitrate in drinking waters pose two human health concerns. First, nitrates may cause infant methemoglobinemia, or blue-baby syndrome, in which the oxygen-carrying capacity of hemoglobin is blocked, causing suffocation.[18] The onset of methemoglobinemia requires relatively high levels of nitrate, at least 10 mg/l but usually on the order of 100 mg/l.[19] Since 1945 about 3,000 cases of methemoglobinemia have been reported worldwide, some fatal. More than 1,300 cases occurred in Hungary between 1976 and 1982, all of which were associated with private wells with very high concentrations of nitrate, greater than 22 mg/l NO_3-N.[20] The other health concern posed by nitrates is their potential role in the formation of cancers of the digestive tract attributable to N-nitrogenated compounds (nitrosamines). Nitrosamines are among the most potent of the known carcinogens in laboratory animals; but the contribution of ingested nitrates to their formation is unclear, and the epidemiological evidence is considered inconclusive. While nitrates currently do not pose a major threat to public health, the rapid and widespread increase in nitrate pollution raises serious concerns about the future quality of many waterbodies.

Nitrogen is always present in aquatic systems, most abundantly as a gas, but overall concentrations and input rates are intimately connected to the surrounding watershed and land use practices. Nitrate ions, the most common form of combined inorganic nitrogen in water, move easily through soils and are lost rapidly from land even in unperturbed watersheds. Stormwater runoff dissolves soil nitrate while erosion transfers particulate nitrate. Even moderate environmental disturbances, such as sensible farming or careful logging, release significant quantities of nitrates to surrounding waters.

The principal natural sources of nitrate in water include soil nitrogen, nitrogen-rich geologic deposits, and atmospheric deposition. The principal anthropogenic sources include fertilizers, septic tank drainage, feedlots, dairy and poultry farming, land disposal of municipal and industrial wastes, disturbance of mineralized soils by cultivation or logging, and the leaching of nitrates through irrigation. However, the amount of nitrate that actually enters aquatic systems is controlled by a complex set of hydrologic, chemical, and biological processes, referred to collectively as the nitrogen cycle. In aquatic systems, nitrogen fixation (the biologic conversion of ammonia to nitrite and subsequently to nitrate) and denitrification (the bacterial reduction of nitrate to nitrogen gas) are the most important transformations affecting nitrate concentrations.

Even though concentrations vary substantially under natural conditions, measurements indicate that the nitrate content of fresh water has been rising steadily in many countries over the last three decades. The major causes of this rise are increased industrial and urban waste, and the increased use of nitrogen fertilizers and manure in agriculture. Meybeck has estimated that about one-third of the total dissolved nitrogen (both organic and inorganic) in river water is the result of pollution.[21] The average nitrate concentration for pristine rivers was estimated to be 0.1 mg/l NO_3-N. Based on this estimate, less than 10% of the rivers in Europe can be classified as pristine.[22] The median level of NO_3-N in rivers outside of Europe monitored as part of the World Health Organization's (WHO) Global Environmental Monitoring System (GEMS) is 0.25 mg/l. For Europe, the median is 4.5 mg/l.[23]

Atmospheric loading has caused substantial increases in nitrate concentrations in Lake Superior. Estimates of springtime nitrate concentration were approximately 75 μg/l in 1906, rising to 311 μg/l in 1976. Moreover, these exponential increases will continue over the next several decades because the lake has not nearly attained equilibrium with existing nitrogen levels in the atmosphere.[24] While concentrations are still well below drinking water standards, this example nonetheless indicates the dramatic impact of human activities on water quality.

Levels of nitrate are generally much higher in ground waters than in surface waters. In the United States, a sampling network established by the Geological Survey showed that in more than one-third of the counties analyzed, 25% of the wells had nitrate concentrations that exceeded background levels, which were liberally estimated to be 3 mg/l NO_3-N. In 5% of the counties, more than 25% of the wells exceeded the federal drinking water criteria of 10 mg/l NO_3-N. The highest measured concentrations exceeded 100 mg/l NO_3-N.[25] Similarly, nitrate levels in Danish ground waters have nearly trebled since the 1940s. Mean concentrations were estimated to be approximately 1 mg/l NO_3-N in the 1940s and 1950s but had risen to 3 mg/l by 1980. Moreover, 8% of Danish waterworks tested exceeded the maximum admissible limit for drinking water of 11 mg/l.[26]

Metals. The earliest records of metal pollution in natural waters d from the 19th century and describe the effects of mine drainage on surfa waters in Great Britain:

> All these streams are turbid, whitened by the waste of the lead mines in their course; and flood waters in which, spreading over the adjoining flats, wither befoul grazing on the dirtied herbage, or, by killing the plants whose roots have held the land together, render the shores more liable to abrasion and destruction on the next occasion of high water.[27]

Like nitrates, metals are natural constituents of soil and water, but recent decades the worldwide production and use of metals has expand dramatically, and so has the associated problem of aquatic pollution. T dispersion of metals into the biosphere as a consequence of industrial a agricultural activity appears now to rival, and sometimes to exceed, na ural mobilizations for certain elements. This is particularly true for lea Present day levels of lead in industrialized countries have been estimate to be two to three orders of magnitude higher than those of the pre-tec nological age.[28] While no other metal has the same prevalence as lea several are widespread in aquatic environments. The ocean influx of ca mium has increased by as much as 60% over natural levels.[29] Aluminu has been mobilized on a regional scale in soils and water affected by ac precipitation. Mercury contamination has also become a problem of r gional significance.

It was not until the 1950s that several mass poisoning episodes broug the toxicity of heavy metals to the attention of the public and the scientif community. The first such episode occurred between 1947 and 196 when the Jintsu River in Japan became heavily contaminated with cad mium from a mine located upstream. Water from the river flooded low lying rice fields, and over a 20-year period, 100 deaths due to cadmiu poisoning (Itai-itai disease) were reported in the region.[30] In 1953, the firs mercury-related deaths were reported around Minamata Bay, also i Japan. Fish and foodstuffs in the villages surrounding the bay were con taminated with methyl mercury, which originated in the effluent of a upstream plastics manufacturing company.[31] Similar episodes were re corded in other parts of Japan, Sweden, and Canada, ultimately leadin to several bans on fishing in mercury-contaminated waters.

These incidents are examples of the indirect poisoning of human beings that resulted from contaminated water affecting foodstuffs. The acute poisoning of human beings by metal-contaminated drinking water is rare because of the large doses required. The primary health concern posed by metals is either indirect poisoning, particularly through the formation of organic metal complexes in foodstuffs, or long-term chronic effects. In addition, however, certain metals are highly toxic to aquatic life at relatively low concentrations.

From a human health perspective, the metals of greatest concern are lead, mercury, arsenic, and cadmium. Lead is one of the most toxic metals found in aquatic systems; it is particularly toxic to young children, and its hazards include kidney damage, metabolic interference, central and peripheral nervous system toxicity, and depressed biosynthesis of protein, nerve, and red-blood cell formation.[32] Mercury is also highly toxic and unique among the metals because it is consistently biomagnified within the aquatic food chain. In its inorganic form, mercury may cause kidney damage and ulceration. In surface waters, however, mercury is frequently converted to its more toxic organic form, methyl mercury. Ingestion of methyl mercury affects the central nervous system and can cause death even at relatively low doses. Arsenic exhibits several chronic effects when it is ingested; the most characteristic are hyperkeratosis of the palms and soles of feet and hyperpigmentation. Arsenic also affects the gastrointestinal tract and liver, and may induce skin tumors and skin cancer. The major health effect associated with long-term ingestion of cadmium is renal disease. Other metals which pose chronic health threats include aluminum, which may be a confounding factor in Alzheimer's disease; chromium, which is associated with dermatitis, pulmonary congestion, and nephritis; and organotin complexes, which are neurotoxic.[33]

Many metals that are not particularly toxic to human beings are, nonetheless, highly toxic to aquatic life. Among these are copper, silver, selenium, zinc, and chromium. The toxicity of metals to aquatic plants and animals is controlled by their oxidation state and their ability to form particular complexes in the environment, which are largely determined by prevailing water chemistry (e.g., pH, salinity, pE, and temperature). For instance, the toxicity of copper is moderated by the formation of water-soluble ligands that bind the metal and reduce its bioavailability; the formation of these complexes is favored by circumneutral pH.[34]

Sources of metal pollution include geologic weathering, the industrial processing of ores and minerals, the use of metals and metal components, the leaching of metals from garbage and solid waste dumps, and animal and human excretions that contain metals. Domestic effluents constitute the largest single source of elevated metal concentrations in rivers and lakes.[35] More recently, atmospheric deposition has been recognized as a source of metal pollution in rural and alpine waters. A study of lake sediments in Denmark, for example, found that atmospheric deposition since 1945 had increased the heavy metal content of sediments in oligotrophic Lake Hampen to levels 180 times greater than background.[36] Nriagu and Pacyna have estimated the global anthropogenic inputs of trace metals into aquatic ecosystems (including oceans), concluding that the most important sources (in descending order) were domestic wastewater effluents (As, Cr, Cu, Mn, and Ni), coal-burning power plants (As, Hg, and Se), non-ferrous metal smelters (Cd, Ni, Pb, and Se), iron and steel plants (Cr, Mo, Sb, and Zn), and the dumping of sewage sludge (As, Mn, and Pb). On a weight basis, anthropogenic inputs are greatest for manganese, zinc, chromium, and lead.[37]

An inventory of Lake Erie conducted in the late 1970s found that among the various sources of metal inputs into the lake, atmospheric inputs accounted for 20% of the copper influx, 35% of the zinc influx, and 50% of the lead influx. Sewage effluents were responsible for 45%, 30%, and 20% of the inputs of copper, zinc, and lead, respectively.[38] A similar inventory of the Ruhr River, which flows through a highly industrialized region of Germany, found that 55% of the heavy metal loading came from wastewater treatment plants (industrial and sewage) and 45% from geochemical loading. Overall, 90% of the chromium entering the Ruhr was discharged by industries, predominantly from metal refining processes such as galvanizing. Industry was primarily responsible for nickel and cadmium pollution as well, but accounted for only 50% of the copper and zinc inputs.[39]

In urban areas, stormwater runoff is a major source of metal pollution in surface waters. The U.S. Environmental Protection Agency's (EPA) Nationwide Urban Runoff study concluded that heavy metals, especially copper, lead, and zinc, were by far the most prevalent pollutants found in urban runoff. End-of-pipe concentrations exceeded both EPA ambient water quality criteria and drinking water standards in many instances. All 13 metals on the EPA's priority pollutant list were detected in urban runoff samples, with a frequency that generally exceeded 10%.[40]

Mining is another important source of metal inputs into surface and ground waters, particularly in Latin America and parts of south-east Asia, where mining activities are both widespread and poorly controlled. Since the late 1970s, many rivers and waterways in the Amazon have been exploited for gold, resulting in extensive mercury pollution of a relatively pristine system. Mercury is used in the mining process as amalgamate to separate the fine gold particles from other mineral constituents in sediments and gravel. Official figures imply that for every kilogram of gold extracted, at least 1.32 kg of mercury is lost to the environment. The Brazilian state of Rondônia has estimated that from 1979 to 1985 approximately 100 tonnes of mercury were discharged into the Madeira River basin, of which about 45% will reach the river. Very high concentrations of methyl mercury have been found in fish in downstream reaches (up to 2.7 μg/g wet weight), exceeding the WHO's criterion for human consumption (0.5 μg/g).[41]

The rate at which metals are mobilized from surrounding soils has been increasing in many regions as a result of acid precipitation. Acid conditions are strongly associated with the mobilization of aluminum, a metal which is generally insoluble in neutral and alkaline water. Until recently, aluminum was regarded as being non-toxic; consequently, there are relatively few data on aluminum exposure and toxicity. Levels of aluminum in drinking water vary. For neutral water, concentrations are generally in the range 0.01–0.1 mg/l. In the southernmost parts of Norway the mean aluminum concentration in waterworks is about 0.4 mg/l, but levels as high as 1.3 mg/l have been found in some well water. Globally, the WHO estimates that aluminum intake via drinking water amounts to only about 3% of total dietary intake, but in regions with highly acidic water this may rise to 30% or 40%.[42]

A strong relationship also exists between lake water pH and mercury levels in fish. Mercury appears to be mobilized at a greater rate by low pH, and both its availability for methylation and its solubility also increase. A correlation between the pH of lake water and mercury body burdens in fish has been observed in North America and Scandinavia in regions where no local anthropogenic sources of mercury exist. In Sweden, more than 9,400 lakes contain fish with methyl mercury concentrations higher than 1 μg/g.[43] The mobility of cadmium and lead in soils is also highly dependent upon the pH of soil moisture.

A nationwide investigation of well water in Finland revealed that out of 100 wells surveyed, the average pH had dropped from 6.7 in 1958 to 6.3 in 1989. More than half of these wells had pH levels below the minimum recommended by the Finnish health authorities for drinking water (6.0). The most extreme declines in pH were observed in areas subject to the highest sulfur fallout. Similarly, distinct geographical variations in drinking water quality have been found in Norway and Sweden, with metal concentrations showing a north–south spatial gradient.[44] Of particular concern is the increased aggressiveness of acid water on pipes, cisterns, and tanks, which may leach lead and other metals into drinking water supplies, posing a direct risk to consumers.

An assessment of the global and regional extent of metals contamination is hampered by both a lack of data and inadequate sampling and analytical techniques. For example, the WHO's GEMS project monitored for dissolved metals in only 35% of the network rivers, and the significance of these limited measurements is still questionable, due to poor quality control procedures.[45] In general, however, metal concentrations in fresh waters vary greatly due to the localization of sources and the tendency of metals to concentrate in sediments and slowly partition into overlying waters as environmental conditions change.

A temporal and spatial analysis of metal concentrations conducted for the Rhine River shows that cadmium concentrations in sediments rose from less than 2 mg/kg before 1920 to about 40 mg/kg in the early 1970s. Following the 1970s, concentrations decline slightly, which may reflect increased controls on cadmium discharges but more likely reflects improved analytical techniques. Overall, dissolved cadmium concentrations increase dramatically from the source (12 ng/l) to the mouth of the river (400 ng/l), suggesting the predominance of anthropogenic sources.[46]

Table 3.2 shows concentrations of cadmium for various rivers, with values for dissolved cadmium ranging from 2 to 400 ng/l. Those rivers with the highest concentrations are not surprisingly those from the most industrialized areas, including the Hudson and the Rhine. Unquestionably, metal concentrations in fresh water have been rising rapidly over the

TABLE 3.2 Concentration of cadmium in rivers

River	Suspended particulate matter (mg/l)	Particulate cadmium (ng/l)	Particulate cadmium (mg/kg)	Dissolved cadmium (ng/l)
Elbe[a]	75	150	2	100–200
		85		35
Weser	50	100	2	100
				70
Varde Å	40	80	2	70
Rhine	30	1800	60	400
Amazon				8
Mississippi			0.6	15
St. Lawrence	10	17	1.7	110
Hudson	10–20	70–80	4–8	200–300
Orinoco				2
Yangzijiang				2
Gota	25–100	14–64	0.3–0.6	9–25

Source: P.A. Yeats and J.M. Bewers, 1987, Evidence for anthropogenic modification of global transport of cadmium, in J.O. Nriagu and J.B. Sprague (eds.) *Cadmium in the Aquatic Environment*, John Wiley, New York, p. 22. (Copyright © 1987, Reprinted by permission of John Wiley and Sons, Inc.)

[a] Different values from the same river were measured by different investigators.

TABLE 3.3 Examples of organic pollutants, by class and typical use

Class and pollutant	Typical use
Halogenated aliphatic (chain) hydrocarbons	
Dibromochloromethane (THM)	Trihalomethanes (THMs) are formed during the disinfection of drinking water
Trichloromethane (THM)	
Dichloromethane	Solvent used to decaffeinate coffee
Carbon tetrachloride	Used in the manufacture of fluorocarbon propellents, general purpose cleaner and solvent
Tetrachloroethylene (PCE)	Most widely used drycleaning chemical in the US; found in spot removers, rug cleaners, paint strippers, etc.
1,1,1–Trichloroethane (TCA)	Very common solvent; used to clean electrical equipment; found in drain cleaners, shoe polish, spot removers, etc.
Trichloroethylene (TCE)	Solvent; formerly used to decaffeinate coffee; metal degreaser; found in dyes, ink spot removers, etc.
Aromatic (ring) hydrocarbons	
Benzene	Derived from petrolem and coal; common feedstock; found in paints, oils, adhesives, aspirin, asphalt, etc.
Toluene	Petroleum by-product and gasoline additive
Naphthalene	Found in moth balls, carpet cleaners, typewriter correction fluid, adhesives, asphalt, etc.
Anthracene (PAH)	Polyaromatic hydrocarbons (PAHs) are formed from incomplete fossil fuel combustion; benzo(*a*)pyrene is present at relatively high concentrations in cigarette smoke
Benzo(*a*)pyrene (PAH)	
Chloro– and nitro–aromatic hydrocarbons	
Hexachlorobenzene	Fungicide
Trinitrotoluene (TNT)	Explosive
Phthalates	
Dimethyl–phthalate	Phthalates are added to plastics to make them flexible; found in rainwear, footwear, shower curtains, children's toys
Bis(2–ethylhexyl)–phthalate	
Halogenated ethers	
Bis(2–chloroisopropyl)ether	
2–Chloroethylvinylether	Halogenated ethers are used in the production of plastics and resins and in research laboratories
Phenols	
Pentachlorophenal	Fungicide; wood preservative
2–Chlorophenol	Chloro–, dichloro–, and trichloro–phenols are by-products in the production of pentachlorophenol
2,4–Dichlorophenol	
Organochlorines	
DDT	DDT, lindane, aldrin and chlordane are examples of the extremely persistent organochlorine pesticides widely used in the 1950s and 1960s
Lindane	
Aldrin/dieldrin	Dieldrin is a degradation product of the pesticide aldrin
Chlordane	
Alpha–hexachlorocyclohexane (HCH)	Common pesticide
2,4–D	Common herbicide
Polychlorinated biphenyls (PCBs)	Used to insulate electrical equipment, hydraulic fluids and lubricants
2,3,7,8–Tetrachlorodibenzon–*p*–dioxin	By-product in the production of certain herbicides; common contaminant of the defoliant Agent Orange

last few decades. Although human health concerns are limited to a few key metals, the prevalence of metal pollution poses widespread risks to aquatic life and ecosystems.

Synthetic and industrial organic pollutants. Over the last three decades, the large-scale manufacture and release of organic chemicals have resulted in widespread environmental contamination. The most well-known examples remain the extremely persistent organochlorine compounds, including the pesticide DDT and its derivatives and the polychlorinated biphenyls (PCBs). DDT has been detected almost everywhere in the world, including in water from melted Antarctic snow.[47] Yet many other classes of organic contaminants now affect ground and surface waters. There are approximately 100,000 synthetic compounds currently in use, and more are introduced every year, often without a full understanding of the risk they pose to the environment and to human health.[48] It is impossible to generalize about the potential toxicity of organic micropollutants because there are so many, all with different derivatives, different solubilities, and different persistence. Yet an important aspect of organic chemicals is that many are thought to be hazardous to aquatic life and human health at concentrations much lower than those that can be reliably measured by common analytical methods. The uncertainty generated by the presence of organic chemicals and their potential health effects is perhaps their most distinctive characteristic. The more important classes of organic micropollutants from a drinking water perspective are given in Table 3.3.

Most organic pollutants originate in industrial activities such as petroleum refining, coal mining, the manufacture of synthetic chemicals and products, iron and steel production, textile production, and wood pulp processing. In addition, the domestic use of petroleum and heating oils, atomizers, pesticides, and fertilizers further diffuses synthetic pollutants into the environment. A study conducted in Los Angeles identified 101 organic substances in urban wastes, 36 of which were on the U.S. EPA list of priority pollutants.[49] Non-point sources also make a significant contribution to organic chemical pollution. For example, the EPA urban runoff study identified 63 organic pollutants in runoff from 19 cities. The most frequently identified were a phthalate plasticizer, the pesticide hexachlorocyclohexane, and several polycyclic aromatic hydrocarbons (PAHs).[50] Agriculture, however, is the principal non-point source of organic micropollutants in drinking water, and the pollution of water with agricultural pesticides and herbicides has become a global concern.[51]

The term "pesticide" is a general one, and in the past 50 years several different classes of synthetic organic pesticides have been developed and used extensively throughout the world. Among these are the "early" chlorinated hydrocarbon insecticides, such as DDT, lindane, aldrin, dieldrin, etc. – most of which have been either banned or severely restricted in the industrialized world. Other classes include the organophosphorus and carbamate pesticides, chlorophenoxy acids, triazines, and bipyridilium herbicides, and the more recent pyrethroid insecticides. Although plants and soil are the recipients of most pesticides applied, water provides the principal transport pathway through both the erosion of contaminated soil and the dissolution of water-soluble compounds.

The environmental behavior of different pesticides is controlled by two principal characteristics: solubility in water and persistence in the environment. Chemicals with low solubility and high persistence, such as many of the older organochlorine insecticides, are generally found in association with particulate bed materials or suspended sediment and may not degrade for several years. These chemicals also have a high lipid solubility and tend to accumulate in aquatic organisms and their predators. Over time, they can reach harmful concentrations in organisms even though concentrations in water and sediment may remain low. Conversely, most newer generation pesticides are much less persistent and have a much lower tendency to bioaccumulate. They may last only days or weeks in the environment before breaking down. Even though these chemicals frequently degrade to a benign form and do not accumulate in organisms, most are more acutely toxic than the organochlorine insecticides. For many of these newer compounds, volatilization is the primary pathway for human exposure, and relatively high concentrations have been detected in rain and dew.[52] The highest concentrations, however, are found in surface water runoff from the edges of fields. A study of the lower Mississippi River found that several triazine and chloroacetanilide herbicides and their degradation products were present in the river system. Daily loadings were found to be as high as thousands of kilograms.[53]

In the U.S., concentrations of organochlorine insecticides, including dieldrin, chlordane, and DDT, appear to have decreased erratically but significantly in both water and sediment since the mid-1970s, when their use was greatly curtailed.[54] The use of herbicides, however, has rapidly increased during the past 20 years, with atrazine and 2,4-D accounting for much of the rise. Other prevalent herbicides include alachlor, butylate, and metachlor, which account for over one-half of all herbicides used in the U.S.[55] These herbicides are both less adsorbent and more soluble in water and therefore have a greater potential to move out of the root zone and to contaminate ground water than their precursors.

In addition to pesticides and herbicides, there are several other important classes of organic micropollutants:

- PCBs, which were used extensively in the electrical industry as dielectrics in large transformers and capacitors. The term PCB is general, and is applicable to a wide range of related compounds. Those with a higher degree of chlorination pose the greatest environmental and health concerns.
- PAHs, which result from the incomplete combustion of organic materials, primarily fossil fuels. These are hydrophobic compounds that are associated with sediments and are relatively immobile in aquatic environments; however, they may be transported long distances in the atmosphere.[56] The toxicity varies among individual compounds, but some, such as benzo(a)pyrene, are known human carcinogens.
- Organic solvents, which are highly volatile, chain carbon compounds frequently found in ground water as the result of both industrial processes (e.g., plating and electronics manufacturing) and leaching from landfills. Many solvents, such as trichloroethane, are common household products (cleaners, paint thinners, etc.). Particular solvents have been associated with cancer, birth defects, and cardiovascular disease, although in most cases the epidemiological data are inadequate to establish causality.
- Phthalates, a large group of chemicals used as plasticizers, especially in the production of polyvinyl chloride resins. Two compounds are of particular concern for human health: butylbenzyl phthalate (BBP) and di(ethylhexyl)phthalate (DEHP).
- Disinfection by-products (DBPs), chemicals that are formed upon the addition of chlorine or a similar disinfectant (ozone, chloramines, chlorine dioxide) to water. For instance, chlorine reacts with naturally occurring humic substances to produce trihalomethanes (THMs), including the carcinogen chloroform. Most of the DBPs of concern are organic, including THMs, haloacetic acids, and chlorinated hydroxyfuranones. Several DBPs are known or suspected human carcinogens.

Since the mid-1970s, public concern has grown steadily over the link between cancer and organic chemicals in drinking water. While several organic chemicals are either known or suspected human carcinogens, many more have not been adequately studied. Moreover, while the risks posed by individual chemicals in drinking water are relatively low, the cumulative effects of long-term exposure to a variety of chemicals may be much larger but cannot be well quantified. However, the rising incidence of cancer in the industrialized world and the identification of both "cancer clusters" and high rates of miscarriages, birth defects, and sterility in areas with contaminated drinking water and high levels of chemical exposure have continued to raise questions about the safety of organic chemicals and the adequacy of their regulation.[57]

Several epidemiological studies have suggested a link between cancer or birth defects and the presence of organic chemicals in drinking water. For instance, a study conducted in 1983 in Santa Clara County, California confirmed a statistically significant increase in adverse pregnancy outcomes in a community exposed to solvent-contaminated ground water, but could not establish a causal connection.[58] Similarly, a correlation has been found between chlorinated drinking water and colon and bladder cancer. While no direct evidence points to DBPs as the cause, recent estimates of the attributable risk (i.e., the proportion of all cancer cases in both exposed and unexposed individuals that is presumed to be caused by the exposure of interest) for colon and bladder cancers are approximately

38% and 21%, respectively.[59] To date, the link between cancer and chlorination remains weak, and it is widely acknowledged that the benefits of chlorination far outweigh the risks. Nonetheless, considerable effort in the industrialized countries is being put towards identifying alternative means of disinfection and methods that reduce chlorine contact time and overall DBP concentrations.

Most studies that have attempted to define the extent of organic chemicals in water have been local in scale, and thus it is not possible to assess the status of fresh waters globally. The expense of laboratory analyses, the variable frequency of detection, regional patterns of use, and the constantly changing array of available pesticides and synthetic compounds make national or regional scale monitoring a very difficult undertaking. The GEMS project, for example, monitored only a few organochlorine pesticides and PCBs at only 25% of the stations. Noticeable was the absence of any measurements in Africa, in the Middle East, and in South America (except for one station in Colombia since 1982).[60] While concentrations of the chlorinated organics appear to be decreasing in many regions of the world, most of the other identified contaminants have not even been tested for. Certainly the increasing usage of organic chemicals in a variety of activities and industries suggests that their prevalence in fresh water is increasing as well. To date, the human health impacts of organic chemicals in water have been relatively minor or extremely uncertain. Nonetheless, the relatively high toxicity of these chemicals, the existence of so many synthetic compounds, and the chronic and cumulative nature of the threat all suggest that in the future the presence of organic chemicals in fresh water will emerge as a major public health concern unless the global trend toward increasing chemical production is curbed.

Radionuclides. Compared to the background exposure of human beings to radiation from natural causes, the radiation risks associated with drinking water are often negligible. Yet, in some areas, radioactive contamination of drinking water from either accidents, such as the Chernobyl disaster, unsafe disposal practices, or high levels of naturally occurring radioactivity, may cause significant health concerns at a local or regional scale. Natural sources of radioactivity and the disposal of nuclear waste may affect ground water and springs, while surface waters are subject to contamination from atmospheric testing, power plant accidents, the mining of radioactive materials, manufacturing and transportation accidents, and the disposal of radioactive wastes. The health effects of radiation are well established: developmental abnormalities, cancer, and death. The most abundant radionuclides in water are given in Table 3.4.

From a drinking water standpoint, naturally occurring radionuclides pose the greatest threat, although anthropogenically produced particles may also be a health concern in specific localities. The level of radioactivity in natural waters generally falls between 1 and 1,000 pCi/l; however, in some naturally radioactive springs, concentrations as high as 100,000 pCi/l have been detected.[61] The WHO guidelines for radioactivity in drinking water, established in 1984, are 0.1 Bq/l (0.003 pCi/l) for alpha radiation and 1 Bq/l (0.03 pCi/l) for beta radiation.[62]

The individual radionuclides of greatest concern are various isotopes of naturally occurring uranium, radon, radium, thorium, lead, and poli nium. Of these, radon, an alpha emitter, is the most prevalent and pose the greatest health risk. A water soluble gas, radon is produced by th decay of radium isotopes. The predominant form is ^{222}Rn. The primar source of radon is soil, from which it emanates directly, while lesse sources include ground water, oceans, phosphate residues, uranium tai ings, coal residues, natural gas combustion, coal combustion, and huma exhalation. Ground water is the most significant of the secondar sources.[63]

The U.S. EPA estimates that indoor radon causes between 8,000 an 40,000 lung cancer deaths each year. In homes supplied by ground wate approximately 5% of these deaths are the result of radon released fron water during showering, bathing, flushing toilets, cooking, and washin clothes and dishes.[64] Radon present in water accounts for about 10 time more morbidity than ^{226}Ra or ^{228}Ra, and 20 times more than natural ura nium.[65] In fact, the calculated incidence of fatal cancers in the U.S. pop ulation from radon in water alone may be larger than the sum of all othe carcinogens known to be present in existing water supplies, making rado in drinking water a significant health threat in some localities.[66]

Radon concentrations in drinking water range from less than 10 pCi/ in typical surface waters to a reported high of 2,000,000 pCi/l in groun water from a private well. A study undertaken by the American Wate Works Association estimated a population-weighted average concentration of 106 pCi/l in U.S. drinking water, and a corresponding lifetime risk of death from cancer of 10^{-4}. The average population-weighted concentration among ground water systems was considerably higher at 273 pCi/l.[67]

In local and regional areas, poor waste disposal practices have led to contamination of surface and ground waters with anthropogenic radionuclides. For example, tritium has been detected in ground water in Burke County, Georgia and Barnwell, South Carolina, and has been attributed to a nearby weapons manufacturing plant. And in December of 1991, a spill of tritium from the same plant entered the Savannah River and forced the temporary shut down of food processing plants that draw water from the river.[68]

Current and emerging trends affecting water quality

Population growth, urbanization, and poverty. In the coming decades, the greatest challenges to water quality will come from continued population growth and the trend towards urbanization in the developing countries. In 1975, 38.5% of the world population lived in urban areas; in 1990 this rose to 42.7%, and it is expected to reach 46.7% by the year 2000 and 60.5% by 2025.[69] While the overall level of urbanization in the developing countries is not yet as high as in the industrialized nations, the trend toward urbanization in the former is even more pronounced. For instance, in Latin America and the Caribbean, which is the most urbanized region in the developing world, there are 215 cities that have populations of more than 100,000. Overall, the region's urban population comprises 69% of the total, and one-third of the urban population is located in 15 "mega-cities" with over 2 million inhabitants.[70]

Among the consequences of this urban influx are the overloading of water and sanitation infrastructure and a rapid deterioration in urban living conditions. In many overcrowded cities often only one-fourth to one-third of the population is served by garbage collection.[71] According to WHO, only 41% of the urban population in Latin America and the Caribbean has access to sewer systems, and over 90% of the wastewater that is collected is discharged directly into receiving waters without any treatment. Another 38% of urban residents is served only by on-site sanitation systems; thus, 59 million urban dwellers do not have access to adequate sanitation. Moreover, higher population densities make many low-cost sanitation options, such as pit latrines and cesspools, less effective in the prevention of disease. If projections of urban growth in the region prove accurate, an additional 141 million people in Latin America will need sanitation services by the year 2000.[72] Similar gaps in service are projected in Asia and Africa.

Improvements in health will be confounded by the pervasive link between urban poverty and water quality. The number of urban poor will have doubled in the period between 1975 and 2000, from 35% to 77% of

TABLE 3.4 Radionuclides most abundant in drinking water

Low LET[a]	High LET
Potassium–40	Radium–226
Tritium	Daughters of Radium–228
Carbon–14	Polonium–210
Rubidium–87	Uranium
	Thorium
	Radon–220
	Radon–222

Source: J. De Zuane, 1990, *Handbook of Drinking Water Quality: Standards and Controls*, Van Nostrand Reinhold, New York, p. 340.

[a] Linear energy transfer = Average amount of energy lost by an ionizing particle per unit length of track in matter.

families, with even higher percentages for South Asia and Africa. Several studies have established the greater prevalence of diarrhea and helminthic infections in environments that have poorer housing, water, and sanitation facilities. For example, in São Paulo, the incidence of diarrhea in the lowest socioeconomic stratum was 13.1 episodes per 100 children-months compared with 9.6 episodes in the next stratum and 3.6 episodes in the upper stratum. With respect to helminths, studies in Durban, Singapore, Guatemala and Seoul have all found a higher prevalence of *Ascaris* and *Trichuris* in poorer parts of the city as compared to more wealthy parts.[73] Similarly, the rapid spread of Chagas disease in Latin America is attributed to the proliferation of urban slums where poor housing, overcrowding, and inadequate health services contribute to transmission.

The United Nations and WHO designated the 1980s as the "International Drinking Water Supply and Sanitation Decade" (the Water Decade) in an attempt to draw both attention and resources to the problem of drinking water supply in the developing world. During this decade, significant improvements were made, especially in rural water supply, where the number of persons served increased by 240% globally, while the number of persons with access to rural sanitation increased by 150%. The number of urban dwellers with access to water supply rose by 150% as well, as did the number with access to sanitation; however, this still translated into an increase in the number of urban dwellers without access to services. Put into absolute numbers, the additional people with water supply at the end of the decade totaled 1.3 billion, while those with sanitation increased by 750 million. Yet on the other side of the equation, this left 1.2 billion people without a safe water supply and 1.7 billion without adequate sanitation. In Latin America and Asia, the percentage of the urban population with access to sanitation remained essentially unchanged, which reflects the rapid growth of cities. Globally the percentage of urban persons with sanitation services increased only marginally, from 69% to 72%.[74]

The failure of the decade to meet its ambitious goal reflects the continuing problem posed by rapid population growth and urbanization in the developing world. Substantial investments in sanitation and water supply are now required merely to keep pace. While population continues to grow rapidly in many developing countries, little progress has been made in alleviating poverty or improving living conditions. Environmental conditions are deteriorating rapidly, particularly in overcrowded urban areas. More and more people are born into poverty and will eventually suffer from and spread waterborne disease. Yet in addition to the problems faced by the Third World, the declining economic situations of eastern Europe and the former Soviet Union are likely to lead to more serious water quality problems. During 1991, the incidence of certain infectious diseases in the Russian Republic increased, reversing previous trends. National incidence rates for bacterial dysentery and other enterically transmitted diseases increased substantially. In the Tom River basin in Siberia, inadequate maintenance of water-purification systems and organic contamination of drinking water supplies were associated with increased incidence rates of gastritis, hepatitis A, and bacterial dysentery. Prevalence rates for these diseases were 82%, 47%, and 22% higher, respectively, than the national incidence rates.[75]

In general, water quality deteriorates along with economic conditions. And to date, the wealthier countries of the world have failed to address the economic situation of poorer regions with the urgency required. Clearly, if current trends continue, the problems posed by deteriorating water quality could prove overwhelming.

Industrial expansion. Along with population growth, rapid industrialization puts pressure on water resources and creates two principal threats to water quality: the increase in industrial effluents, particularly in countries that lack adequate environmental controls, and the increased risk of chemical spills and accidents.

The major urban centers in the developing world have increasingly become centers of industrial concentration, and severe industrial pollution problems have arisen in most large cities. While this situation is similar to that faced by the countries of Europe and North America 50 years ago, the critical difference is the much greater pressure on water and other natural resources in many parts of the less developed world. It is estimated that industrial effluents constitute 90% of non-agricultural water pollution in Mexico. The paper and steel industries, which rank among the most important industrial sources of water pollution in Latin America, have been growing twice as fast as the economy of these countries as a whole. Companies are finding it increasingly profitable to move manufacturing processes into regions with lower labor costs and less stringent environmental regulations. This is particularly true for very hazardous industries, such as those that manufacture asbestos products, certain dyes, and pesticides, as well as mineral processing. Table 3.5 shows the overall increase in the manufacture of certain classes of chemicals in India. And Latin America, which had only 5.3% of the world total in value-added industry, had proportionately higher shares in pollution-intensive industries such as petroleum refining (17.7%) and chemical production (14.7%).[76] In developing countries, advanced pollution control technologies are rarely adopted in newer, chemical-intensive industries such as high technology. But even in traditional industries such as auto manufacturing and food processing, there is now a greater reliance on chemicals.[77]

TABLE 3.5 The production of selected classes of chemicals in India, 1950 to 1980 (10^3 tonnes)

Class	1950	1960	1970	1980
Pesticides	–	1.46	3.00	40.68
Dyes/pigments	–	1.15	13.55	30.85
Pharmaceuticals	0.25	1.23	1.79	5.07
Organic chemicals	200	580	17,100	24,100
Fertilizers	18	153	1,059	3,005
Caustic soda	11	101	304	457

Source: B.B. Sundarensan *et al.*, 1983, An overview of toxic and hazardous waste in India, *Industrial Hazardous Waste Management: Industry and Environment*, special issue no. 4, United Nations Environmental Programme, Paris, p. 70, Environmental Pollution Control in Relation to Development, cited in: World Health Organization, 1985, Technical Report Series no. 718, WHO, Geneva.

Food processing is an example of an industry widespread in the developing world in which large amounts of wastes are discharged into surface water with little regulation and no treatment. In Latin America, more than 17.5 million tonnes are processed annually and an estimated 10 million tonnes of waste are discarded, with little or no treatment.[78] Similarly, in Kenya coffee is the leading cash crop; over 120,000 tonnes are processed annually. There are over 1,200 coffee processing factories in the country, and all are located near watercourses, which become severely polluted during the coffee season. A survey of several rivers and streams between Nairobi and Thika during the processing season found gross pollution. Every river and stream surveyed was anaerobic, with all measurements of 5-day biological oxygen demand (BOD-5) exceeding 10 mg/l and some rising as high as 100 mg/l.[79] For the most part coffee wastes are treatable; however, economic constraints have slowed the adoption of environmental control technologies.

The expansion of industrial activities throughout the world also brings with it an increased risk of large-scale industrial accidents, such as the 1986 chemical fire which polluted the Rhine River with pesticides, solvents, dyes, and other hazardous chemicals. The fire burned a storehouse that contained at least 90 different chemicals, including a few highly toxic mercury-based pesticides. An estimated 1%–3% of the 1,300 tonnes of stored materials reached the river. Following the accident, biota in the river were heavily damaged for several hundred kilometers downstream. Benthic organisms were among the most severely affected, along with eels, which were eradicated over a distance of 400 km. Downstream, ground water was also contaminated, with many wells in the Alsace region showing the presence of organophosphate compounds and mercury.[80] Although the Rhine is a source of drinking water for approximately 12 million people, no direct health threats occurred because the water is extensively treated and well-monitored before use. Yet had the accident occurred in a region any less prepared, widespread human health impacts would have accompanied the destruction of the ecosystem. During November 1990, a tank-filling accident at a plastics plant in Novopolotsk, Byelorussia spilled several thousands gallons of acetocyanohydrin, a toxic chemical. Mishandling of what should have been a minor incident allowed toxic amounts of cyanide to flow into tributaries of the Daugava River, Latvia's chief waterway. The Daugava supplies drinking water to about 1 million people in the cities of Daugave and Riga.[81]

While these are only isolated examples of the threat posed by industrial accidents, they are indicative of both the magnitude and the variability of accidental pollution. In many regions, the technology for adequate monitoring of industrial pollution is not available, much less the regulatory infrastructure for responding to massive spills. Poorer countries are also unable to mitigate the effects of environmental catastrophes. As polluting industries shift into those regions that are less prepared to deal, both technically and financially, with environmental concerns, the result will be the increasing pollution of soil, air, and water.

Agricultural pollution. Traditional water quality problems associated with agriculture will continue, including sedimentation and eutrophication, but from the perspective of human health, the major concern in the future will be the increase in nitrate and pesticide contamination of ground and surface water as greater quantities of chemicals are introduced into agriculture. As discussed above, nitrate concentrations in water have been rising rapidly since the 1940s, corresponding with the increased use of fertilizers and the expansion of agriculture. The prospect of a similar rise in pesticide concentrations is particularly disturbing.

In the U.S., the realization that agricultural pesticides threatened ground water resources came in 1979 with the discovery of aldicarb in 96 wells on Long Island and 1,2-dibromon-3-chlorpropane (DBCP) in more than 2,000 wells in California.[82] To date, nearly 100 different pesticides have been detected in ground water. According to an assessment made by the U.S. EPA, 74 different pesticides were detected in ground water in 38 states. Of these, 32 pesticides in 12 states were thought to be related to point sources and 46 pesticides detected in 26 states were attributed to agricultural non-point sources.[83]

Globally, there are two disturbing trends in pesticide usage: the continued use of extremely hazardous and highly persistent organochlorine compounds in the developing countries, and the propagation of a new generation of herbicides in the industrialized countries for which current water quality monitoring is inadequate. The less developed countries have continued to use the organochlorine chemicals in agriculture and for the control of disease-carrying insect vectors. For example, India still uses DDT in cotton production and in malaria control. In Latin America, governments restrict only 20%–25% of the agricultural chemicals that appear on the United Nations list of chemicals that have been banned or restricted by other national governments (Table 3.6). Brazil used both the extremely toxic hexachlorocyclohexane (HCH) and DDT extensively from 1970 to 1980; currently Brazil bans these chemicals in agriculture but continues to allow their use in public health applications. In addition, overall fertilizer and pesticide application rates are rising throughout the world. While application rates are highest in the industrialized countries, the rate of increase is most rapid in the developing countries. The total volume of consumption is not known; however, estimates of global pesticide usage in 1985 yield a figure of approximately 3 million tonnes. The fastest growing market is Africa, which had an increase in pesticide sales (182% between 1980 and 1984. Latin America is also experiencing rap growth in usage, with pesticide imports increasing by almost half betwe 1973 and 1985.[84] Total pesticide usage also continues to rise in the indu trialized countries, despite the restriction of several of the most tox compounds. In the U.S., pesticide use grew by roughly 170% betwe 1964 and 1985.[85]

The severity and extent of ground water contamination cannot be ad quately assessed for several reasons. First, even in the industrializ world, most of the data that exist are for shallower drinking water well and little information is available for deeper wells. Second, contamina concentrations vary over time, making it difficult to assess ground wat quality without undertaking long-term, and costly, monitoring program Third, once the temporal and spatial variability of water quality are ad quately described, it is difficult to relate contamination to selected ag cultural practices, in part because ground water velocities are relative low. Agricultural practices undertaken today may not be reflected in t hydrologic regime for several months or possibly years.[86]

Finally, almost all the data that exist come from the more develop countries. The rapid introduction of pesticides into less developed cou tries has not been accompanied by monitoring. Today's practices may affecting vital water resources over large areas without our knowled This is unlikely to change in the near term because ground water mo toring is an expensive undertaking that may not seem economically ju tifiable in many poorer regions of the world. At this time, we may be on beginning to detect contamination resulting from agricultural practices 30–40 years ago; the impact of the last 15 years of chemically depende agriculture remains to be seen.

Water supply development. Ironically, the rapid increase in t number of large reservoir projects in recent years has contributed to d clines in water quality. The most common water quality problem asso ated with reservoirs is accelerated eutrophication, which is attributable the accumulation of nutrients, particularly nitrogen and phosphorus (s Chapter 4). While not usually harmful to human health in themselves, t presence of these nutrients in large quantities can lead to excessive pl growth and impaired water quality. Eutrophication poses a severe thr to fisheries and aquatic life. In addition, from a drinking water and hum health perspective, eutrophication creates taste and odor problems, pi corrosion, water treatment difficulties, and health hazards to bathers. A in some cases, toxin-producing algae such as cyanobacteria may ca diarrheal disease when ingested.

Reservoirs may also exacerbate both water-vector and water-habi diseases, such as malaria and schistosomiasis. And more recently, co cern has developed over the relationship between surface impoundme and methyl mercury concentrations. Numerous studies have demo strated that mercury methylation is enhanced by the increased availabil of organic carbon, and the increased decomposition of organic matte a major cause of increased methylation in newly flooded reservoirs. study in Manitoba, Canada found that mercury levels in northern pike a walleye in natural lakes increased rapidly from levels of 0.2–0.3 μg/g 0.5–1.0 μg/g following impoundment.[87] In 1984, a study of the Chiasa

TABLE 3.6 Pesticides used in or sold to Latin American countries during the 1980s whose use has been banned or restricted elsewhere

Product	Country[a]
Aldrin	Argentina, Ecuador, El Salvador, Guatemala, Guyana, Mexico, Suriname, Uruguay
Arsenicals	Uruguay
BHC	Argentina, El Salvador, Mexico, Suriname
DDT	Argentina, Ecuador, El Salvador, Guatemala, Mexico, Suriname
Lindane	Agentina, Guatemala, Honduras, Mexico, Uruguay
Parathion	Argentina, Ecuador, El Salvador, Guatemala, Honduras, Mexico, Uruguay
Toxaphene	El Salvador, Mexico
2,4–D	Argentina, Ecuador, Honduras, Mexico, Suriname, Uruguay
2,4,5–T	Argentina, El Salvador, Guatemala, Mexico, Suriname

Source: Adapted from UN Economic Commission for Latin America and the Caribbean (CEPAL), 1990, The Water Resources of Latin America and the Caribb Planning, Hazards, and Pollution, Santiago, Chile, pp. 157–158.

[a] Listing of countries is not necessarily comprehensive but reflects only those countries for which data are available.

a Cree Indian village located in the vicinity of Quebec's James Bay project, found that 64% of the residents, all of whom were heavy fish consumers, had mercury concentrations that exceeded WHO standards.[88]

Finally the development and utilization of water supplies for the purposes of irrigation may bring not only the economic benefits of agriculture to a region, but also associated water quality problems, such as:

- A reduction in the assimilative capacity of regulated streams where waste disposal competes seasonally with irrigation and energy uses.
- The increased use of fertilizers and pesticides as a result of expanded agriculture and the resulting pollution of surface and ground waters. For example, in Egypt the total amount of nitrate and phosphate fertilizers introduced increased from 0.88 million tonnes in 1951 before the construction of the Aswan High Dam to 6.19 million tonnes in 1987–1988.[89]
- The salinization of arid and semi-arid lands and adjacent waters due to intensive irrigation projects (see Chapter 5).

Changes in land use. Globally, many of the trends in water quality can be attributed to large-scale changes in land use, including deforestation, the conversion of grasslands and savannahs, and the loss of wetlands. Even though individual land uses may not significantly degrade water quality or aquatic habitat, the combined effects of several activities may be devastating. Widespread logging has several direct impacts on water quality. The most obvious is increased erosion and sediment loading, which increases turbidity, decreases dissolved oxygen concentrations, and destroys many of the more sensitive aquatic organisms. In many areas, logging has been correlated with declines in fish catch and long-term changes in species composition.[90] In addition, deforestation releases large quantities of nutrients from soils, which may change patterns of primary productivity in surface waters and cause accelerated eutrophication in lakes and reservoirs. By some estimates, deforestation is now proceeding at a rate of up to 20 million hectares per year, with the most rapid rates currently in tropical evergreen forests.[91] More generally, the conversion of wildlands to agricultural uses implies the introduction of fertilizers and pesticides, which eventually make their way into ground and surface waters.

The conversion of wetlands presents a different problem: the loss of natural pollutant sinks. As water floods into wetlands from rivers and streams, the loss in velocity causes sediments and their sorbed pollutants to settle out before they can enter waterbodies. In the U.S., artificial wetlands have been proposed as a means of controlling pollution from non-point sources. Brillion Marsh in Wisconsin, a cattail marsh, has received domestic sewage since 1923. After passing through the marsh, the biological oxygen demand of wastewater decreased by 80%, coliform bacteria decreased by 86%, nitrates by 50%, chemical oxygen demand by 40%, and phosphorus by 13%.[92] The dramatic decline in wetlands globally thus suggests not only loss of habitat but decreases in water quality (see Chapter 4). In sum, surface and ground waters are intimately connected to the land that surrounds them, and global trends in land use, such as deforestation and wetland filling, will inevitably be reflected in the quality of natural waters.

Water quality management

Given the rapid spread of water pollution and the growing concern over resource availability, the links between water supply and water quality, while always present, have become more apparent. One obvious linkage is the potential impact of large-scale water resources development on water quality, described above. While some of these problems can be avoided through careful site selection and construction techniques, in other cases they are the unavoidable effects of large water projects.

Another link between water supply and quality materializes when water availability diminishes, making it increasingly inefficient to use surface waters for excessive waste disposal. When surface water is plentiful and wasteloads do not exceed the capacity of waterbodies to absorb them, discharging wastes to surface waters provides adequate treatment. Yet as population and waste volumes increase, waterbodies become more polluted, rendering them unfit for certain uses, such as drinking. Ultimately, water quality may become the primary determinant of regional water availability.

The management of water quality is comprised of two principal components: the protection of fresh water sources from contamination and the treatment of drinking water prior to use. The protection of water sources requires the regulation of waste discharges. In the early phases of water pollution control in the industrialized countries, specific treatment techniques were required.

While the implementation of these "technology-based" standards has led to substantial improvements in water quality in some areas, it has also allowed the continued degradation of more pristine waterbodies. Thus, newer standards in the U.S. and in other industrialized countries are tailored to specific waterbodies. Regulations must take into account multiple pollution sources, the sensitivity of local aquatic species, and regional hydrologic conditions. Effluent limitations and treatment technologies are then specified so as to ensure that ambient water quality standards are not exceeded. Obviously, the development of such standards is both a lengthy and a costly process, and consequently it has not spread beyond the world's wealthiest countries.

Non-point sources of pollution, including agricultural and stormwater runoff, pose a more difficult problem. Because non-point sources are more difficult to monitor, the regulation of land use, or "watershed management", has emerged as the principal tool for protecting water quality. In the U.S., the regulation of non-point sources occurs primarily on the local level, and relies heavily on the identification of "best management practices", such as erosion control measures in agricultural areas, which are intended to minimize pollutant loadings. In essence, this is a new set of technology-based standards that specifies the practices that must be adopted in a region rather than setting absolute limits on the discharge of particular pollutants. The effectiveness of this approach in controlling non-point sources of pollution varies widely from region to region and depends upon the scope of the problem, the rigor of the regulations, and the level of enforcement. Yet the difficulty of adopting contaminant-specific standards for non-point sources suggests that best management practices and land use regulation will remain the primary components of non-point pollution control. However, a policy debate has nonetheless ensued from resistance to the mandatory regulation of land use on one hand, and doubt about the efficacy of purely voluntary regulation on the other.

The treatment of drinking water, the second principal aspect of water quality management, became common in the U.S. and Europe at the end of the 19th century when filtration was introduced in order to control the transmission of typhoid and cholera, as well as other waterborne diseases. Filtration removes many microbiologic contaminants and quickly proved effective in controlling the spread of these two major diseases. Chlorination for public water supplies was first introduced in the U.S. in 1908 and was rapidly adopted in most large towns and cities.

Filtration and chlorination remain the essential components of drinking water treatment in the industrialized world. However, because these treatments do not remove chemical contaminants, including dissolved pesticides and metals, governments have begun to impose monitoring requirements and standards for many different contaminants that occur in water, particularly those organic micropollutants that are known or suspected carcinogens. The emphasis on drinking water standards is the most notable trend in water quality management in the industrialized world. Until the last decade, standards existed only for fecal coliforms and a few other contaminants known to cause taste and odor problems. But by 1991, the U.S. EPA had adopted federal standards for 60 different contaminants, with many more currently proposed or under review. The adoption and enforcement of standards, however, presuppose regular water quality monitoring and treatment, which are costly and technology-intensive processes, making them infeasible for many poorer regions and countries. For example, in January of 1991, the U.S. EPA adopted new standards for 38 contaminants, and estimated that the total cost to water suppliers would be $88 million per year, which included $64 million annually for treatment and another $24 million for monitoring.[93] A recent assessment of EPA's proposed standard for radon estimates that the cost of compliance for this single contaminant could be as high as $2.5 billion per year;

the EPA's cost estimate, $307 million annually, is considerably less, but still substantial.[94]

One result of the proliferation of new standards has been the development and adoption of new technologies. Many water treatment plants currently employ advanced methods to remove metals, organic chemicals, and radionuclides. While new technologies are being rapidly developed, older technologies are being re-evaluated for their potential to address new problems. For instance, one alternative for the control of disinfection by-products is the optimization of conventional treatment. Up to 50% of the DBP precursors can be removed by pH adjustment, changing coagulant and coagulant dosage, and improved mixing conditions.[95] Similarly, ion-exchange processes, which have traditionally been employed to remove cations responsible for water hardness, may also be used to remove radium, barium, iron, manganese, cadmium, lead, chromium III (cation exchange), as well as nitrates, uranium, chromium VI, selenium, and arsenic V (anion exchange).

Of the newer technologies, granular activated carbon (GAC) is one of the most common. GAC is capable of removing many synthetic organic chemicals as well as mercury and radon. GAC readily adsorbs aromatic compounds, chlorinated aliphatics, pesticides, herbicides, and trihalomethanes, but is less effective at removing lower molecular weight compounds (simple aliphatics, ketones, acids, aldehydes). A closely related technology, powdered activated carbon, is effective at removing heavy metals. Air stripping, in which contaminants are transferred from a liquid to a gas phase, is widely used to remove volatile organics in ground water.

Membrane technology is a newer process that has not been widely used in water treatment, with the exception of reverse osmosis, which has been used in desalting plants. In addition to reverse osmosis, other pressure-driven membrane processes include membrane filtration and ultrafiltration. Membrane processes that utilize driving forces other than pressure include electrodialysis (electric potential), pervaporation (concentration), and membrane distillation (temperature gradient). Membrane technology may have important applications in the future. Reverse osmosis, for example, can be used to remove nitrate and other salts, organic chemicals, and microorganisms. Electrodialysis is very effective at removing nitrates. To date, the primary technical limitations of membrane technology have been the problem of frequent membrane blocking and the large volume of rejected water and consequent low efficiency. Possible solutions to these problems include the development of dynamic membranes, which are easily replaced, and the use of other pretreatment technologies in conjunction with membranes to reduce blocking and water rejection.[96]

Bioorganisms may also be used either to transform or to concentrate water pollutants. For instance, both aerobic and anaerobic bacteria have been used for many years to break down human wastes. In recent years, however, bacteria have been applied to remove petroleum products, PAHs, phenol compounds, nitrates, and certain chlorinated organics. A potentially new class of remediating bioorganism is that of "biosorbents", naturally occurring biological materials that are able to adsorb and concentrate pollutants, particularly metals, from aqueous solutions.[97] The major advantage of biosorbents over conventional treatment processes, such as chemical precipitation or ion exchange, is their ability to accumulate metals present at very dilute concentrations.

Despite the promise of new technologies, in almost every case they are limited by their costs. Membrane processes are particularly technology-intensive, with the estimated capital cost of a 0.10 mg reverse osmosis plant equal to $275,000 and operating costs equal to $35,000 per year.[98] This puts reverse osmosis beyond the reach of most smaller water supply systems and out of the question for most regions in the developing world. Moreover, the development of new technologies is complicated by the wide variety of pollutants now present in water and their very different chemical and physical characteristics. Membrane processes have the greatest potential to address multiple contaminants. Thus far, however, water sources frequently require multiple treatments, raising the cost of ensuring water quality still higher.

Because of the expense involved in monitoring for and removing so many chemicals and the relatively low levels of risk involved, a debate has emerged over the appropriate level of water quality. Acceptable risk levels for environmental pollution vary considerably in the U.S.; however, the permissible lifetime risk for carcinogens in drinking water i the order of 10^{-4} to 10^{-6}, which implies one additional death for e 10,000–1,000,000 persons exposed over a lifetime.[99] Yet compared to enormous risk posed by microbiologic disease in the less developed co tries, even the cumulative risk posed by multiple chemical contamin in drinking water is trivial.

Much more attention is also being placed on the water quality need aquatic life in the industrialized countries. Most of the major lakes waterways in the industrialized world are highly managed for hu needs and chronically polluted. In many cases, water quality needs aquatic life are greater than those for human usage, both because sc species are more sensitive and because most surface waters are tre before being tapped as drinking water sources. The needs of aquatic raise different management issues. For instance, ecosystem protect requires information on the impact of long-term exposure to conta nated water and sediments, the behavior of compounds under diffe physical and chemical conditions, and the relative toxicities of efflu and ambient water to numerous different species. These concerns changing the focus of regulation from developing simple ambient w quality criteria for individual contaminants to assessing the cumula impacts of aquatic pollution and ecosystem disturbance. Water qua management is becoming increasingly sophisticated, complex, costly.

In the developing world, the most basic components of water qua management are not in place for large segments of the population, while ecosystem concerns are acknowledged they are rarely address Drinking water standards are almost non-existent except in major ur areas, where basic tests for fecal contamination may be carried out. W significant efforts have been made to provide well-head protection many localities, water sources are still frequently unprotected. Munici and industrial discharges are rarely treated or monitored. Surface wat are used directly for human waste disposal, industrial discharges, wa ing, recreation, drinking, and irrigation. Drinking water treatment prio delivery may consist of filtration in larger towns and cities that h centralized supplies; chlorination, however, is rare.

The primary obstacle to more comprehensive water quality mana ment is cost. Levels of investment in the water supply and sanitat sector in 1990 were estimated to be approximately $10 billion per ye yet, to achieve complete coverage using conventional piped supplies centralized wastewater treatment, practitioners estimate that an inve ment at least five times greater will be required.[100] Thus, there is a co pelling need to focus on low-cost technologies that can be eas maintained, so that coverage can be extended to more people, m quickly. Practitioners and funding agencies are at last moving away fr the conventionally held belief that full-scale piped water and sewer systems should be the standard in all areas. In fact, in rural areas provision of simpler technologies such as pour-flush latrines and ha pumps has proven effective in preventing disease and improving comn nity health.[101] These "appropriate" technologies are much more fin cially feasible. More to the point, however, is the need to prevent wa quality deterioration because the costs of future remediation are likely be prohibitive.

The problems of sanitation and water supply are further complica by social and cultural factors. The provision of safe water supply a sanitation systems alone may not necessarily lead to improved health. Egypt, the first developing country to extend potable water supplies to its rural population, the infant mortality rate remains as high as that countries with much less infrastructure, and diarrheal disease remain major cause of death, estimated at 88 deaths per 1,000 in 1986.[102] T reasons for this failure lie in both behavioral patterns and a popular la of knowledge about the cause and transmission of disease, pointing that infrastructure improvements alone are not sufficient to improve wa quality. Community education and involvement are critical compone of any water quality improvement effort that have been too frequen overlooked in the past.

Conclusions

Water quality problems fall into two broad categories: microbiolo contamination responsible for outbreaks of acute disease, and more recent chemical contamination, which poses cumulative and chronic health risks to human beings and aquatic life. On a global scale, the risks of toxic chemicals, metals, and radionuclides in water are clearly not comparable to those posed by viral and bacterial contamination. Yet although the human health risks of chemical pollutants in drinking water are still relatively small, the increasing prevalence and magnitude of chemical contamination suggest that these risks will rise considerably in the future. More importantly, chemicals have led to the contamination of water on a regional, and, in a few cases, on a global, scale. Atmospheric transport has become a key pathway, allowing chemicals to move long distances and to contaminate areas quite distant from their source.

Several regional trends are also affecting global water quality. In the developing world, rapid population growth and urbanization are straining infrastructure and eating up recent gains made in water supply and sanitation coverage, posing an enormous challenge that the world is unlikely to meet without a fundamental readjustment of priorities. Concurrently, the rapid proliferation and diffusion of chemicals are forcing the less developed countries to shoulder two distinct threats to water quality at one time. They will not have the luxury of addressing water quality problems sequentially and implementing control measures gradually, as Europe and North America did, without risking the unmanageable degradation and depletion of their water resources.

Globally, we are still in the assessment stage. In much of the developing world, little data exist on even the most common water quality problems, such as fecal contamination and microbiologic disease. The extent of chemical contamination is almost totally unknown, and much remains to be learned about water quality, such as how to assess the chronic health risks posed by organic chemicals, how to predict pollutant fate in ground water, and how multiple pollutants affect the long-term health of aquatic ecosystems. Thus, one of the major emphases in the coming decade will be the collection and interpretation of regional-level data. Yet at the same time, the rising costs of treatment and cleanup, combined with the increasing value of fresh water, point to a critical need to prevent further contamination using the information that we already have. The protection of water resources from further degradation must become an immediate focus of international efforts. For instance, better agricultural practices, a decreasing emphasis on pesticides, the recycling and reuse of wastewater, and more careful water development must all become central to water and resource planning. To date, the more developed countries have failed to address the question of source reduction and comprehensive watershed management, and have instead relied on much more costly monitoring and treatment strategies that will not be available to most of the less developed countries in the foreseeable future.

Water quality remains a key indicator of a country's ability to invest in the health of its population and its environment; it is but one of an integrated set of environment and development issues that require immediate attention. In the coming decades, governments face formidable challenges. Population growth continues apace. Infrastructure in many cities is stretched beyond capacity. The introduction and uncontrolled use of chemicals is putting ever greater stress on the natural environment, and the depletion and degradation of water resources are causing the costs of new water supplies to rise. Without fundamentally new approaches to both development and environmental protection, the widespread degradation of water quality that we currently face could become an unmanageable crisis.

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