8 Disease Transmission in Water

Abstract

Disease transmission through water can occur through drinking water contaminated with microorganisms causing disease, through inhalation of aerosols of water at swimming pools, or through air-conditioners, or finally through contact in swimming pools. Diseases transmitted through drinking water include bacterial diseases (cholera, dysentery, typhoid, gastrointestinal disorders by *E. coli*, *Yersinia*, and *Campylobacter*), viruses (hepatitis A and E), and protozoan and helminth parasites (*Cryptosporidium*, *Giardia*, *Entamoeba*). Inhalation of aerosols can lead to Legionnaires' disease and tuberculosis, while persons with open wounds can contact infections by *Aeromonas* and non-tubercular mycobacteria.

Keywords

Atypical tuberculosis • Cholera • Cryptosporidiosis • Cyanotoxins • Disease transmission drinking water • Disease transmission recreational waters • Enteroviruses • Legionella • Parasitic worms • Shigellosis • Tuberculosis

8.1 Disease Transmission Through Drinking Water

Long before the demonstration that water was a vehicle of disease, man sometimes suspected it. Following an outbreak of cholera in 1854 in London, England, a commission was set up under the chairmanship of John Snow, an anesthetist. This commission which reported a year later, in 1855, for the first time established a casual relationship between water and the transmission of bacterial disease. It was found by the commission that the epidemic was restricted to a particular area of London where the inhabitants drank from a well into which sewage entered from a nearby sewer (Cliff and Haggett 1988). A similar and more recent study (Pineo and Subrahmanyam 1975) carried out in Malawi in March 1974 showed that by simply directing water in a piped system, which though untreated came from high in the mountain, a dramatically different picture of cholera distribution occurred (see Fig. 8.1). The great majority of evident water-related health problems are the result of microbial (bacteriological, viral, protozoan, or other biological) contamination (see Table 8.1). Nevertheless, as will be seen below, an appreciable number of serious health concerns may also occur as a result of the chemical contamination of drinking-water.

Crude sewage is one of the most important pollutants of water. Besides supplying organic nutrients, it frequently contains the agents causing enteric infectious diseases in man. In general terms, the greatest microbial enteric disease risks are associated with ingestion of water that is contaminated with human or animal (including bird) feces. Feces can thus be a

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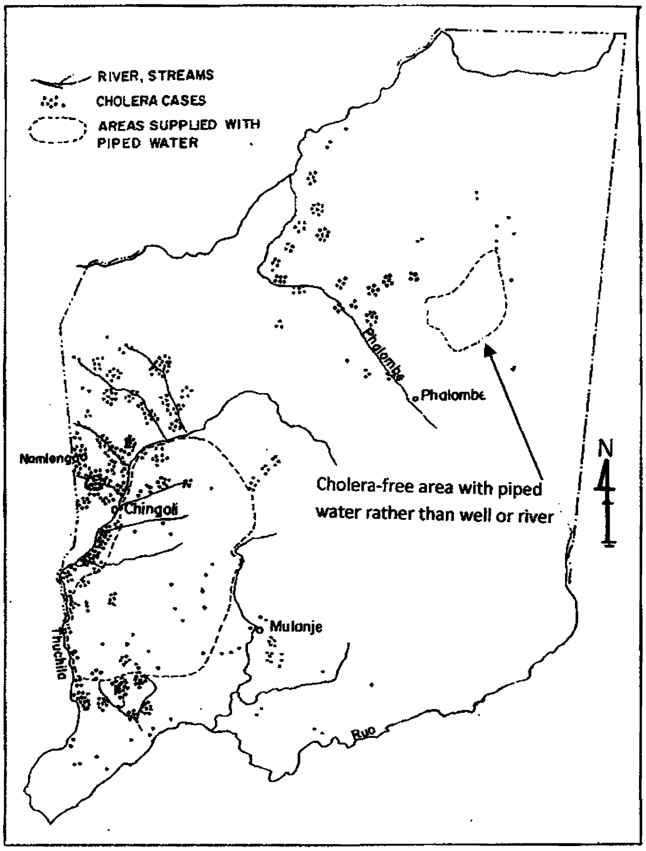

Fig. 8.1 Map showing cholera-free zone in Malawi, March 1974 (Note: The cholera-free zone had piped water, whereas other areas obtained their water from the river or well) (From Pineo and Subrahmanyam 1975. With permission)

source of pathogenic bacteria, viruses, protozoa, and helminthes.

There are four ways by which water, or the lack of it, may be associated with disease:

Waterborne diseases are caused by the ingestion of water contaminated by human or animal feces or urine containing pathogenic bacteria or viruses. The diseases which can be transmitted include cholera, typhoid, amoebic and bacillary dysentery, and other diarrheal diseases. This list can be stretched to include diseases which occur by the ingestion of a toxin produced by an organism growing in drinking water such as toxins produced by cyanobacteria (Anonymous 2006a).

Water-washed diseases are caused by poor personal hygiene and skin or eye contact with contaminated water. They include scabies, trachoma, and flea, lice, and tick-borne diseases.

Water-based diseases are caused by parasites found in intermediate organisms living in water. They include dracunculiasis, schistosomiasis, and diseases caused by other helminths.

Water-related diseases are caused by insect vectors which breed in water. They include dengue, filariasis, malaria, onchocerciasis, trypanosomiasis, and yellow fever.

Diseases may thus be transferred through water in ways outside drinking (see Fig. 8.2).

In this chapter, we shall look at diseases transmitted through drinking water, through recreational waters such as swimming pools and through the eating of aquatic invertebrates, shellfish, which ingest aquatic microorganisms.

8.1.1 Communicable Diseases Transmitted Through Drinking Water

Communicable diseases are those which are brought about by microorganisms. Drinking-water-borne outbreaks of any kind are particularly to be avoided because of their capacity to result in the simultaneous infection of a large number of persons and potentially a high proportion of the community. Thus, in the

Table 8.1 Waterborne pathogens and their significance in water supplies (From Anonymous 2006a. With permission)

Pathogen	Health significance	Persistence in water supplies[a]	Resistance to chlorine[b]	Relative infectivity[c]	Important animal source
Bacteria					
Burkholderia pseudomallei	Low	May multiply	Low	Low	No
Campylobacter jejuni, *C. coli*	High	Moderate	Low	Moderate	Yes
Escherichia coli – Pathogenic[d]	High	Moderate	Low	Low	Yes
E. coli – Enterohaemorrhagic	High	Moderate	Low	High	Yes
Legionella spp.	High	Multiply	Low	Moderate	No
Non-tuberculous mycobacteria	Low	Multiply	High	Low	No
Pseudomonas aeruginosa[e]	Moderate	May multiply	Moderate	Low	No
Salmonella typhi	High	Moderate	Low	Low	No
Other salmonellae	High	May multiply	Low	Low	Yes
Shigella spp.	High	Short	Low	Moderate	No
Vibrio cholerae	High	Short	Low	Low	No
Yersinia enterocolitica	High	Long	Low	Low	Yes
Viruses					
Adenoviruses	High	Long	Moderate	High	No
Enteroviruses	High	Long	Moderate	High	No
Hepatitis A virus	High	Long	Moderate	High	No
Hepatitis E virus	High	Long	Moderate	High	Potentially
Noroviruses and sapoviruses	High	Long	Moderate	High	Potentially
Rotaviruses	High	Long	Moderate	High	No
Protozoa					No
Acanthamoeba spp.	High	Long	High	High	No
Cryptosporidium parvum	High	Long	High	High	Yes
Cyclospora cayetanensis	High	Long	High	High	No
Entamoeba histolytica	High	Moderate	High	High	No
Giardia intestinalis	High	Moderate	High	High	Yes
Naegleria fowleri	High	May multiply[f]	High	High	No
Toxoplasma gondii	High	Long	High	High	Yes
Helminths					
Dracunculus medinensis	High	Moderate	Moderate	High	No
Schistosoma spp.	High	Short	Moderate	High	Yes

Note: Waterborne transmission of the pathogens listed has been confirmed by epidemiological studies and case histories. Part of the demonstration of pathogenicity involves reproducing the disease in suitable hosts. Experimental studies in which volunteers are exposed to known numbers of pathogens provide relative information. As most studies are done with healthy adult volunteers, such data are applicable to only a part of the exposed population, and extrapolation to more sensitive groups is an issue that remains to be studied in more detail

[a]Detection period for infective stage in water at 20°C: short, up to 1 week; moderate, 1 week to 1 month; long, over 1 month

[b]When the infective stage is freely suspended in water treated at conventional doses and contact times. Resistance moderate, agent may not be completely destroyed

[c]From experiments with human volunteers or from epidemiological evidence

[d]Includes enteropathogenic, enterotoxigenic and enteroinvasive

[e]Main route of infection is by skin contact, but can infect immunosuppressed or cancer patients orally

[f]In warm water

10 year period between 1991 and 2000, nearly half a million people were affected by all categories of water-associated diseases system in the USA in a total of 155 outbreaks (Anonymous 2003). Table 8.1 gives the causes of waterborne outbreaks in the USA by type of water system between 1991 and 2000, while Fig. 8.3 summarizes all the outbreaks of diseases linked to drinking water in the same period.

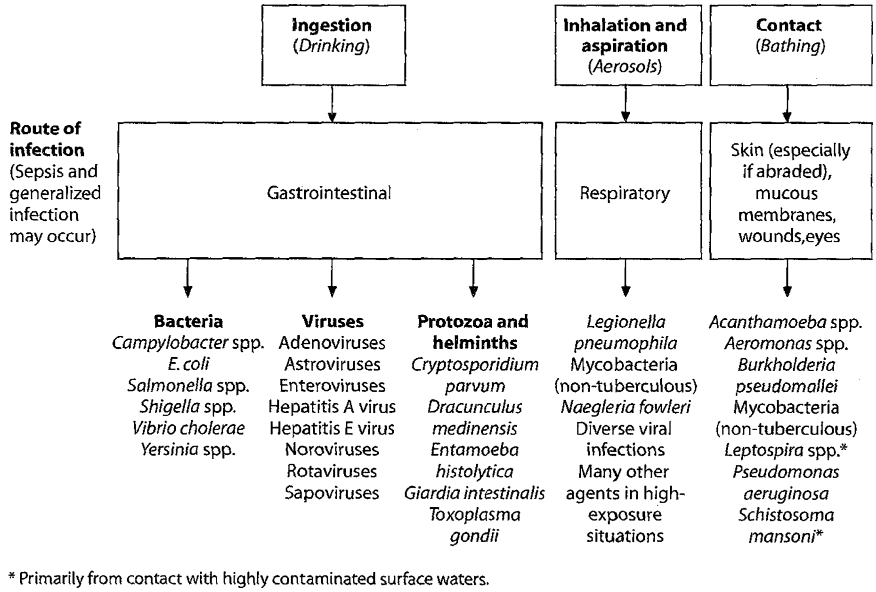

Fig. 8.2 Routes of transmission of water-associated diseases (From Anonymous 2006a. With permission)

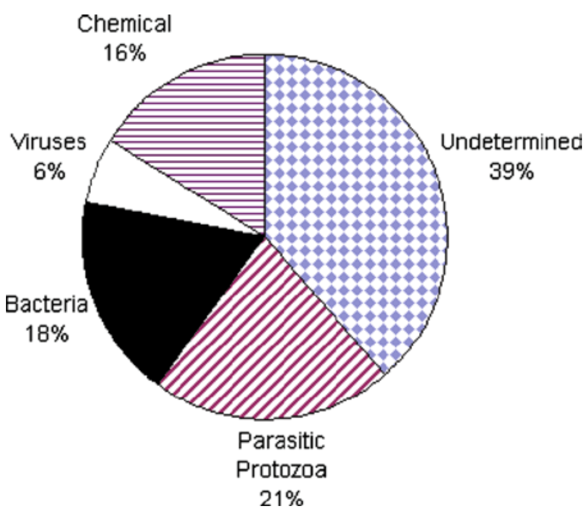

Fig. 8.3 Summary of the causes of outbreaks of diseases linked to drinking water in the US, 1991–2000 (From the American Chemistry Council; Anonymous 2003. With permission)

The type and incidence of water borne diseases varies according to the economic circumstance of the country. This is reflected in the ability of a society to provide clean potable water for its members. Thus, while cholera is endemic in Asian countries, it does not exist at all in the USA. Figures for many developing countries are not available, but if they were they would most probably be unreliable as many of these countries do not have laws which compel the reporting of certain diseases. That water-borne diseases are important is not in doubt. Even in a country of high economic development such as the USA, where treated water is easily available, data show (Fig. 8.3) a good number of cases annually (Anonymous 2003).

As seen in Fig. 8.3, the cause of water-associated diseases recorded in the US between 1991 and 2000 could not be determined in 39% of the cases. Where the cause was known, protozoa topped the list followed by bacteria, chemicals, and viruses (Fig. 8.3, Table 8.1). Indeed the number of cases appears to be rising, although this could be a reflection of greater reporting and more investigation than of absolute increase in cases.

In addition to fecally borne pathogens, other microbial hazards (e.g., guinea worm *Dracunculus medinensis*, toxic cyanobacteria, and *Legionella*) may be of public health importance under specific circumstances. The infective stages of many helminths, such as parasitic roundworms and flatworms, can be transmitted to humans through drinking water. As a single mature larva or fertilized egg can cause infection, these should be absent from drinking water. However, the water route is relatively unimportant for helminth infection, except in the case of the guinea worm.

Public health concern regarding cyanobacteria relates to their potential to produce a variety of toxins, known as “cyanotoxins.” In contrast to pathogenic bacteria, cyanobacteria do not proliferate within the human body after uptake; they proliferate only in the

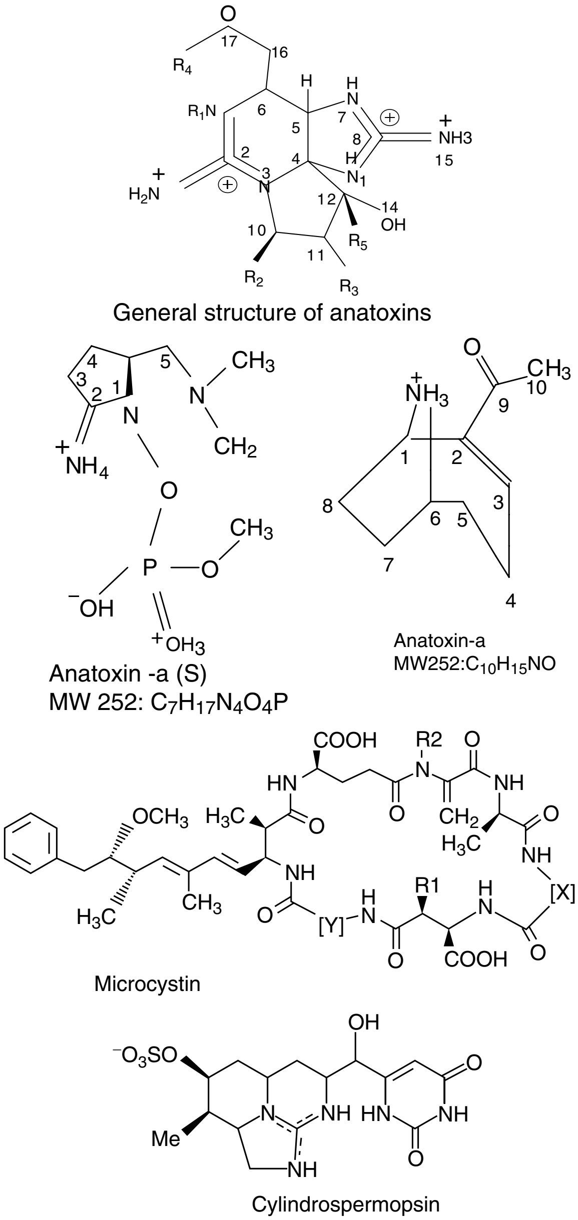

Fig. 8.4 Akaloid neurotoxins from Cyanobacteria (From Falconer and Humpage 2005. With permission)

aquatic environment before intake. While the toxic peptides (e.g., microcystins) are usually contained within the cells (Falconer and Humpage 2005) and thus may be largely eliminated by filtration, toxic alkaloids such as cylindrospermopsin and neurotoxins are also released into the water and may break through filtration systems (see Fig. 8.4).

8.1.2 Disease Outbreaks in Drinking Water Due to the Presence of Chemicals, and Biotoxins

It should be pointed out that water-borne diseases are not restricted to communicable diseases (Fig 6.2); some water-associated diseases are caused by chemicals or lack of them. For example, it has been shown that mortality due to cardio-vascular disease incidence is higher by at least 24% in towns with soft water than in those with hard water. Cities with high amounts of magnesium (Mg^{2+}) and calcium (Ca^{2+}), the ions responsible for hardness, show lower incidence of cardiovascular disease by 17% and 22% respectively. Goiter and tooth decay have been attributed to the absence of iodine and fluoride respectively, in drinking water. On the other hand, nitrate levels have been incriminated with methanogloblinemia in infants; while yet unknown chemicals in water have been implicated with the high incidence of bladder cancer in some cities. Although the short-term or long-term presence or absence of certain amounts of some chemicals in drinking water is important, the incidence of water borne diseases due to microorganisms and biological agents appears far more important, especially in developing countries.

Biotoxins are sometimes produced in drinking water by cyanobacteria. Examples are the neurotoxin, anatoxins and the cytotoxin, cylindrospermopsin (Fig. 8.4).

8.1.2.1 Brief Notes on Some Water-Borne Diseases

This section will give some insight into the nature of waterborne diseases (Anonymous 2006b).

Cholera

Frequently called Asiatic cholera or epidemic cholera, the disease is caused by the Gram-negative, comma-shaped bacterium *Vibrio cholera* with a single polar flagellum. Cholera is characterized by a diarrhea with profuse watery stool, vomiting, rapid dehydration, fall of blood pressure, subnormal temperature and collapse may occur within 48 h unless medical care is given. The bacterium produces cholera toxin, an enterotoxin, whose action on the mucosal epithelium lining of the small intestine is responsible for the characteristic massive diarrhea of the disease. In its most severe forms, cholera is one of the most rapidly fatal illnesses known; a healthy person may become hypotensive within an hour of the onset of symptoms and may die within 2–3 h if no treatment is provided. More commonly, the disease progresses from the first liquid stool to shock in 4–12 h, with death following in 18 h to several days, if rehydration treatment is not given.

Members of the species are typed according to their O antigens. There are a number of pathogenic species, including *V. cholerae*, *V. parahaemolyticus*, and *V. vulnificus*. However, *Vibrio cholerae* is the only pathogenic species of significance from freshwater environments. While a number of serotypes can cause diarrhea, only the serological varieties (serovars) O1 and O139 currently cause the classical cholera symptoms in which a proportion of cases suffer fulminating and severe watery diarrhea. The O1 serovar has been further divided into "classical" and "El Tor" biotypes. The latter is distinguished by features such as the ability to produce a dialyzable heat-labile haemolysin, active against sheep and goat red blood cells. The classical biotype is considered responsible for the first six cholera pandemics, while the El Tor biotype is responsible for the seventh pandemic that commenced in 1961. Strains of *V. cholerae* O1 and O139 that cause cholera produce an enterotoxin (cholera toxin) that alters the ionic fluxes across the intestinal mucosa, resulting in substantial loss of water and electrolytes in liquid stools. Other factors associated with infection are an adhesion factor and an attachment pilus. Not all strains of serotypes O1 or O139 possess the virulence factors, and they are rarely possessed by non-O1/O139 strains.

These types are further sub-divided into the *Inaba* (A,C) and *Ogawa* (A,B).and *Hikojima* (A,B,C) serotypes on somatic O1 biotypes antigens, and each biotype may display the "classical" or El Tor phenotype.

Healthy carriers (i.e., individuals who have suffered from cholera and carry the vibrio without manifesting illness) vary from 2% to 9% while for the El Tor biotype it could be as high as 25% for up to about 1 month. Chronic carriers may carry and shed the organisms in their stools for up to 1 year.

A large number of non-cholera vibrios are found in water. They are distinguished from the cholera vibrio because they lack the somatic O1 antigen, hence they are known as non-agglutinating vibrios (NAG) or non-cholera vibrios.

Salmonellosis

Salmonellae are motile, gram-negative, lactose-fermenting rod-shaped bacteria of the family *Enterobacteriaceae*. They are named after Daniel E. Salmon, who first isolated the organism from porcine intestine. Salmonellae have been implicated in a wide spectrum of other diseases, including enteric or typhoid fever (primarily *Salmonella typhi* and *Salmonella paratyphi*), bacteremia, endovascular infections, focal infections (e.g., osteomyelitis), and enterocolitis (typically *Salmonella typhimurium*, *Salmonella enteritidis*, and *Salmonella heidelberg*).

All salmonellae are grouped into a single species, *Salmonella choleraesuis*, which is divided into seven subgroups based on DNA homology and host range. Most of the salmonellae that are pathogenic in humans belong to a single subgroup (subgroup I). Additionally, each of the salmonellae can be serotyped according to their particular complement of somatic O, surface Vi, and flagellar H antigens. Presently, more than 2,300 *Salmonella* serovars exist.

The transmission of salmonellae to a susceptible host usually occurs by consumption of contaminated foods or water. Although nontyphoid salmonellae generally precipitate a localized response, *S typhi* and other especially virulent strains invade deeper tissues via lymphatics and capillaries and elicit a major immune response. In the USA, in 1997, the estimated annual incidence of salmonellosis was 13.8 cases per 100,000 people, especially among persons who traveled to developing countries. In 1994, the most frequently isolated *Salmonella* strains causing human disease reported to the US Centers for Disease Control and Prevention was *S enteritidis*. Carriage is usually from 2% to 5%.

Cryptosporidiosis

This is a disease characterized by the stomach cramps, fever, diarrhea, dehydration, and low grade fever and lasts for 1–2 weeks in healthy persons. However, in immune-compromised persons, e.g., AIDS patients, it produces a debilitating, cholera-like diarrhea of up to 20 l/day, severe abdominal cramps, weight loss and tiredness.

Between March 23 through April 8, 1993, about 400,000 persons came down with cryptosporidiosis in the Wisconsin city of Milwaukee, out of which about 100 died. It was the greatest incidence of water borne infection in US history. It turned out that raw sewage had leaked into one of the two reservoirs serving the city.

It is caused by a Protozoon belonging to the Sporozoa (see Chap. 4). However, it is atypical in that

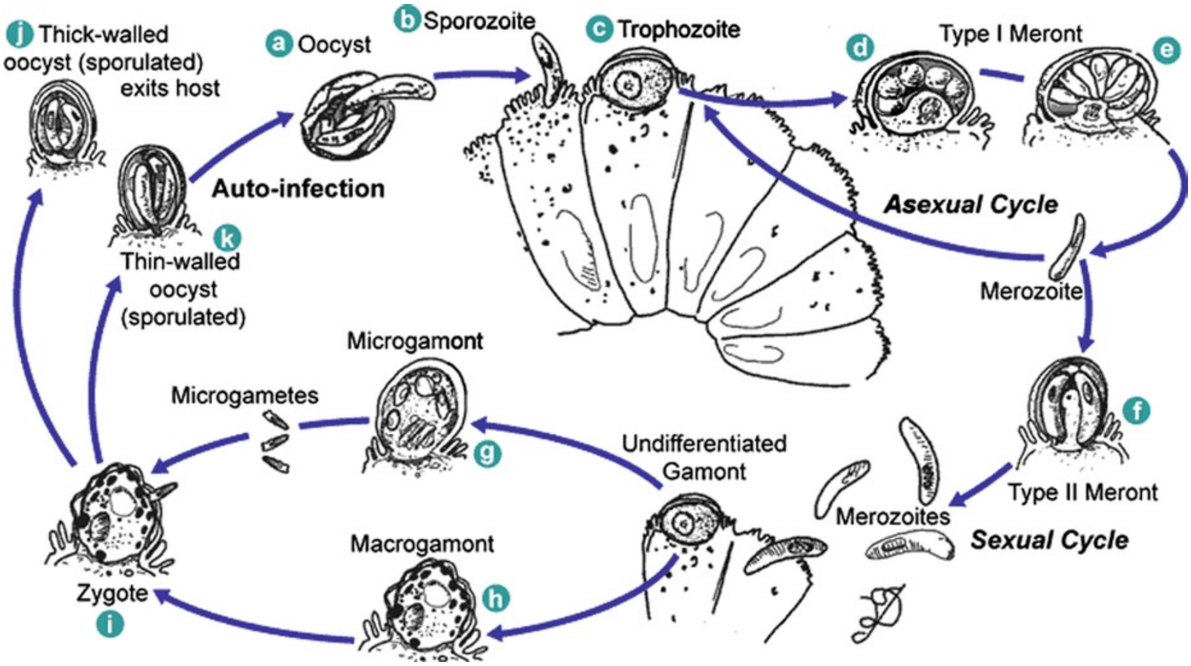

Fig. 8.5 Life history of *Cryptosporidium parvum* (Note the oocysts whose thick walls shield them from disinfectants) (From http://www.dpd.cdc.gov/dpdx/html/frames/A-/Cryptosporidiosis/body_Cryptosporidiosis_life_cycle_lrg.htm; Credit: Center for Disease Control [CDC])

it completes its life history in a single host, unlike other Sporozoans which complete their life history in two hosts, such as the malaria parasite, *Plasmodium* spp. Members of this group produce different kinds of spores (hence their name, *Sporozoa*). *Cryptosporidium* isolated from humans is now referred to as *C. parvum*. *Cryptosporidium* infections have been reported from a variety of wild and domesticated animals, and in the last 6 or 7 years, literally hundreds of human infections have been reported, including epidemics in several major urban areas in the United States. Cryptosporidiosis is now recognized as an important opportunistic infection, especially in immunocompromised hosts. The disease is transmitted when feces of infected persons or animals enter drinking water. The thick walled oocytes of *Cryptosporidium parvum*, are known to be resistant to chlorine at concentrations typically applied for water treatment (Fig. 8.5).

Shigellosis

Shigellosis, also known as bacillary dysentery is a water borne illness caused by infection by bacteria of the genus *Shigella*. The causative organism is frequently found in water polluted with human feces, and is transmitted via the fecal-oral route. An estimated 18,000 cases of shigellosis occur annually in the United States, mainly affecting infants, the elderly, and especially those suffering from AIDS. It is characterized by diarrhea, often with blood or mucus in the watery stool, cramps, fever, and sometimes vomiting. It sets in a day or 2 after contact.

Discovered over a 100 years ago, the organism is named Shiga, the Japanese discover of the organism. There are four species of *Shigella: Boydii*, *dysenteriae*, *flexneri*, *and sonnei*. The genus *Shigella* is divided into four groups, A, B, C, and D, with the common nomenclature of *Shigella dysenteriae*, *S. flexneri*, *S. boydii*, and *S. sonnei*, respectively. There are 49 recognized serological types or serovars, representing subtypes from three of the four groups. Infection and outbreaks associated with this organism are prominent in developing countries and are strongly associated with overcrowding and poor hygienic conditions. Shigellosis is also travel associated, and several outbreaks have been reported in developed countries such as Canada and the United States which are travel-related. *Shigella sonnei* ("Group D" *Shigella*) accounts for over two-thirds of the shigellosis in the United States. *Shigella* *flexner* ("group B" *Shigell*) accounts for almost all of the rest. Other types of *Shigella* are rare in this country, although they are important causes of disease in the developing world. One type, *Shigella dysenteriae* type 1, causes deadly epidemics in many developing regions and nations. Following the invasion of the walls of the large intestine or colon, blood leaks into the colon hence the subsequent leakage of blood; due to the colon inflammation, mucus and pus may also be seen in the stool.

Tuberculosis

The tuberculous or "typical" species of *Mycobacterium*, such as *M. tuberculosis*, *M bovis*, *M. africanum,* and *M. leprae*, have only human or animal reservoirs and are not transmitted by water. In contrast, the non-tuberculous or "atypical" species (see below) of *Mycobacterium* are natural inhabitants of a variety of water environments. These aerobic, rod-shaped, and acid-fast bacteria grow slowly in suitable water environments and on culture media. Mycobacteria are called acid-fast because the high lipid content of their walls absorbs the red dye basic fuchsin and therefore the walls retain the dye when decolorized with dilute acid.

Tuberculosis, pulmonary tuberculosis (abbreviated as TB for *Tubercle Bacillus*), is a common and deadly infectious disease that is caused by *Mycobacterium tuberculosis*. Tuberculosis most commonly affects the lungs (as pulmonary TB) but can also affect the central nervous system, the lymphatic system, the circulatory system, the genitourinary system, bones, joints, and even the skin.

In 2004, 14.6 million people had active TB and there were 8.9 million new cases and 1.7 million deaths, mostly in developing countries. In addition, a rising number of people in the developed world are contracting tuberculosis because their immune systems are compromised by immunosuppressive drugs, substance abuse or HIV/AIDS.

Pulmonary (or lung) tuberculosis caused by *Mycobacterium tuberculosis* can be transmitted via water although this is uncommon. The difficulty of a categorical statement stems in part from the fact that the incubation period of tuberculosis is long, lasting from 4 to 6 weeks. Hence, it is often difficult to tell when contact was first made with the organisms. Children who had fallen into a river at a point where sewage from a chest clinic was discharged were shown to have pulmonary tuberculosis after it was shown that the water in which the children had fallen contained mycobacteria. The organisms have been shown to persist in water for up to 36 days.

Atypical Tuberculosis

Atypical tuberculosis is also known as atypical mycobacterial disease, MOTT (mycobacteria other than tuberculosis), opportunist mycobacterial disease, environmental tuberculosis, and NTM TB. The organism that causes tuberculosis is *Mycobacterium tuberculosis* (*M. tb*). The atypical mycobacteria belong to the same family of mycobacterial organisms as *M.tb*, and it is also acid-fast but include other species such as *M. avium*, *M. intracellularae*, *M. kansasii*, *M. xenopi*, and *M. fortuitum*. Most infections with these organisms are believed to arise from environmental exposure to organisms in infected water, soil, dust, or aerosols. Person-to-person and animal-to-animal transmission of atypical mycobacteria is not an important factor in acquisition of infection with these organisms. Atypical tuberculosis is more common in immunosuppressed persons and in young children.

A simple TB skin test is the best way to address any concerns about infections. The test is only sensitive for mycobacterium tuberculosis; a positive test is usually followed by a chest x-ray to look for evidence of infections in the lungs.

Leptospirosis

Leptospirosis is an acute bacterial infection which affects the kidneys, liver, the central nervous system of man and other animals. It is caused by bacteria of the genus *Leptospira*. In humans, it causes a wide range of symptoms, and some infected persons may have no symptoms at all. Symptoms of leptospirosis include high fever, severe headache, chills, muscle aches, and vomiting, and may include jaundice (yellow skin and eyes), red eyes, abdominal pain, diarrhea, or a rash. When jaundice is involved, it is known as Weir's disease after the German doctor who first described it. If the disease is not treated, the patient could develop kidney damage, meningitis (inflammation of the membrane around the brain and spinal cord), liver failure, and respiratory distress. In rare cases, death occurs. Many of these symptoms can be mistaken for other diseases. Leptospirosis is confirmed by laboratory testing of a blood or urine sample.

The spirochete enters recreational waters and lakes directly through urination of infected cattle, swine, rodents, pigs, and frogs in whose kidneys the organisms lodge. Once inside the water, the spirochete enter the human body through abrasions, cuts, etc.

Enteropathogenic *Escherichia coli*

E. coli is normally a harmless commensal in the alimentary canals of man and other animals. However, some sero-types frequently cause a gastroenteritis characterized by severe diarrhea with little mucus or blood, and with dehydration but usually without fever. Children, especially the newborn, are usually affected but increasing cases of adult diarrhea caused by EEC are also being noted. The cases have usually been due to contaminated drinking water.

Currently, there are four recognized classes of enterovirulent *E. coli* (collectively referred to as the EEC group) that cause gastroenteritis in humans. Among these are the enteropathogenic (EPEC) strains. EPEC are defined as *E. coli* belonging to serogroups epidemiologically implicated as pathogens but whose virulence mechanism is unrelated to the excretion of typical *E. coli* enterotoxins. Humans, bovines, and swine can be infected, and the latter often serve as common experimental animal models. *E. coli* are present in the normal gut flora of these mammals. Acute infantile diarrhea is usually associated with EPEC.

Aeromonas

Species of *Aeromonas* are Gram-negative, non-spore-forming, rod-shaped, facultatively anaerobic bacteria that occur ubiquitously and autochthonously in aquatic environments. The aeromonads share many biochemical characteristics with members of the Enterobacteriaceae, from which they are primarily differentiated by being oxidase-positive. There are about 17 species. Among them is the psychrophilic *A. salmonicid*, which is a fish pathogen and has not been associated with humans. On the other hand, the mesophilic species, including mesophilic *A. hydrophila*, *A. caviae*, *A. sobria*, *A. veronii*, and *A. schubertii*, have been associated with a wide range of infections in humans. The species principally associated with gastroenteritis are *A. caviae*, *A. hydrophila*, and *A. veronii* biovar sobria ; *A. caviae* is particularly associated with young children (under 3 years of age). Numerous studies have resulted in the isolation of several species of *Aeromonas* from patients with gastroenteritis, but attempts to artificially infect volunteers have not been clear cut. They are also associated with sepsis and wounds, and with eye, respiratory tract, and other systemic infections. Many of the systemic infections arise following contamination of lacerations and fractures with *Aeromonas*-rich waters.

Amoebiasis

Amoebiasis is a parasitic infection of the large intestine caused by *Entamoeba histolytica*. Dysentery with mucus and blood, sometimes alternating with constipation, is a common feature. It is usually contracted by ingesting water or food contaminated with amoebic cysts. Amoebiasis is an intestinal infection that may or may not be symptomatic. When symptoms are present, it is generally known as invasive amoebiasis.

Contaminated drinking water or consumption of vegetables, fruits contaminated with feces are common sources and the organism survives adverse conditions by the production of cysts. Amoebiasis is usually transmitted by contamination of drinking water and foods with fecal matter, but it can also be transmitted indirectly through contact with dirty hands or objects as well as by sexual intercourse.

Giardiasis

Giardiasis is caused by *Giardia lamblia*, a flagellated protozoon. The clinical manifestations may vary from the passage of cysts without major malfunctions to severe malabsorption. Its typical symptoms are diarrhea, gas or flatulence, greasy stools that tend to float, stomach cramps, and upset stomach or nausea. It has become more important in the United States, where it has reportedly been spread from tourists returning to that country after holidays abroad. The cysts of the protozoon are not destroyed – as also is the case with *E. histolytica* – by chlorination at the level of contact normally employed in water treatment. Once an animal or person has been infected with *Giardia intestinalis*, the parasite lives in the intestine and is passed in the stool. Because the parasite is protected by an outer shell, it can survive outside the body and in the environment for long periods of time.

During the past two decades, *Giardia* infection has become recognized as one of the most common causes of waterborne disease (found in both drinking and recreational water) in humans in the United States. *Giardiasis* is found worldwide and within every region of the United States.

Table 8.2 Causes of waterborne outbreaks in the US by type of water system, 1991–2000 (From Anonymous 2003. With permission)

	Community water systems[a]		Noncommunity water systems[b]		Individual water systems[c]		All systems	
Etiological agent	Outbreaks	Cases	Outbreaks	Cases	Outbreaks	Cases	Outbreaks	Cases
Giardia	11	2,073	5	167	6	16	22	2,256
Cryptosporidium[d]	7	407,642	2	578	2	39	11	408,259
Campylobacter	1	172	3	66	1	102	5	340
Salmonellae, nontyphoid	2	749	0	0	1	84	3	833
E. coli	3	208	3	39	3	12	9	259
E. coli O157:H7/C. jeuni	0	0	1	781	0	0	1	781
Shigella	1	83	5	484	2	38	8	605
Plesiomonas shigelloides	0	0	1	60	0	0	1	60
Non-01 V. cholerae	1	11	0	0	0	0	1	11
Hepatitis A virus	0	0	1	46	1	10	2	56
Norwalk-like viruses	1	594	4	1,806	0	0	3	2,400
Small, round-structured virus	1	148	1	70	0	0	2	218
Chemical	18	522	0	0	7	9	25	531
Undetermined	11	10,162	38	4,837	11	238	60	15,237
Total	57	422,364	64	8,934	34	548	155	431,846

Data in Table 8.2 are compiled from CDC Morbidity and Mortality Weekly Report Surveillance Summaries for 1991–1992, 1993–1994, 1995–1996, 1997–1998 and 1999–2000. Figures include adjustments to numbers of outbreaks and illness cases originally reported, based on more recent CDC data

[a]Community water systems are those that serve communities of an average of at least 25 year-round residents and have at least 15 service connections

[b]Noncommunity water systems are those that serve an average of at least 25 residents and have at least 15 service connections and are used at least 60 days per year

[c]Individual water systems are those serving less than 25 residents and have less than 15 service connections

[d]There were 403,000 cases of illness reported in Milwaukee in 1993

Viruses

Viruses which are excreted in feces may be contacted through drinking water. Over 100 viruses which cause a variety of illnesses in man have been encountered in water contaminated by sewage (Bosch 1998). These include infectious hepatitis virus, adenoviruses, enteroviruses (i.e., polio-virus, coxsackie viruses and ECHO entero cytopathic human orphans) (see Table 8.2). However, the virus which has been definitely shown to be transmissible through drinking water is the infections hepatitis virus. The transmission of poliomyelitis virus appears to be mainly by contact and only secondarily by water. Some of the viruses in sewage-contaminated are described below**.**

1. *Enetroviruses*

   These are small RNA viruses and are divided into two: The polioviruses and the non-polio viruses. The polio viruses have been eliminated in the western hemisphere and most parts of the world through extensive vaccination. A few pockets of polio endemicity remain in parts of Africa.

   There are 62 non-polio enteroviruses that can cause disease in man: 23 Coxsackie A viruses, 6 Coxsackie B viruses, 28 echoviruses, and 5 other enteroviruses. They are second only to the "common cold" viruses, the rhinoviruses, as the most common viral infectious agents in humans. The enteroviruses cause an estimated 10–15 million or more symptomatic infections a year in the United States, especially in the summer and fall. Most people who are infected with an enterovirus have no disease at all. Those who become ill usually develop either mild upper respiratory symptoms (a "summer cold"), a flu-like illness with fever and muscle aches, or an illness with rash. In rare cases, some persons have "aseptic" or viral meningitis, illnesses that affect the heart (myocarditis) or the brain (encephalitis) or causes paralysis. Enterovirus infections are suspected to play a role in the development of juvenile-onset diabetes mellitus (sugar diabetes).

2. *Hepatoviruses*
A genus of Picornaviridae (non-enveloped, positive-stranded RNA viruses with an icosahedral capsid) causing infectious hepatitis naturally in humans and it is transmitted through fecal contamination of food or water. Hepatitis A virus (HAV) is the type species. Hepatitis A virus (HAV) is readily transmitted through water. HAV causes infectious hepatitis, an illness characterized by inflammation and necrosis of the liver. HAV can be removed from drinking water through coagulation, flocculation, and filtration**.**
3. *Reovirus*
A group of viruses that contain double-stranded RNA and are associated with various diseases in animals, including human respiratory and gastrointestinal infections. They derive their name from the acronym [r(espiratory) + e(nteric) + o(rphan) + viru]. They are suspected to cause respiratory and enteric illness.
4. *Rotavirus*
Rotaviruses are non-enveloped, icosahedral, double stranded (ds) RNA viruses with double capsid. Their electron microscopic appearance shows a 60–80 nm wheel with radiating spokes (Latin, rota, ≡ wheel).
Rotaviruses are the major cause of childhood gastroenteritis world-wide. In developing countries, deaths are common among children <5 years. Although the disease occurs in all age groups, it is mild and inapparent in adults. Infection is generally not recognized as food borne but outbreaks associated with food and water have been reported in a number of countries.
5. *Mastaldenovirus*
They are a genus of adenoviruses that infects mammals including humans and causes a wide range of diseases, including enteric and respiratory. The type species is Human adenovirus C. Of the many types of adenovirus, only two types, 40 and 41, are generally associated with fecal–oral spread and gastroenteritis (especially in children). Most infections are subclinical or mild.
6. *Astroviruses, Caliciviruses, Parvoviruses*
The above are all diarrhea viruses; they are of great economic importance, causing millions of lost working days each year, as well as much discomfort. Diarrhea continues to be a major cause of morbidity and mortality worldwide resulting in an estimated 1,000 deaths among children each day, the highest incidence being in developing countries of the world. One well documented source of infection is the consumption of shellfish (polluted by sewage) – and therefore, they also have economic consequences for fishermen and the food industry. Such viruses often cause mini-epidemics in families, hospital wards, etc. and are potentially very dangerous to seriously ill hospital patients. More importantly, these viruses contribute to the massive mortality caused by infantile diarrhea in developing countries and are responsible for uncounted millions of deaths each year.
The Norwalk-like viruses (NLV, now renamed as Norovirus) and Hepatitis E virus belong to the calicivirus group. Noroviruses are believed to be the most common causative agent for community gastroenteritis world-wide. On the other hand, the Hepatitis E virus appears to occur widely in Asia, Africa, and Latin America, where waterborne outbreaks are common. It has rarely been identified elsewhere. The virus infects the liver and symptoms of hepatitis.

Parasitic Worms

Various parasitic worms may be transmitted through water, including *Schistosoma* spp., *Taenia* spp., *Ascaris* spp., and *Enterobius* spp.

1. Guinea worm disease (GWD, *Dracunculiasis*) is an infection caused by the parasite *Dracunculus medinensis*. It affects poor communities around the world, including parts of Africa that do not have safe water to drink. In 2003, only 32,193 cases of GWD were reported. Most (63%) of those cases were from Sudan where the ongoing civil war makes it impossible to eradicate the disease. All affected countries except Sudan are aiming to eliminate Guinea worm disease as soon as possible.
2. Roundworm (*Ascaris lumbricoides*) is symptomless in many people. It is estimated that over one billion people in the world may be infected with roundworm. The source of infection is contamination of soil and vegetables with feces. Adult roundworms live in the small intestines and can exit through the mouth or nose of the infected person.

Occasionally, there is obstruction of the pancreatic or bile duct, appendix, or small intestines. Dry cough, fever, and sleep disturbance may occur. Diagnosis is by stool exam for eggs and blood test.

3. Hookworms (*Necator americanus)* is transmitted through unbroken skin by walking barefoot. Hookworms travel into blood and through the lung and intestines. Hookworm infection is usually symptomless. There may be itching at the area of skin penetration. There can be digestive symptoms. The worms attach to and suck the blood from the mucous of the small intestines, leading to iron deficiency anemia, low energy, and peptic ulcer-like symptoms in severe infections.
4. Pinworm (*Enterobius vermicularis*) infection is common in the United States. It is transmitted through contaminated food and water. The worms live in the intestines near the rectum and travel at night outside to the skin around the anus. From there, it can be transmitted through person to person contact. It can be symptomless. There is often itching at night around the anus. There can also be unusual symptoms such as hyperactivity, vision problems, vaginitis, and psychological disturbances. Tape is often applied to the anal area at night. When the tape is removed, adult worms may be seen with the unaided eye. At least five to seven tests are required to rule out infection.
5. Whipworm (*Trichuris trichiura*) is a large intestine parasite that rarely shows symptoms. It is transmitted by ingestion of the eggs in soil or on vegetables. Symptoms of heavy infection include diarrhea, stomach pain, rectal prolapse, and stunted growth.

8.2 Disease Transmission in Recreational Waters

Apart from regular swimming pools, there are a number of other types of recreational waters: *Hot tubs* is the term used to encompass a variety of facilities that are designed for sitting in (rather than swimming), contain water usually above 32°C, are generally aerated, contain treated water and are not drained, cleaned, or refilled for each user. They may be domestic, semi-public, or public and located indoors or outdoors. A wide range of names is used for them, including spa pools, whirlpools, whirlpool spas, heated spas, bubble baths, and Jacuzzi, a term that is used generically but is in fact a trade name.

Plunge pools are usually used in association with saunas, steam rooms, or hot tubs and are designed to cool users by immersion in unheated water. They are usually only large enough for a single person, but can be larger. They may be considered to be the same as swimming pools.

Natural spa is the term used to refer to facilities containing thermal and/or mineral water, some of which may be perceived to have therapeutic value and because of certain water characteristics may receive minimal water quality treatment.

Some of the microorganisms found in swimming pools and similar recreational water environments, have caused disease outbreaks. In the case of drinking water, which is taken into the human body, the concern is the consumption of water containing fecal material and hence the possibility of being infected by the pathogenic microorganisms or helminthic parasites present in such contaminated water. With recreational waters, however, while some of the disease causing agents could come from fecal material, some do not. Therefore, in looking at disease transmission through recreational waters, the disease agents will be looked at in two ways: The fecally transmitted and the non-fecally transmitted. Such a distinction will facilitate the control of diseases acquired through the use of recreational waters.

Fecal and non-fecal sources of disease causing agents in recreational waters (see Fig. 8.6):

(a) Fecal contamination of a recreational water can occur when
   1. The source water used in the recreational is pre-contaminated, and remains untreated.
   2. Fecal material is accidentally released by bathers as formed stool or diarrhea.
   3. There is residual fecal material on swimmers' bodies and this is washed into the pool.
   4. When feces from animals and birds get into recreational waters, e.g., in outdoor pools.

(b) Non-fecal contamination of recreational waters can occurs when
   1. There is nonfecal introduction of body fluids into the water, though vomiting, mucus, saliva, or skin peelings.
   2. Infected users directly contaminate pool waters and the surfaces of objects or materials at a facility with pathogens (notably viruses or fungi), which may lead to skin infections in other patrons who come in contact with the contaminated water or surfaces.

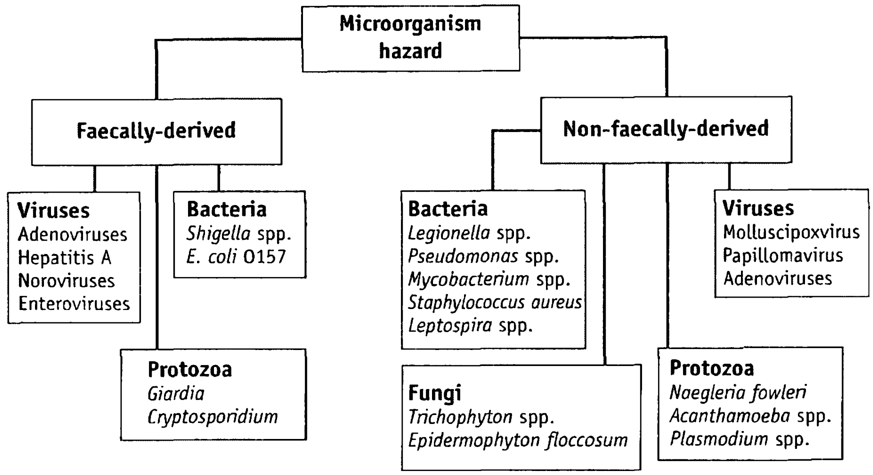

Fig. 8.6 Disease transmission hazards in recreational waters (Reproduced from http://www.who.int/water_sanitation_health/bathing/srwe2begin.pdf; Anonymous 2006c. With permission)

3. Some free-living aquatic bacteria and amoebae which can grow in pool, natural spa, or hot tub waters, in pool or hot tub components or facilities (including heating, ventilation, and air-conditioning (HVAC) or on other wet surfaces within the facility, develop to a point at which some of them may cause a variety of respiratory, dermal, or central nervous system infections or diseases.

8.2.1 Disease Transmission in Recreational Waters Through Fecal Material

8.2.1.1 Fecal Bacteria Which Have Caused Disease Outbreaks in Recreational Waters

Shigella species and *Escherichia coli* O157 are two related bacteria that have been linked to outbreaks of illness associated with swimming in pools or similar environments. *Shigella* has been responsible for outbreaks related to artificial ponds and other small bodies of water, where water movement has been very limited. The lack of water movement means that these water bodies behave very much as if they were swimming pools, except that chlorination or other forms of disinfection are not being used. Similar non-pool outbreaks have been described for *E. coli* O157, although there have also been two outbreaks reported where the source was a children's paddling pool. The contaminations which led to the outbreaks were due mostly to accidental fecal releases, and incidentally, the waters were not treated or had received inadequate chlorine treatment. The two organisms are controlled by chlorine and when accidental fecal release occurs and is detected, the water should be emptied and disinfected with chlorine.

8.2.1.2 Fecal Protozoa Which Have Caused Disease Outbreaks in Recreational Waters

Giardia and particularly *Cryptosporidium* spp. are fecally derived protozoa that have been linked to outbreaks of illness in swimming pools and similar environments. These two organisms are similar in a number of respects in that they have a cyst or oocyst form that is highly resistant to both environmental stress and disinfectants; they both have a low infective dose and they are both shed in high densities by infected individuals. There have been a number of outbreaks of disease attributed to these pathogens, but about five times as many outbreaks have occurred with *Cyptosporidium* than with *Giardia*. Most outbreaks have resulted from accidental fecal discharges. Outbreaks of the former have been recorded in the US, Canada, Australia, and UK and generally affect children, perhaps because they swallow swimming pool water more than adults. Chlorine is not very effective eliminating the two protozoa; ozone and UV light are better. However, these later two do not, like chlorine, have residual doses in water.

The most practical approach to eliminating cysts and oocysts is through the use of filtration. *Cryptosporidium* oocysts are removed by filtration where the porosity of the filter is less than 4 μm. *Giardia* cysts are somewhat larger and are removed by filters with a porosity of 7 μm or less, Removal and inactivation of cysts and oocysts occur only in the fraction of water passing through treatment and the rate of

Table 8.3 Non-fecally derived bacteria found in swimming pools and similar environments and their associated diseases (Reproduced from http://www.who.int/water_sanitation_health/bathing/srwe2begin.pdf; Anonymous 2006c. With permission)

Organism	Infection/disease	Source
Legionella spp.	Legionellosis (Pontiac fever and Legionnaires' disease)	Aerosols from natural spas, hot tubs and HVAC systems
		Poorly maintained showers or heated water systems
Pseudomonas aeruginosa	Folliculitis (hot tubs)	Bather shedding in pool and hot tub waters and on wet surfaces around pools and hot tubs
	Swimmer's ear (pools)	
Mycobacterium spp.	Swimming pool granuloma	Bather shedding on wet surfaces around pools and hot tubs
		Aerosols from hot tubs and HVAC systems
Staphylococcus aureus	Skin, wound and ear infections	Bather shedding in pool water
Leptospira spp.	Haemorrhagic jaundice	Pool water contaminated with urine from infected animals
	Aseptic meningitis	

HVAC heating, ventilation and air conditioning

reduction in concentration in the pool volume is slow. Most outbreaks of giardiasis and cryptosporidiosis among pool swimmers have been linked to pools contaminated by sewage, accidental fecal releases, or suspected accidental fecal releases. Pool maintenance and appropriate disinfection levels are easily overwhelmed by accidental fecal releases or sewage intrusion; therefore, the only possible response to this condition, once it has occurred, is to prevent use of the pool and physically remove the oocysts by draining or by applying a long periods of filtration, as inactivation in the water volume (i.e., disinfection) is impossible. However, the best intervention is to prevent accidental fecal releases from occurring in the first place, through education of pool users about appropriate hygienic behavior. Immunocompromised individuals should be aware that they are at increased risk of illness from exposure to pathogenic protozoa.

8.2.1.3 Fecal Viruses Which Have Caused Disease Outbreaks in Recreational Waters

Viruses cannot multiply in water, and therefore their presence must be a consequence of pollution. Viruses which have been linked to outbreaks of virus diseases derived from fecal viruses in swimming pool water are linked to Adenoviruses (3, 4 7, 7a), Hepatitis A Norovirus, and Echovirus 30. Some adenoviruses may also be shed from eyes and the throat and are responsible for swimming pool conjunctivitis. Viruses of six types (rotavirus, norovirus, adenovirus, astrovirus, enterovirus, and hepatitis A virus) are all shed following infection. Ordinarily, rotaviruses are by far the most prevalent cause of viral gastroenteritis in children, and noroviruses cause the most cases of viral diarrhea in adults. However, few waterborne pool outbreaks have been associated with these agents. Even when outbreaks are detected, the evidence linking the outbreak to the pool is generally circumstantial.

Sampling water for viruses is not done routinely and is only carried out if the swimming pool is suspected to be the source of an infection. The control of viruses in swimming pool water and similar environments is usually by the application of disinfectants. Episodes of gross contamination of a swimming pool due to an accidental fecal release or vomit from an infected person cannot be effectively controlled by normal disinfectant levels. The only approach to maintaining public health protection under conditions of an accidental fecal release or vomit is to prevent the use of the pool until the contaminants are inactivated, through draining and the application of a disinfectant. The education of parents/caregivers of small children and other water users about good hygienic behavior at swimming pools is another approach that may contribute to the health of pool users. People with gastroenteritis should be advised not to use public or semipublic pools and hot tubs while ill and for at least a week after their illness, in order to avoid transmitting the illness to other pool or hot tub users.

8.2.2 Disease Transmission in Recreational Water Through Non-fecal Material

8.2.2.1 Disease Transmission by Bacteria in Recreational Water Through Non-fecal Material

Infections and diseases associated with non-enteric pathogenic bacteria found in swimming pools and similar recreational water environments are summarized in Table 8.3. A number of these bacteria may be shed by bathers or may be present in biofilms. Biofilms may form on the lining of pipes, e.g., in contact with water and may serve to protect the bacteria from disinfectants.

1. *Legionella* spp.

   Legionella are Gram-negative, non-spore-forming, motile, aerobic bacilli, which may be free-living or living within amoebae and other protozoa or within biofilms. *Legionella* spp. are heterotrophic bacteria found in a wide range of water environments and can proliferate at temperatures above 25°C. They may be present in high numbers in natural spas using thermal spring water, and they can also grow in poorly maintained hot tubs, associated equipment, and HVAC systems. *Legionella* spp. can also multiply on filter materials, namely granular activated carbon. However, exposure to *Legionella* is preventable through the implementation of basic management measures, including filtration, maintaining a continuous disinfectant residual in hot tubs (where disinfectants are not used, there must be a high dilution rate with freshwater) and the maintenance and physical cleaning of all natural spa, hot tub, and pool equipment, including associated pipes and air-conditioning units.

   Legionella spp. cause legionellosis (or Legionnaires' disease), a range of pneumonic and non-pneumonic diseases are caused by *L. pneumophila*. Males are roughly three times more likely than females to contract Legionnaires' disease among people 50 or older; chronic lung disease, cigarette smoking, and excess consumption of alcohol are predisposing factors. Specific risk factors, in relation to pools and hot tubs, include frequency of hot tub use and length of time spent in or around hot tubs. Although the attack rate is often less than 1%, mortality among hospitalized cases ranges widely up to 50%. Risk of legionellosis from pools and similar environments is associated with proliferation of *Legionella* in spas or hot tubs, associated equipment, and HVAC systems. Inhalation of bacteria or aspiration following ingestion, during natural spa or hot tub use, may lead to disease; showers may sometimes present a greater risk of legionellosis than pool water. Most of the reported legionellosis associated with recreational water use has been associated with hot tubs and natural spas. Natural spa waters (especially thermal water) and associated equipment create an ideal habitat (warm, nutrient-containing aerobic water) for the selection and proliferation of *Legionella*. Hot tubs used for display in retail/wholesale outlets are also potential sources of infection. In order to control the growth of *Legionella* in hot tubs and natural spas, physical cleaning of surfaces is critical, and high residual disinfectant concentrations should be required. Features such as water sprays, etc., in pool facilities should be periodically cleaned and flushed with a level of disinfectant adequate to eliminate *Legionella* spp. (e.g., by use of a solution of at least 5 mg of hypochlorite per liter). Bathers should be encouraged to shower before entering the water. This will remove pollutants such as perspiration, cosmetics, and organic debris that can act as a source of nutrients for bacterial growth and neutralize oxidizing biocides. Bather density and duration spent in hot tubs should also be controlled. Public and semipublic spa facilities should have programmed rest periods during the day. High-risk individuals (such as those with chronic lung disease) should be cautioned about the risks of exposure to *Legionella* in or around pools and hot tubs.

   Legionella spp. are ubiquitous in the environment and can proliferate at the higher temperatures experienced at times in piped drinking-water distribution systems and more commonly in hot and warm water distribution systems. Exposure to *Legionella* from drinking-water is through inhalation and can be controlled through the implementation of basic water quality management measures in buildings and through the maintenance of disinfection residuals throughout the piped distribution system.

2. *Pseudomonas aeruginosa*

   Pseudomonas aeruginosa is an aerobic, non-spore-forming, motile, Gram-negative, straight or slightly curved rod with dimensions 0.5–1 μm × 1.5–4 μm. It can metabolize a variety of organic compounds and is resistant to a wide range of antibiotics and disinfectants. *P. aeruginosa* is ubiquitous in water, vegetation, and soil. Although shedding from infected humans is the predominant source of *P. aeruginosa* in pools and hot tubs, the surrounding environment can be a source of contamination. The warm, moist environment on decks, drains, benches, and floors provided by pools and similar environments is ideal for the growth of *Pseudomonas*, and it can grow well up to temperatures of 41°C. *Pseudomonas* tends to accumulate in biofilms in filters that are poorly maintained and in areas where pool hydraulics are poor (under moveable floors, for example). It is also likely that bathers pick up the organisms on their feet and hands and transfer them to the water. It has been proposed that the high water temperatures and turbulence in aerated hot tubs promote perspiration and desquamation (removal of skin cells).

These materials protect organisms from exposure to disinfectants and contribute to the organic load, which, in turn, reduces the residual disinfectant level; they also act as a source of nutrients for the growth of *P. aeruginosa*. In hot tubs, the primary health effect associated with the presence of *P. aeruginosa* is folliculitis. Otitis externa and infections of the urinary tract, respiratory tract, wounds, and cornea caused by *P. aeruginosa* have also been linked to hot tub use. Infection of hair follicles in the skin with *P. aeruginosa* produces a pustular rash, which may appear under surfaces covered with swimwear or may be more intense in these areas. The rash appears 48 h (range 8 h–5 days) after exposure and usually resolves spontaneously within 5 days. It has been suggested that warm water supersaturates the epidermis, dilates dermal pores, and facilitates their invasion by *P. aeruginosa*. There are some indications that extracellular enzymes produced by *P. aeruginosa* may damage skin and contribute to the bacteria's colonization. Other symptoms, such as headache, muscular aches, burning eyes, and fever, have been reported. Some of these secondary symptoms resemble humidifier fever and therefore could be caused by the inhalation of *P. aeruginosa* endotoxins.

In swimming pools, the primary health effect associated with *P. aeruginosa* is otitis externa or swimmer's ear, although folliculitis has also been reported. Otitis externa is characterized by inflammation, swelling, redness, and pain in the external auditory canal. Risk factors reported to increase the occurrence of otitis externa related to water exposure include amount of time spent in the water prior to the infection, people less than 19 years of age, and a history of previous ear infections. Repeated exposure to water is thought to remove the protective wax coating of the external ear canal, predisposing it to infection. An indoor swimming pool with a system of water sprays has been implicated as the source of two sequential outbreaks of granulomatous pneumonitis among lifeguards. Inadequate chlorination led to the colonization of the spray circuits and pumps with Gram-negative bacteria, predominantly *P. aeruginosa*. The bacteria and associated endotoxins were aerosolized and respired by the lifeguards when the sprays were activated. When the water spray circuits were replaced and supplied with an ozonation and chlorination system, there were no further occurrences of disease among personnel. An outbreak of pseudomonas hot-foot syndrome, erythematous plantar nodules, has been reported as a result of exposure to a community wading pool. The floor of the pool was coated in abrasive grit, and the water contained high concentrations of *P. aeruginosa.* Another outbreak occurred in Germany due to high concentrations of *P. aeruginosa* on the stairs to a water slide and resulted in some of the children being admitted to hospital.

Maintaining adequate residual disinfectant levels and routine cleaning are the key elements to controlling *P. aeruginosa* in swimming pools and similar recreational environments. Under normal operating conditions, disinfectants can quickly dissipate. Most hot tubs use either chlorine- or bromine-based disinfectants; chlorination was superior to bromine in controlling *P. aeruginosa*.

3. *Mycobacterium* spp.

   Mycobacterium spp. are rod-shaped bacteria that are 0.2–0.6 μm × 1.0–10 μm in size and have cell walls with a high lipid content. This feature means that they retain dyes in staining procedures that employ an acid wash; hence, they are often referred to as acid-fast bacteria. Atypical mycobacteria (i.e., other than strictly pathogenic species, such as *M. tuberculosis*) are ubiquitous in the aqueous environment and proliferate in and around swimming pools and similar environments. In pool environments, *M. marinum* is responsible for skin and soft tissue infections in normally healthy people. Infections frequently occur on abraded elbows and knees and result in localized lesions, often referred to as swimming pool granuloma. The organism is probably picked up from the pool edge by bathers as they climb in and out of the pool. Respiratory illnesses associated with hot tub use in normally healthy individuals have been linked to other atypical mycobacteria. For example, *M. avium* in hot tub water has been linked to hypersensitivity pneumonitis and possibly pneumonia. Symptoms were flu-like and included cough, fever, chills, malaise, and headaches. The illness followed the inhalation of heavily contaminated aerosols generated by the hot tub. The reported cases relate to domestic hot tubs, many of which were located outdoors. In most instances, the frequency of hot tub use was high, as was the duration of exposure (an extreme example being use for 1–2 h each day), and maintenance of disinfection and cleaning were not ideal. It is likely that detected cases are only a small fraction of the total number of cases. Amoebae may also play a role in the transmission of *Mycobacterium* spp. Mycobacteria are more resistant to disinfection than most bacteria due to the high lipid content of their cell wall. Therefore, thorough cleaning of surfaces and materials around pools and hot tubs where the organism may persist is necessary, supplemented by the maintenance of disinfection at appropriate levels. In addition, occasional shock dosing of chlorine may be required to eradicate mycobacteria accumulated in biofilms within pool or hot tub components. In natural spas where the use of disinfectants is undesirable or where it is difficult to maintain adequate disinfectant levels, superheating the water to 70°C on a daily basis during periods of nonuse may help to control *M. marinum*.

4. *Staphylococcus aureus*

The genus *Staphylococcus* comprises nonmotile, non-spore-forming and nonencapsulated Gram-positive cocci (0.5–1.5 µm in diameter) that ferment glucose and grow aerobically and anaerobically. They are usually catalase positive and occur singly and in pairs, tetrads, short chains and irregular grape-like clusters. In humans, there are three clinically important species – *Staphylococcus aureus*, *S. epidermidis* and *S. saprophyticus*. *S. aureus* is the only coagulase-positive species and is clinically the most important. Humans are the only known reservoir of *S. aureus*, and it is found on the anterior nasal mucosa and skin as well as in the feces of a substantial portion of healthy individuals. *S. aureus* is shed by bathers under all conditions of swimming, and the bacteria can be found in surface films in pool water. Coagulase-positive *Staphylococcus* strains of normal human flora have been found in and around swimming pools and similar environments.

The presence of *S. aureus* in swimming pools is believed to have resulted in skin rashes, wound infections, urinary tract infections, eye infections, otitis externa, impetigo, and other infections. Infections of *S. aureus* acquired from recreational waters may not become apparent until 48 h after contact. Recreational waters with a high density of bathers present a risk of staphylococcal infection that is comparable to the risk of gastrointestinal illness involved in bathing in water considered unsafe because of fecal pollution. Fifty percent or more of the total staphylococci isolated from swimming pool water samples are *S. aureus*. Adequate inactivation of potentially pathogenic *S. aureus* in swimming pools can be attained by maintaining free chlorine levels. There is evidence that showering before pool entry can reduce the shedding of staphylococci from the skin into the pool. Continuous circulation of surface water through the treatment process helps to control the build-up of *S. aureus*. Pool contamination can also be reduced if the floors surrounding the pool and in the changing areas are kept at a high standard of cleanliness. Although it is not recommended that water samples be routinely monitored for *S. aureus*, where samples are taken, levels should be less than 100/100 ml.

5. *Leptospira interrogans sensu lato*

Leptospires are motile spirochaete (helically coiled) bacteria. Traditionally, the genus *Leptospira* consists of two species, the pathogenic *L. interrogans* sensu lato and the saprophytic *L. bifl exa* sensu lato. Serological tests within each species revealed many antigenic variations, and, on this basis, leptospires are classified as serovars. In addition, a classification system based on DNA relatedness is used. The current species determination is based on this principle. The serological and genetic taxonomies are two different systems with only little correlation.

Free-living strains (*L. bifl exa* sensu lato) are ubiquitous in the environment, but the pathogenic strains (*L. interrogans* sensu lato), however, live in the kidneys of animal hosts.

Pathogenic leptospires live in the proximal renal tubules of the kidneys of carrier animals (including rats, cows, and pigs) and are excreted in the urine, which can then contaminate surface waters. Humans and animals (humans are always incidental hosts) become infected either directly through contact with infected urine or indirectly via contact with contaminated water. Leptospires gain entry to the body through cuts and abrasions of the skin and through the mucosal surfaces of the mouth, nose, and conjunctiva. Diseases caused by *Leptospira interrogans* sensu lato have been given a variety of names, including swineherd's disease, Stuttgart disease, and Weil's syndrome, but collectively all of these infections are termed leptospirosis.

Table 8.4 Non-fecally transmitted viruses found in water and their associated diseases (Reproduced from http://www.who.int/water_sanitation_health/bathing/srwe2begin.pdf; Anonymous 2006c. With permission)

Organism	Infection	Source
Adenoviruses	Pharyngo-conjunctivitis (swimming pool conjunctivitis)	Other infected bathers
Molluscipoxvirus	Molluscum contagiosum	Bather shedding on benches, pool or hot tub decks, swimming aids
Papillomavirus	Plantar wart	Bather shedding on pool and hot tub decks and floors in showers and changing rooms

The clinical manifestations of leptospirosis vary considerably in form and intensity, ranging from a mild flu-like illness to a severe and potentially fatal form of the disease, characterized by liver and kidney failure and hemorrhages (Weil's syndrome). Severity is related to the infecting serovar as well as host characteristics, such as age and underlying health and nutritional status. Specific serovars are often associated with certain hosts. Compared with many other pathogens, leptospires have a comparatively low resistance to adverse chemical and physical conditions, including disinfectants. They are seldom found in water of pH below 6.8, and they cannot tolerate drying or exposure to direct sunlight. The majority of reported outbreaks of waterborne leptospirosis have involved fresh recreational waters, and only two outbreaks have been associated with non-chlorinated swimming pools. Domestic or wild animals with access to the implicated waters were the probable sources of *Leptospira*.

The risk of leptospirosis can be reduced by preventing direct animal access to swimming pools and maintaining adequate disinfectant concentrations. Informing users about the hazards of swimming in water that is accessible to domestic and wild animals may also help to prevent infections. Outbreaks are not common; thus, it appears that the risk of leptospirosis associated with swimming pools and hot tubs is low. Normal disinfection of pools is sufficient to inactivate *Leptospira* spp.

8.2.2.2 Disease Transmission by Viruses in Recreational Water Through Non-fecal Material

Infections associated with non-fecally derived viruses found in swimming pools and similar environments: Adenoviruses, Molluscipoxvirus and Papillomavirus (see Table 8.4):

1. *Adenoviruses*
   The adenoviruses are same as had been discussed.
2. *Molluscipoxvirus*
   Molluscipoxvirus is a double-stranded DNA virus in the Poxviridae family. Virions are brick-shaped, about 320 nm × 250 nm × 200 nm. The virus causes molluscum contagiosum, an innocuous cutaneous disease limited to humans. It is spread by direct person-to-person contact or indirectly through physical contact with contaminated surfaces. The infection appears as small, round, firm papules or lesions, which grow to about 3–5 mm in diameter. The incubation period is 2–6 weeks or longer. Individual lesions persist for 2–4 months, and cases resolve spontaneously in 0.5–2 years. Swimming pool-related cases occur more frequently in children than in adults. The total number of annual cases is unknown. Since the infection is relatively innocuous, the reported number of cases is likely to be much less than the total number. Lesions are most often found on the arms, back of the legs and back, suggesting transmission through physical contact with the edge of the pool, benches around the pool, swimming aids carried into the pool or shared towels. Indirect transmission via water in swimming pools is not likely. Although cases associated with hot tubs have not been reported, they should not be ruled out as a route of exposure.

   The only source of molluscipoxvirus in swimming pool and similar facilities is infected bathers. Hence, the most important means of controlling the spread of the infection is to educate the public about the disease, the importance of limiting contact between infected and noninfected people and medical treatment. Thorough frequent cleaning of surfaces in facilities that are prone to contamination can reduce the spread of the disease.
3. *Papillomavirus*
   Papillomavirus is a double-stranded DNA virus in the family Papovaviridae. The virions are spherical and approximately 55 nm in diameter. The virus

causes benign cutaneous tumors in humans. An infection that occurs on the sole (or plantar surface) of the foot is referred to as a verruca plantaris or plantar wart. Papillomaviruses are extremely resistant to desiccation and thus can remain infectious for many years. The incubation period of the virus remains unknown, but it is estimated to be 1–20 weeks. The infection is extremely common among children and young adults between the ages of 12 and 16 who frequent public pools and hot tubs. It is less common among adults, suggesting that they acquire immunity to the infection. At facilities such as public swimming pools, plantar warts are usually acquired via direct physical contact with shower and changing room floors contaminated with infected skin fragments. Papillomavirus is not transmitted via pool or hot tub waters.

The primary source of papillomavirus in swimming pool facilities is infected bathers. Hence, the most important means of controlling the spread of the virus is to educate the public about the disease, the importance of limiting contact between infected and noninfected people, and medical treatment. The use of pre-swim showering, wearing of sandals in showers and changing rooms, and regular cleaning of surfaces in swimming pool facilities that are prone to contamination can reduce the spread of the virus.

8.2.2.3 Disease Transmission by Protozoa in Recreational Water Through Non-fecal Material

The non-fecally derived protozoa found in or associated with swimming pools and similar environments and their associated infections are *Naegleria fowleri*, *Acanthamoeba* spp., and *Plasmodium* spp.

1. *Naegleria fowleri*
   Naegleria fowleri is a free-living amoeba (i.e., it does not require the infection of a host organism to complete its life cycle) present in freshwater and soil. The life cycle includes an environmentally resistant encysted form. Cysts are spherical, 8–12 µm in diameter, with smooth, single-layered walls containing one or two mucus-plugged pores through which the trophozoites (infectious stages) emerge. *N. fowleri* is thermophilic, preferring warm water and reproducing successfully at temperatures up to 46°C.

   N. fowleri causes primary amoebic meningoencephalitis (PAM). Infection is usually acquired by exposure to water in ponds, natural spas, and artificial lakes. Victims are usually healthy children and young adults who have had contact with water about 7–10 days before the onset of symptoms. Infection occurs when water containing the organisms is forcefully inhaled or splashed onto the olfactory epithelium, usually from diving, jumping, or underwater swimming. The amoebae in the water then make their way into the brain and central nervous system. Symptoms of the infection include severe headache, high fever, stiff neck, nausea, vomiting, seizures, and hallucinations. The infection is not contagious. For those infected, death occurs usually 3–10 days after onset of symptoms. Respiratory symptoms occur in some patients and may be the result of hypersensitivity or allergic reactions or may represent a subclinical infection. Although PAM is an extremely rare disease, cases have been associated with pools and natural spas.
2. *Acanthamoeba* spp.
   Several species of free-living *Acanthamoeba* are human pathogens (*A. castellanii*, *A.culbertsoni*, *A. polyphaga*). They can be found in all aquatic environments, including disinfected swimming pools. Under adverse conditions, they form a dormant encysted stage, measuring 15–28 µm, depending on the species. *Acanthamoeba* cysts are highly resistant to extremes of temperature, disinfection, and desiccation. The cysts will retain viability from −20°C to 56°C. When favorable conditions occur, such as a ready supply of bacteria and a suitable temperature, the cysts hatch (excyst) and the trophozoites emerge to feed and replicate. All pathogenic species will grow at 36–37°C, with an optimum of about 30°C. Although *Acanthamoeba* is common in most environments, human contact with the organism rarely leads to infection. Human pathogenic species of *Acanthamoeba* cause two clinically distinct diseases: Granulomatous Amoebic Encephalitis (GAE) and inflammation of the cornea (keratitis). GAE is a chronic disease of the immunosuppressed; GAE is either sub-acute or chronic but is invariably fatal. Symptoms include fever, headaches, seizures, meningitis, and visual abnormalities. GAE is extremely rare, with only 60 cases reported worldwide. The route of infection in GAE is unclear; although invasion of the brain may result from the blood following a primary infection elsewhere in the body, possibly the skin or lungs (Martinez 1991). The precise source of such infections is unknown because of the almost ubiquitous presence of *Acanthamoeba* in the environment.

Acanthamoeba keratitis affects previously healthy people and is a severe and potentially blinding infection of the cornea. In the untreated state, *Acanthamoeba* keratitis can lead to permanent blindness. Although only one eye is usually affected, cases of bilateral infection have been reported. The disease is characterized by intense pain and ring-shaped infiltrates in the corneal stroma. Contact lens wearers are most at risk from the infection and account for approximately 90% of reported cases. Poor contact lens hygiene practices (notably ignoring recommended cleaning and disinfection procedures and rinsing or storing of lenses in tap water or non-sterile saline solutions) are recognized risk factors, although the wearing of contact lenses while swimming or participating in other water sports may also be a risk factor. In noncontact lens related keratitis, infection arises from trauma to the eye and contamination with environmental matter such as soil and water

Although *Acanthamoeba* cysts are resistant to chlorine- and bromine-based disinfectants, they can be removed by filtration. Thus, it is unlikely that properly operated swimming pools and similar environments would contain sufficient numbers of cysts to cause infection in normally healthy individuals. Immunosuppressed individuals who use swimming pools, natural spas or hot tubs should be aware of the increased risk of GAE. A number of precautionary measures are available to contact lens wearers, including removal before entering the water, wearing goggles, post-swim contact lens wash using appropriate lens fluid and use of daily disposable lenses.

3. *Plasmodium* spp.
   Swimming pools are associated not with *Plasmodium* spp., but with anopheline mosquito larvae, the insect vectors of *Plasmodium*. Many swimming pools in malaria-prong region harbor the larvae. The problem relates to the seasonal use of the pools. Before people leave their summer houses, it is common to drain the pool; however, rainwater accumulated during the rainy season provides a suitable habitat for mosquito breeding, with the attendant risks of malaria as a result. This especially occurs in out of use pools. Such pools should be grained or sprayed worth kerosene or other oils which stop the larvae getting oxygen.

   During the rains, when the pools fill with water, they should be drained every 5–7 days to avoid mosquito larvae developing into adults. The swimming pools may also be treated with appropriate larvicides when not in use for long periods.

8.2.2.4 Disease Transmission by Fungi in Recreational Water Through Non-fecal Material: *Trichophyton* spp. *and Epidermophyton floccosum*

Epidermophyton floccosum and various species of fungi in the genus *Trichophyton* cause superficial fungal infections of the hair, fingernails, or skin. Infection of the skin of the foot (usually between the toes) is described as tinea pedis or, more commonly, as "athlete's foot" Symptoms include maceration, cracking and scaling of the skin, with intense itching. Tinea pedis may be transmitted by direct person-to-person contact; in swimming pools, however, it may be transmitted by physical contact with surfaces, such as floors in public showers, changing rooms, etc., contaminated with infected skin fragments. The fungus colonizes the stratum corneum when environmental conditions, particularly humidity, are optimal. From in vitro experiments, it has been calculated that it takes approximately 3–4 h for the fungus to initiate infection. The infection is common among lifeguards and competitive swimmers, but relatively benign; thus, the true number of cases is unknown.

The sole source of these fungi in swimming pool and similar facilities is infected bathers. Hence, the most important means of controlling the spread of the fungus is to educate the public about the disease, the importance of limiting contact between infected and noninfected bathers, and medical treatment. The use of pre-swim showers, wearing of sandals in showers and changing rooms, and frequent cleaning of surfaces in swimming pool facilities that are prone to contamination can reduce the spread of the fungi. People with severe athlete's foot or similar dermal infections should not frequent public swimming pools, natural spas or hot tubs. Routine disinfection appears to control the spread of these fungi in swimming pools and similar environments.

8.3 Disease Transmission Through Shellfish Growing in Fecally Contaminated Water

8.3.1 Description of Shellfish

Shellfish is a culinary term for aquatic invertebrates used as food: Molluscs, crustaceans, and echinoderms. Shellfish come from both saltwater and freshwater.

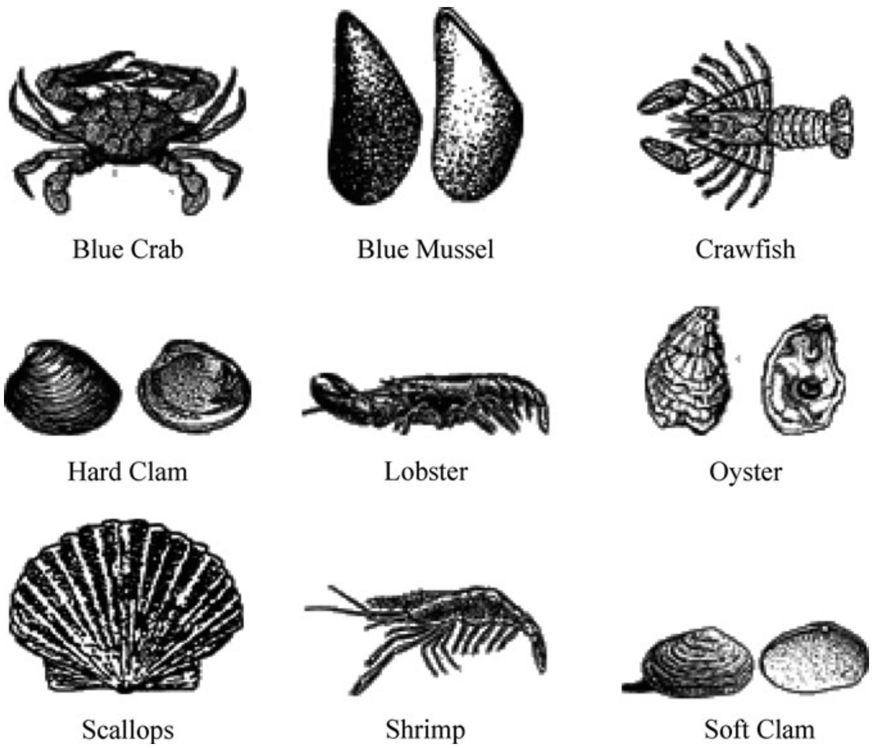

Fig. 8.7 Illustrations of different shellfish (Illustrations courtesy of Delaware Sea Grant College Program; http://deseagrant.org/outreach/seafood; www.decoastday.org; Anonymous 2009. With their permission)

The term finfish is sometimes used to distinguish them from ordinary fish which are vertebrates. Molluscs commonly used as food include the clam, mussel, oyster, eye winkles, and scallop. Some crustaceans commonly eaten are shrimps, prawn, lobster, crayfish, and crab. Echinoderms are not eaten as commonly as mollusks and crustaceans. In Asia, sea cucumber and sea urchins are eaten. Edible cephalopods, such as squid, octopus, and cuttlefish and terrestrial snails, though all molluscs, are sometimes classified as shellfish (Fig. 8.7).

8.3.2 Monitoring the Aquatic Environment of Shellfish Growth

Shellfish thrive best in coastal areas of the sea including estuaries. These locations are close to human habitations and are thus influenced by urbanization. There is great trend toward coastal habitation in the US and around the world and this trend impacts on the quality of water in which shellfish grow. Thus, in the United States, coastal counties cover only 17% of the total land area yet are home to more than 53% of the nation's population. Estimated at 139 million people in 1994, the nation's coastal population is projected to reach 165 million people and an average density of 327 people per square mile by 2015. Globally, approximately 37% of the world's population lives within 100 km of the coastline and 50% within 200 km. This means the favorite sites for the growth of shellfish is subject to pollution, including microbial contamination, by human activities.

Microorganisms are discharged to shellfish growing areas from a variety of pollution sources along three main pathways: (1) Direct discharges from sewage outfalls, boaters, marine mammals, and other sources; (2) Subsurface flows from such sources as shoreline on-site sewage systems; and (3) Overland flows in the form of storm water runoff, stream flows, and other surface runoff. These sources and pathways are determined by a variety of human activities and land uses that tend to exert a progressively greater influence on the landscape and environmental conditions as development intensifies over time.

Oysters, clams, mussels, and scallops are filter feeders that pump large quantities of water through their bodies when actively feeding. During this process, molluscan shellfish can concentrate microorganisms, toxigenic micro-algae, and poisonous or deleterious substances from the water column when they are present in the growing waters. Concentrations in the shellfish may be as much as 100 times that found in the water column. If human pathogens are concentrated to an infective dose, and if the shellfish are consumed raw or partially cooked, human disease can result. If toxigenic micro-algae are present and producing toxin, human illness or death can occur, and cooking is not reliable as an effective barrier against intoxication.

Therefore, bodies of water where commercial shellfish are grown are monitored by the States bordering the sea where the shellfish industry contributes in an important way to the states' economy. Such States include Florida, Washington, and North Carolina to name a few.

Following the oyster-borne typhoid outbreaks during the winter of 1924–1925 in the United States, which threatened the collapse of the oyster industry, the National Shellfish Certification Program, now the National Shellfish Sanitation Program (NSSP), was initiated by the states, the Public Health Service, and the shellfish industry. The NSSP is today administered by the U.S. Food and Drug Administration. It has established guidelines for water quality in shellfish growing areas to decrease the risk of illness associated with these the consumption of shellfish; it has also put in place, sanitary controls over all phases of the growing, harvesting, shucking, packing, and distribution of fresh and fresh-frozen shellfish.

Other countries also monitor shellfish growing areas. Thus Canada, the European Union, and Japan all have agencies which regulate and control provide guidelines for the microbial content of water where shellfish is harvested.

8.3.2.1 Procedure for Monitoring Shellfish Growing Areas in the US

Monitoring the procedure by which the NSSP controls sites for the growing of shellfish is the *sanitary survey*. The principal components of a sanitary survey are:

1. *Identification and evaluation of the pollution sources that may affect the areas*. A pollution source survey (also known as a shoreline survey) must be conducted of the growing area shoreline and watershed to locate direct sewage discharges (e.g., municipal and private sewage and industrial waste discharges, sewage package treatment units, malfunctioning septic tanks, and animal manure treatment lagoons) etc.
2. *An evaluation of the meteorological factors*, since *climate and weather can affect the distribution of pollutants or can be the cause of pollutant delivery to a growing area*. Rainfall patterns and intensity can affect water quality through pollutant delivery in runoff or cause flooding which can affect the volume and duration of pollutant delivery.
3. *An evaluation of hydrographic factors that may affect distribution of pollutants throughout the area*. Examples of hydrographic factors are tidal amplitude and type (most shellfish are grown in estuaries), water circulation patterns, and the amount of freshwater. These factors, along with water depths and stratification caused by density (salinity and temperature) differences, and wastewater and other waste flow rates are used to determine dilution, and time of transport.
4. *An assessment of water quality; the assessment of water quality is based on the total coliform status of the water*. The National Shellfish Sanitation Program (NSSP) allows growing areas to be classified using either a total or fecal coliform standard. The guidelines set up by the NSSP require that the total coliform geometric mean MPN of the water sample results for each sampling station shall not exceed 70 MPN per 100 ml; and not more than 10% of the samples shall exceed an MPN of:
   (a) 230 MPN per 100 ml for a 5-tube, decimal dilution test
   (b) 330 MPN per 100 ml for a 3-tube, decimal dilution test
   (c) 140 MPN per 100 ml for the 12-tube, single dilution test

The goal of the NSSP is to control the safety of shellfish for human consumption by preventing harvest from contaminated growing waters. In implementing this concept, the NSSP uses five classifications for growing areas: Approved, conditionally approved, restricted, conditionally restricted, and prohibited.

All shellfish growing areas are surveyed every 3 years to document all existing or potential pollution sources, to assess the bacteriological quality of the water, and to determine the hydrographic and meteorological factors that could affect water quality. Water samples are collected at least six times a year from each growing area and tested for fecal coliform bacteria, which are an indicator that human or animal wastes are present in the water. In addition, reviews of bacteriological data and pollution sources are conducted annually.

Classification of Shellfish Growing Areas

The information gathered from the sanitary survey, including the probable presence or absence of pathogenic microorganisms, marine biotoxin or other poisonous or deleterious substances in growing area waters is used to classify each shellfish growing area as either approved, conditionally approved, restricted, or prohibited.

The major industrialized countries and regions of the world categorize the sites from where shellfish is grown to protect the health of consumers. This is based, in general, on the hygienic (i.e., the number of *E. coli* found in the monitoring of the areas. Thus, the codified Shellfish Waters Directive of the European Union (2006/113/EC), adopted on 12 December 2006 specifies standards based on traditional bacteria. The guidelines of the National Shellfish Sanitation Program (NSSP), a unit of the United States Food and Drug Administration, and the Fisheries Agency of the Japanese Ministry of Agriculture, Forestry and Fisheries, responsible for preserving and managing marine biological resources and fishery production, all use the traditional indicators i.e., *E. coli* and fecal coliforms.

Directive 91/492/EEC specifies standards based on traditional bacterial indicators i.e., *E. coli* and fecal coliforms; however, it is now widely recognized that these sanitary controls, whilst they play an important role in protecting public health, do not guarantee protection against viral infection. In Europe and elsewhere, viruses are responsible for the majority of outbreaks associated with shellfish, and many outbreaks have occurred when shellfish have been fully compliant with the Directive. The most common viruses that cause illness are Norwalk-like viruses, which cause diarrhea and vomiting. Hepatitis A virus occurs in a very small number of cases. Within the UK, these problems were highlighted in 1998 by the Advisory Committee on the Microbiological Safety of Foods report on Foodborne Viral Infection (Table 8.5).

In many cases, the risk of illness or infection has been linked to fecal contamination of the water. The fecal contamination may be due to feces released by bathers or a contaminated source water or, in outdoor pools, may be the result of direct animal contamination (e.g., from birds and rodents). Fecal matter is introduced into the water when a person has an accidental fecal release – AFR (through the release of formed stool or diarrhea into the water) or residual fecal material on swimmers' bodies is washed into the pool. Many of the outbreaks related to swimming pools would have been prevented or reduced if the pool had been well managed. Non-fecal human shedding (e.g., from vomit, mucus, saliva, or skin) in the swimming pool or similar recreational water environments is a potential source of pathogenic organisms. Infected users can directly contaminate pool or hot tub waters and the surfaces of objects or materials at a facility with pathogens (notably viruses or fungi), which may lead to skin infections in other patrons who come in contact with the contaminated water or surfaces. "Opportunistic pathogens" (notably bacteria) can also be shed from users and transmitted via surfaces and contaminated water (Anonymous 2007).

Some bacteria, most notably non-fecally derived bacteria may accumulate in biofilms and present an infection hazard. In addition, certain free living aquatic bacteria and amoebae can grow in pool, natural spa or hot tub waters, in pool or hot tub components or facilities (including heating, ventilation, and air-conditioning [HVAC] systems) or on other wet surfaces within the facility to a point at which some of them may cause a variety of respiratory, dermal, or central nervous system infections or diseases. Outdoor pools may also be subject to microorganisms derived directly from pets and wildlife.

8.4 Recent Developments Regarding Knowledge of Pathogens in Drinking Water

Today, in most industrialized countries, while outbreaks of waterborne infections from the classical pathogens like *Vibrio cholerae* and *Salmonella typhi* do not occur (except for sporadic, imported cases), *S. typhi*, *V. cholerae* O1, and *Shigella* spp. are rarely found in drinking water distribution systems, and their appearance points to a major failure of the systems (insufficient treatment or secondary fecal contamination of the distribution systems). "New" or "emerging" pathogens seem to have occurred, including bacteria, viruses, and parasites.

In recent years, several so-called "new or emerging pathogens" have arisen as problems in drinking water production and distribution from two sources. Firstly, newly recognized pathogens from fecal sources have occurred like *Campylobacter jejuni*, pathogenic

Table 8.5 Composite table showing classification criteria of shellfish harvest sites by the US Food and Drugs Administration and the EU Parliament and Council (Modified from Anonymous 2006d, 2008)

Classification by the National Shellfish Sanitation Program (NSSP), of the Food and Drugs Administration (FDA) (Anonymous 2008)			Classification by the Directive 2006/113/EC of the European Parliament and of the Council (Anonymous 2006d)		
Grade	Description	Method: Water sampled (per ml of water)	Grade	Description	Method: Shellfish sampled (cfu /100 g shellfish)
A	Sanitation survey finds growing areas safe found for the direct marketing of shellfish or is not subject to human or animal fecal pollution.	Fecal coliform MPN <14/100 ml	A	No restriction. Shellfish acceptable for immediate consumption	<230 *E. coli* or <300 Fecal *No Salmonella* in 25 g
CA	Sanitation survey finds growing areas are in the open status for a reasonable period of time and when pollution factors are predictable. There may be direct potential for distribution of pollutants based on unusual conditions or specific times of the year when bacterial numbers are increased by heavy water runoff that affects wastewater treatment plant function		B	Shellfish must be depurated or relayed until they meet category A standard	<4,600 *E. coli* or <6,000 Fecal coliforms in 90% of samples
R	Sanitation survey finds growing areas have suffered a limited degree of pollution and the levels of fecal pollution, human pathogens, or poisonous or deleterious pollutants are at such levels that shell stock can be made safe through either relaying or depuration.		C	Shellfish must be relayed over a long period (>2 months) until they meet category A standard	<60,000 Fecal coliforms
P	Sanitation survey finds no current sanitary survey exits for the growing area or when the survey determines that the growing area is adjacent to a sewage treatment plant outfall or other point source with public health significance or when the water is polluted because of previous or current sources of contamination.	Fecal coliform MPN <88/100 ml			

The approaches of the US FDA and the EU are different: the FDA samples water in the shellfish growing area and the EU samples actual shell fish. Both methods have their advantages and disadvantages
US FDA: *A* acceptable, *CA* conditionally acceptable, *R* restricted, *P* prohibited

Escherichia coli, *Yersinia enterocolitica*, new enteric viruses like rotavirus, calicivirus, small round-structured virus, astrovirus, and the parasites *Giardia lamblia*, *Cryptosporidium parvum*, and microsporidia. Secondly, some new pathogens comprise species of environmental bacteria that are able to grow in water distribution systems and only recently were recognized as relevant pathogens, such as *Legionella* spp., *Aeromonas* spp., *Mycobacterium* spp., and *Pseudomonas aeruginosa*.

There are a number of reasons for the emergence of these new pathogens. Many of these pathogens are not actually new and may have been causing disease for a long time, but they were not identified owing to a lack of detection methods. This is especially true for the viruses and parasites, but also for *Legionella* spp. Other new pathogens have been known to cause infections, but they were not associated with drinking water or were known only as animal pathogens. For example, *Campylobacter jejuni* had been known only as a rare opportunistic pathogen causing bloodstream infections, until it was recognized as a cause of diarrhea, in the 1970s, and even later as a possible infectious agent in drinkingwater. *Cryptosporidium* sp. was first described in 1907 and first recognized as an animal pathogen in 1955, but not until about 20 years later was it recognized as a human pathogen. The emergence of new pathogens has also been promoted by a change in habits of water usage. The increasing use of heated drinking water with warm water reservoirs in houses has the disadvantage that these systems are an ideal habitat for *Legionella* spp. leading to an increased number of infections. Furthermore, *P. aeruginosa* and environmental mycobacteria are able to use the in-house installations and reservoirs as new habitats, posing new risks to susceptible water consumers. Another important factor for the emergence of new pathogens is the increasing number of people who are susceptible to infections with specific potential pathogens, including on one hand immunocompromised persons, such as AIDS patients and patients receiving cancer chemotherapy or undergoing organ transplantation, and on the other hand, elderly persons whose immune systems are not as active as in healthy young adults. These persons are subject to infections that do not occur in healthy adults or, if they do occur, are much less severe. Like young children, the elderly have, for instance, a higher risk of death from diarrhea. Several of the new pathogens were recognized because they caused severe infections in these subpopulations. Infections with environmental mycobacteria, e.g., are almost exclusively found in immunocompromised persons (e.g., *Mycobacterium avium* infections in AIDS patients).

Severe infections with *P. aeruginosa* are described for immunocompromised patients or persons with underlying diseases like diabetes or cystic fibrosis. Similarly, elderly and immunocompromised patients are at the highest risk of infection by *Legionella* spp., with smoking as an additional risk factor. Although infections with *C. parvum* do occur in healthy adults, the outcome in elderly or immunocompromised patients is much more severe and may be fatal. Very few of these new pathogens are really of recent origin. Besides emerging antibiotic-resistant strains, this is true for bacteria that have acquired new virulence factors. The most prominent example is pathogenic *E. coli* strains that are supposed to have taken up virulence genes by horizontal gene transfer, resulting in very potent new pathogens, the enterohemorrhagic *E. coli* (EHEC). In addition to new pathogens transmitted via drinking water, the production of toxins by cyanobacteria growing in water resources is an increasing problem in drinking-water supplies from surface water.

Among the new or emerging pathogens which are fecally related are: *Enteric viruses* including hepatitis A, rotaviruses, small round structured viruses, Norwalk virus, and caliciviruses, the protozoa, *Cryptosporidium parvum and Giardia lamblia*. Among the bacteria are *Campylobacter fetus*, *C. jejuni* and *C. col Enterohemorrhagic Escherichia coli* EHEC, *Yersinia enterocolitica*, *Helicobacter pylori*. *Microsporidia*, are very small (0.5–1.2 m), obligate intracellular parasites of vertebrates and invertebrates.

Of the new pathogens growing in the distribution system, several have a natural reservoir in the environment including water or soil, and are introduced from the surface water into the drinking-water system usually in low numbers. They are able to multiply in the water or in the adjoining biofilms, and hence their numbers increase in the distribution system. Such bacteria include *Legionella pneumophila*, *Pseudomonas aeruginosa*, environmental mycobacteria including *M. gordonae*, *M.avium*, *M. intracellulare*, *M. kansasii*, *M. chelonae*, and *M. fortuitum*. *Aeromonas* spp. (*A. hydrophila*, *A. caviae*, and *A. sobria*).

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