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4.06 Safe Sanitation in Low Economic Development Areas

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4.06.1 Introduction

Before reading this chapter, it should be considered whether it is justifiable to have a specific section dealing with sanitation for low economic development areas (developing countries). Evidently, the editors of this book think so. The reasons include

- an increasing evidence that wastewater quality in high and low economic areas is different regarding some parameters that determine treatment options and
- differences in economic conditions necessitate alternative solutions not only at the technical level but also in terms of the ways to implement them.

To protect health, raise the quality of life, and increase the economic level, a good sanitation service is required in developing countries. While in developed countries, sanitation coverage is almost 99% as a result of a clear commitment of governments to provide it as part of the public services, in developing ones it is only around 50% (WHO–UNICEF, 2006). In addition, in the developed countries, the term sanitation applies not only to the installation of sewers but also to the full implementation of systems for the safe disposal and reuse of treated wastewater, sludge, and septage. In contrast, in developing countries, the term sanitation mostly

applies to the use of sewers not always ending in treatment plants. In fact, reported sanitation figures frequently do not reveal the disposal of wastewater or excreta uncontrolled into the environment, the existence of malfunctioning wastewater treatment plants, or the use of rudimentary and inefficient basic sanitation facilities sometimes contributing to increased environmental pollution rather than to control it. As a result, waterborne diseases affect millions of people in the developing world, and the water quality of surface and groundwater bodies is increasingly deteriorating.

The aim of this chapter is to assist the process of increasing sanitation in low-income regions by contrasting the differences in needs and solutions' options with high-income regions. Most technical publications have traditionally grouped developing countries together as low-income societies without considering that in them there are high- and low-income areas and that among the latter ones there are several factors that create differences that need to be taken into consideration to provide suitable solutions, that rarely fall under the logic used in developed countries to provide sanitation. Most people lacking sanitation include the millions of poor people (Figure 1) living under precarious institutional conditions and under an economical and social situation that avoids the use of conventional solutions. This renders the provision of sanitation in low-income areas a major challenge.

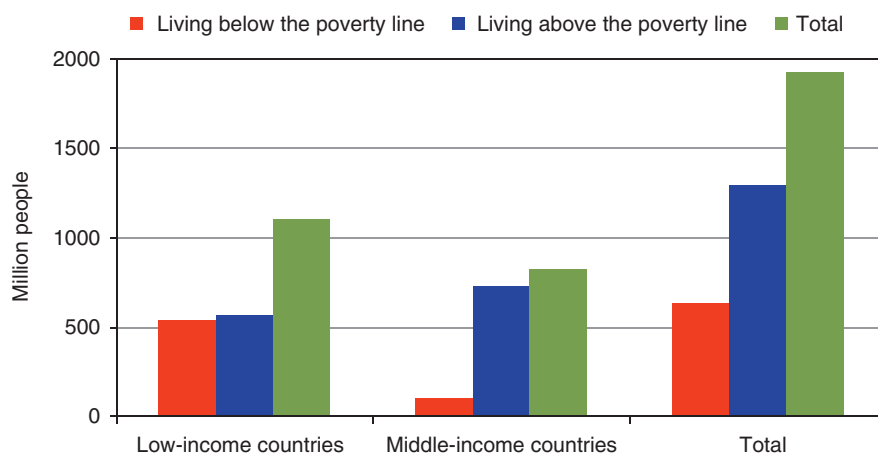


Figure 1 Poverty distribution of the global population without access to basic sanitation in low- and middle-income countries (with information from Lenghton *et al.* (2005)).

4.06.2 Historical Background

The history of sanitation is mainly about three aspects: toilets, sewers, and final disposal. As sanitation is a broken subject in developing countries, the story of these three is also the same. When mankind was nomadic and lived in very small communities, sanitation was not an issue. Nature could absorb human wastes. Later, when villages grew, there was the need to set up special practices and facilities. In ancient Egypt (~3000 BC), each household had the responsibility to dispose of their garbage and excreta at the communal dump, in irrigation canals, or in open fields. Irrigation canals were the first drainage and waste disposal systems. At that time, toilets were a luxury that only the wealthier people could afford in cities. Toilets were carved of limestone, and the used water was disposed of into pits in the streets (MSU, 2009). Flushing toilets – some of them communal – existed in India since the twenty-sixth century BC. Reports on the use of toilets and other safe sanitation practices in ancient civilizations from Asia, Latin America, and Africa were common in places where nowadays lack of sanitation is a problem.

The earliest covered sewers reported are from the Indus Civilization (2600–1900 BC) where Pakistan is located today. Cities used sewers to control inundations caused by pluvial water. The *Cloaca Maxima* or Roman sewer dates from around 600 BC. Initially, it was an open drain that was covered and left below the urban level, as the city building space became costly (Wikipedia, 2009). Later, when water began to be supplied in large quantities to households, getting rid of the used water became a problem and water was considered as a waste. It was then when sewers were found to be a useful infrastructure to convey wastewater out of the city in addition to stormwater.

Concerning disposal, land application of wastewater and excreta has a long tradition in many countries. For centuries, farmers in China used human and animal excreta as fertilizers. The oldest references to the use of excreta in aquaculture come from some Asian countries, where it was employed to increase fish production (WHO, 2006). Further, even now in China, Mexico, Peru, Egypt, Lebanon, Morocco, India, and Vietnam

wastewater is used as a source of crop nutrients (Jiménez and Asano, 2008).

According to Rusong (2001), in contrast to the ‘mechanical’ ideas predominant in industrial societies, human ecological thoughts in ancient China emphasized the use of systems advocating ‘man and nature as one’. This principle is considered as equivalent to the sustainability principle and is based on terms describing concepts that are dissociated in modern civilizations, such as

- *Tian* – heaven or nature;
- *Di* – Earth or resources;
- *Ren* – people or society;
- *Wuxing* – the five fundamental elements and movements within any ecosystem, that need to be in equilibrium by promoting and restraining each other; and
- *Zhong Yong* – describing that things should never go to their extremes but should be kept at equilibrium.

For several centuries, based on these ecological principles, China has developed and supported 21% of the world’s population with only 7% of the world’s arable land and less than 7% of the world freshwater resources (Rusong, 2001). Once again, similar conceptions can be found in ancient civilizations from Asia, Africa, and Latin America, in the same places where there are environmental crises now.

4.06.3 Sanitation as Part of The Hydrological Cycle or Properly Closing the Water Loop

The urban water cycle is a relatively new concept used to analyze water quality problems in cities (Jiménez, 2009b), which is depicted in Figure 2. It is useful in identifying conventional and nonconventional sources of pollution, in particular those that are specific to developing countries. It is important to understand the difference in order to be able to apply proper solutions to sanitation that go beyond the simplistic approach of merely installing wastewater treatment plants. A similar analysis could be made for rural areas.

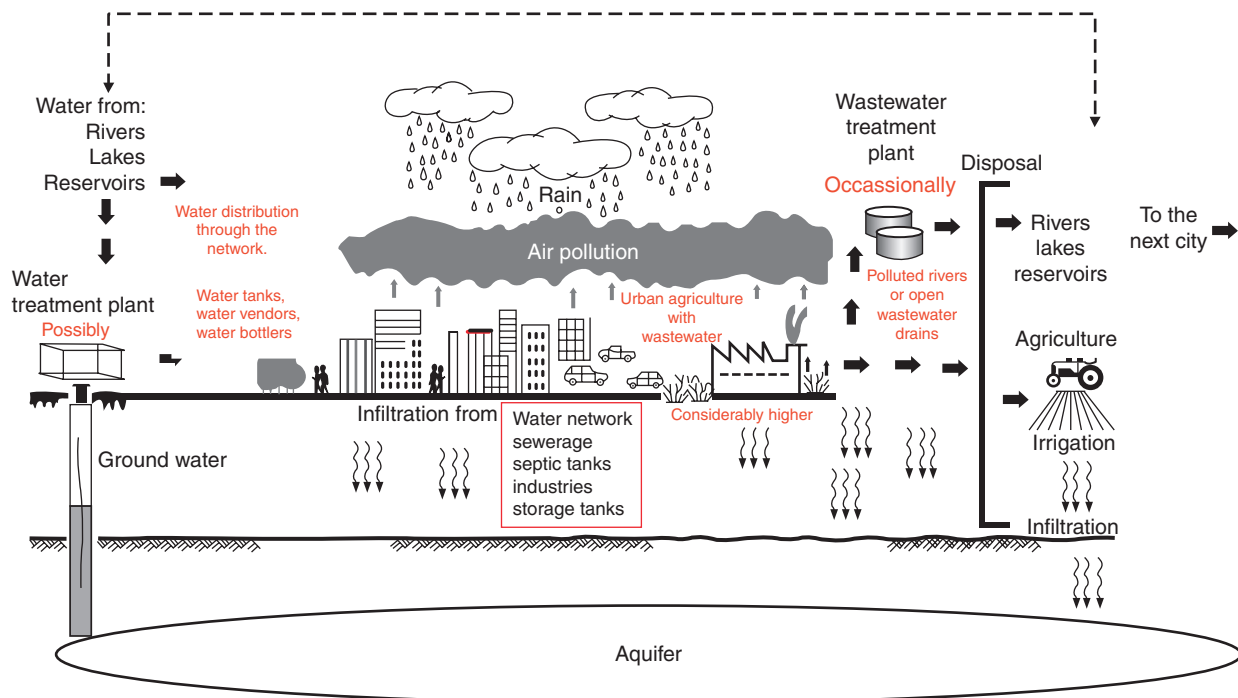


Figure 2 Hydrological urban cycle. Differences compared to developed countries are shown in red. Adapted from Jiménez B (2003) Health risks in aquifer recharge with recycle water. In: Aertgeerts R and Angelakis A (eds.) *State of the Art Report Health Risk in Aquifer Recharge Using Reclaimed Water*, pp. 54–172. Rome: WHO Regional Office for Europe.

The urban water cycle is important because of the large increase in urban population that is being experienced worldwide. By 2030, the urban proportion of the global population is expected to be around 60%. Over the next 50 years, in developing countries, most of the population growth will occur in urban and periurban areas. Furthermore, most of the 19 cities with the most rapid growth are located in chronically water-short regions in the developing world (UN-Habitat, 2006). Providing water sources to urban areas from the developing world is a challenge because nearly one-third of the population (31.2% compared to a 6% in developed countries in 2001) are poor people living in slum areas. The slum growth rate is of 2.37%, a value significantly higher than the average world urban growth rate of 1.78%.

4.06.3.1 Sources of Pollution

Traditionally, pollution sources are classified as point and nonpoint sources. Municipal and industrial wastewater discharges are considered to be point sources, while agriculture (considered as the surface return flow from irrigation), storm runoff, and a wide variety of others are considered as nonpoint sources (Jiménez, 2009a).

4.06.3.1.1 Municipal discharges

Municipal discharges are those produced by cities and small towns. They are considered to be point sources of pollution where they are produced and collected in sewers and thus disposed of as a well-identified source. When not treated, the main environmental concerns relate to conventional

pollutants, such as biological, biodegradable, and non-biodegradable organic matter, and heavy metals, in that order of importance. The content of almost all these of pollutants is similar around the world, tending to be more concentrated in arid and semiarid areas because of lack of water. In some cases, higher concentrations of pollutants result from increased industrialization of cities. Unfortunately, even when treated, municipal discharges introduce used water containing used compounds, some of which are pollutants, to water bodies. Municipal wastewater is never treated to recover its original quality (the one it had at the water source) as the self-cleansing and dilution capability of nature is used to complete the task. This is confirmed by the increasing amount of trace pollutants, such as endocrine disruptors, found in water sources. The presence of these compounds might be considered as an indicator that we have surpassed the natural depollution capability of the environment. Despite this, the idea of using water bodies or soil to depollute wastewater is still very common, and it could be reduced in water bodies as the depollution capability is lost as result of the water temperature increase due to climate change. In developing countries, the environment is frequently used to depollute wastewater, included when not treated at all, explaining the low quality of water bodies and the widespread presence of diarrheic diseases.

4.06.3.1.2 Industrial discharges

Industrial wastewater has very variable quality and volume depending on the type of industry producing it. It may be highly biodegradable or not at all, and may or may not

contain compounds recalcitrant to treatment. These include organic synthetic substances or heavy metals whose content in developing countries' wastewater may be considerably different (in quantity and quality) from that of developed ones. The main concern with industrial wastewater is the increasing amount (in quantity and variety) of synthetic compounds contained in and discharged to the environment. A list of the most common pollutants in industrial discharges can be found in Jiménez (2009a). Due to the difficulty in tracking toxic compounds and their fate, combined with the need to use complex and costly treatment methods to remove them from wastewater, it is advisable and cost effective to consider the implementation of cleaner production methods in industries (such as the replacement of toxic recalcitrant compounds with others that are less harmful or not harmful at all) and, also to raise awareness of society to reduce the use of such types of compounds (Jiménez, 2009b).

4.06.3.1.3 Nonpoint and nonconventional pollutant sources to water

Water pollutants come not only from urban and municipal wastewater discharges, but also from nonpoint sources, some of which are not perceived as such. Most of the nonpoint sources have been initially recognized as such by groundwater experts (Foster *et al.*, 2003) who realized that soil (urban or rural) was an important means of transporting pollution to ground and surface water through complex interactions. A list of such pollutants is presented in Table 1 and a detailed description of some of the pollution sources can be found in Jiménez (2009a).

4.06.4 Pollutants

In this section, the types of different pollutants are reviewed, emphasizing those of special interest in developing countries.

4.06.4.1 Biological Pollutants

Biological pollutants are the major threat to low-income countries as diseases caused by them are rapidly manifested and have important effects on children and the elderly, sometimes even resulting in fatalities. According to WHO (2004), diarrheal diseases accounts for an estimated 4.1% of the total daily global disease burden and is responsible for 1.8 million deaths every year. It is estimated that 88% of that burden is attributable to unsafe water supply, sanitation, and hygiene. Biological pollutants cause hydraulic diseases that are frequently divided into three categories:

1. Waterborne diseases that are caused by pathogenic organisms ingested when consuming water polluted with fecal contamination or food irrigated with polluted water. Examples of these types of diseases are giardiasis and amebiasis.
2. Water-washed diseases that are caused by the lack of safe water or simply any water for hygiene purposes. Disease transmission is linked to skin or eye contact. An example is trachoma, a disease that causes blindness. Some 6 million people have been blinded by trachoma. Another 150 million need treatment, and an estimated 500 million are at

risk. The disease is endemic in 55 countries, with only China and India accounting for 2 million cases. Productivity losses caused by trachoma are estimated to be US\$2.9 billion (WHO, 2004).

3. Water-based diseases that are caused when water accumulates and stagnates, promoting the breeding of vectors such as mosquitoes that cause dengue or malaria.

There are four groups of organisms that can be found in waste and polluted water: viruses, bacteria, protozoa, and helminths (in the form of eggs, Jiménez (2003)). The general characteristics of these organisms can be found in specialized literature. In the following sections, properties relevant to developing countries will be highlighted for each type of group. A list of pathogens that have been detected in wastewater is presented in Annex 1. The main aspect to highlight is the notable difference in the quantity and variety of pathogens found in wastewater between developed and developing countries (Table 2).

4.06.4.1.1 Viruses

Viruses are the smallest (0.01–0.3 μm) infectious agents. There are more than 150 types of enteric viruses capable of producing infections or illnesses that multiply in the intestine and are expelled in feces. Unlike bacteria, pathogenic viruses are found in wastewater and feces when people are infected, independently of whether they display symptoms. In regions where viral diseases are endemic, they are constantly isolated from wastewater. The presence of viruses and their concentration in wastewater is linked to the season of the year and the age distribution of the population. Concentrations are usually higher during summer and lower in the autumn months. The composition, type, and especially the content of viruses contained in wastewater are poorly known, particularly in developing countries, as a result of the complex and costly analytical techniques required to identify them (Jiménez, 2003).

The enteric viruses most relevant to man are enteroviruses (polio, echo, and coxsackie viruses), Norwalk, rotaviruses, reoviruses, caliciviruses, adenoviruses, and hepatitis A viruses. Rotaviruses are responsible for between 0.5 and 1 billion cases of diarrhea per year in children under 5 years of age in Africa, Asia, and Latin America and up to 3.5 million deaths. Usually, between 50% and 60% of the cases of children with gastroenteritis that are hospitalized are caused by rotaviruses. Reoviruses and adenoviruses are the main causes of respiratory illness, gastroenteritis, and eye infections and have been isolated from wastewater. To date, there is no evidence that the human immunodeficiency virus (HIV) causing the acquired immunodeficiency syndrome (AIDS) can be transmitted via a waterborne route. It is recognized that low virus levels may cause infection or illness; wastewater contains thousands of them, some of which are much more resistant to chlorine disinfection than bacteria (Jiménez, 2003). Viruses discharged in polluted water can migrate long distances in soil and groundwater. The reported horizontal migration varies between 3 and 400 m, while vertical migration ranges from 0.5 to 70 m depending on soil conditions.

Table 1 Sources of pollution for surface and groundwater

Origin	Main polluting agents	Relative importance	Concern	
			Developing countries	Developed countries
<i>Urban infrastructure</i>				
Water network	Cl, NMA	+	+++	+
Sewerage system	ED, F, N, OM, T, PCP, sediments	+++	+++	++
Septic tanks and latrines	ED, N, OM, PCP	+++	+++	+
Storage or treatment ponds	Variable	++	+++	+
Storage tanks	DBP, HC, OM, T	+++	+++	+
Municipal landfills	ED, H, OM, PCP, S, T	+++	++	+
Hazardous wastes confinement sites	A, ED, EP, H, HC, NMA, OM, PCP, S, T			
Highways drainage soakways	EP, S, T	+		+
Pipelines	HC, OM, T			
Injection wells	ED, H, OM, PCP, S, T	+++	+++	+
Cemeteries	F, M, N, NMA, OM	++	+++	+
<i>Urban activities</i>				
Industries	Variable, more relevant synthetic compounds	+++	+++	++
Factories and small commerce	Variable, more relevant synthetic compounds	+++	+++	++
Irrigation of amenity areas	N, P, T	+	+	++
Application of ice melting substances	NMA, T	+	+	++
Transport and transference of material	HC, T	+	+	+
Storage of substances in tanks and reservoirs	Depending on the type of substance stored	++	+++	+
<i>Urban disposal options</i>				
Unsewered sanitation	EP, F, N, OM, T	+++	+++	-
Transportation of polluted water in channels or rivers	EP, F, H, HC, N, OM, T	++	+++	-
Nontreated sewage disposal in soil with impact on water bodies	ED, EP, F, OM, N, PCP, S, T	+++	+++	-
Nontreated sewage discharge in rivers and lakes	ED, EP, F, N, OM, PCP, S, T	+++	+++	-
Treated wastewater disposal	DBP, ED, EP, N, NMA, PCP	++	+	+
Sludge disposal	ED, EP, F, N, OM, PCP, S, T	++	+	++
Uncontrolled dumping sites	ED, EP, H, OM, PCP, S, T	+++	+++	-
<i>Other urban sources</i>				
Atmospheric pollutants deposition	A, EP, H, HC, N, M	++	++	++
Urban run-off	A, B, EP, HC, M	+++	+++	++
Saline intrusion	NMA	++	+++	+
Industrial accidental spillage	EP, T, HC	+	++	+
<i>Industrial sources</i>				
Industries located in urban or rural areas, in general	Variable, mostly synthetic compounds	+++	+++	++
<i>Agricultural sources</i>				
First use water	N, P	+++	+++	+++
Treated wastewater	EP, N, P, S	+	+	++
Nontreated wastewater	EP, F, N, OM, P, S,	+++	+++	+
<i>Rural areas</i>				
On-site sanitation systems and unsewered areas	EP, F, N, OM,			
Storage of substances in tanks and reservoirs	Depending on the type of substance stored	++	+++	+
Disposal of solid wastes	EP, ED, F, H, NMA, OM, PCP, S, T	+++	+++	+
Transportation of polluted water in channels or rivers	EP, F, H, HC, N, OM, T	++	+++	-

Adapted from Jiménez B (2009a) Coming to terms with nature: Water reuse new paradigm towards integrated water resources management *Encyclopedia of Biological, Physiological and Health Sciences, Water and Health, Vol. II: Life Support System*, pp. 398–428. Oxford: EOLSS Publishers/UNESCO; Jiménez (2009b) Wastewater risks in the urban water cycle. In: Jiménez B and Rose J (eds.) *Urban Water Security: Managing Risks*, p. 324 Paris: UNESCO Leiden: Taylor and Francis Group.

(a): May include industrial compounds.

(b): Only present in industrial areas.

A: Acids; Cl: Residual chlorine; DBP: Disinfection by-products; ED: Endocrine disrupters; EP: Emerging pollutants; F: Fecal pathogens; H: heavy metals; HC: Hydrocarbons; N: Nutrients; NMA: Nonmetal and anions; OM: Organic matter; P: Pesticides; PCP: Personal care products; S: Salinity; T: Toxics; +: Magnitude increase.

Annex 1 Biological disease-causing agents that have been reported in wastewater

<i>Agent</i>	<i>Classification</i>	<i>Illness</i>
Adenoviruses (31 to 51 types)	Viruses	Respiratory illness, conjunctivitis, vomiting, diarrhea
Arbovirus	Viruses	Arboviral disease
Astroviruses (five types)	Viruses	Vomiting, diarrhea
Calicivirus or Norwalk agent	Viruses	Vomiting, diarrhea
Coronavirus	Viruses	Gastroenteritis, vomiting, diarrhea
Coxsackie A (enterovirus)	Viruses	Meningitis, fever, herpangina, respiratory illness
Coxsackie B (enterovirus)	Viruses	Myocarditis, congenital heart anomalies, rash, fever, meningitis, respiratory illness, pleurodynia
Echovirus (enterovirus)	Viruses	Meningitis, encephalitis, respiratory illness, rash, diarrhea, fever
Enterovirus 68–71	Viruses	Meningitis, encephalitis, respiratory illness, acute hemorrhagic conjunctivitis, fever
Flavivirus	Viruses	Dengue fever
Hepatitis A virus	Viruses	Infectious hepatitis
Hepatitis E virus	Viruses	Hepatitis
Norwalk virus	Viruses	Epidemic vomiting and diarrhea, gastroenteritis
Parvoviruses (three types)	Viruses	Gastroenteritis
Poliovirus (enterovirus)	Viruses	Poliomyelitis, paralysis, meningitis, fever
Reoviruses (three types)	Viruses	Not clearly established
Rotaviruses (four types)	Viruses	Diarrhea, vomiting, gastroenteritis
Snow Mountain Agent	Viruses	Gastroenteritis
Small and round viruses	Viruses	Diarrhea, vomiting
Yellow fever viruses	Viruses	Yellow fever
<i>Brucella tularensis</i>	Bacteria	Tularemia
<i>Campylobacter jejuni</i>	Bacteria	Gastroenteritis, diarrhea
<i>Escherichia coli</i> enteropathogenic	Bacteria	Gastroenteritis
<i>Legionella pneumophila</i>	Bacteria	Acute respiratory illness, Legionnaire's disease
<i>Leptospira</i> spp., 150 types	Bacteria	Leptospirosis (septic meningitis, jaundice, neck stiffness, haemorrhages in the eyes and skin)
<i>Clostridium perfringens</i>	Bacteria	Gaseous gangrene, food poisoning
<i>Mycobacterium leprae</i>	Bacteria	Leprosy
<i>Mycobacterium tuberculosis</i>	Bacteria	Pulmonary and disseminated tuberculosis
<i>Salmonella</i> spp., 1700 a 2400 strains (paratyphi, schottmuelleri, etc.)	Bacteria	Salmonellosis
<i>Salmonella thyphimurium</i>	Bacteria	Typhoid fever, paratyphoid or salmonellosis
<i>Shigella</i> spp., 4 types	Bacteria	Bacillary dysentery, Shigellosis
<i>Treponema pallidum-pertenue</i>	Bacteria	Yaws (frambuesia)
<i>Yersinia enterocolitica</i>	Bacteria	Gastroenteritis, Yersiniosis
<i>Vibrio cholerae</i>	Bacteria	Cholera
<i>Aspergillus fumigatus</i>	Fungi	Aspergillosis
<i>Candida albicans</i>	Fungi	Candidiasis
<i>Balantidium coli</i>	Protozoa	Mild diarrhea colonic ulceration, dysentery, balantidiasis
<i>Cyclospora cayetanensis</i>	Protozoa	Severe infectious, dehydration: diarrhea, nausea, vomiting
<i>Cryptosporidium parvum</i>	Protozoa	Diarrhea and cryptosporidiosis
<i>Entamoeba histolytica</i>	Protozoa	Amoebic dysentery
<i>Giardia lamblia</i>	Protozoa	Giardiasis
<i>Naegleria fowleri</i>	Protozoa	Amoebic meningo-encephalitis
<i>Plasmodium malariae</i>	Protozoa	Malaria
<i>Trypanosoma</i> spp.	Protozoa	Trypanosomiasis
<i>Toxoplasma gondii</i>	Protozoa	Congenital or postnatal, toxoplasmosis
<i>Ancylostoma duodenale</i>	Helminths	Anaemia, ancylostomiasis
<i>Ascaris lumbricoides</i>	Helminths	Ascariasis
<i>Echinococcus granulosus</i>	Helminths	Hydatidosis
<i>Enterobius vermicularis</i>	Helminths	Enterobiasis
<i>Necator americanus</i>	Helminths	Anaemia
<i>Schistosoma</i> spp.	Helminths	Schistosomiasis
<i>Strongyloides stercoralis</i>	Helminths	Diarrhea, abdominal pain, nausea, Strongyloidiasis
<i>Taenia solium</i>	Helminths	Taeniasis, cysticercosis
<i>Trichuris trichiura</i>	Helminths	Diarrhea
<i>Toxocara</i> spp.	Helminths	Fever, abdominal pain, nausea

The presence of biological disease-causing agents is not necessarily an indication of a confirmed risk.

From Jiménez B (2003) Health risks in aquifer recharge with recycle water. In: Aertgeerts R and Angelakis A (eds.) *State of the Art Report Health Risk in Aquifer Recharge Using Reclaimed Water*, pp. 54–172. Rome: WHO Regional Office for Europe.

4.06.4.1.2 Bacteria

Bacteria are single-celled microorganisms ranging from 0.2 to 10 μ in size with different shapes. They reproduce and grow in an appropriate environment at defined ranges of temperature,

Table 2 Comparison of the biological pollutant content in wastewater from developing and developed countries

Organism	Developed world	Developing world
Enteric viruses, PFU 100 ml ⁻¹ (U, I)	10 ² –10 ⁴	10 ⁴ –10 ⁶
<i>Salmonella</i> , MPN 100 ml ⁻¹ (M, U, F, SA, IN, H)	10 ⁰ –10 ⁴	10 ⁶ –10 ⁹
<i>Fecal streptococci</i> , No. 100 ml ⁻¹ (U, B, K)	10 ⁴ –10 ⁶	10 ⁶ –> 10 ⁷
Protozoan cysts, organisms l ⁻¹ (U, M)	10 ¹	10 ³
<i>Giardia lamblia</i> , cysts l ⁻¹ (U, E, K)	1–10 ³	10 ² –10 ³
<i>Cryptosporidium parvum</i> , oocysts l ⁻¹ (U, E)	1–10 ³	ND
Helminth ova, egg l ⁻¹	1–9	6–800

Data from: E, England; H, Holland; In, India; I, Israel; K, Kenya; M, Mexico; SA, South Africa; U, USA; ND, No data.

Adapted from Jiménez B (2009b) Wastewater risks in the urban water cycle. In: Jiménez B and Rose J (eds.) *Urban Water Security: Managing Risks*, p. 324. Paris: UNESCO Leiden: Taylor and Francis Group.

salinity, pH, etc. They may or may not be encapsulated. The environmental distribution of bacteria is ubiquitous and has different nutritional requirements. Many species of bacteria are not harmful to man. In fact, some even live inside humans forming intestinal colonies. Bacteria are expelled in feces at high concentrations (Jiménez, 2003). Table 3 shows some characteristics of pathogenic bacteria that can be found in the feces of infected people. In wastewater, pathogenic bacteria are always present but at a variable concentration, depending on the local health conditions. As shown in Table 3, due to the high rate of diseases caused in developing countries, *Salmonella*, *Shigella*, and *Helicobacter pylori* are bacteria of importance as agents causing endemic diseases. In contrast, *Vibrio cholerae* is present only when an epidemic exists.

4.06.4.1.3 Protozoa

Protozoa are the group of parasites most closely associated with diarrheas. They are single-celled organisms (2–60 μ m in size) that develop in two ways: as trophozoites and as cysts. Infections are produced when mature cysts are consumed. Cysts are resistant to gastric juices and transform themselves into trophozoites in the small intestine, lodging in the wall where they feed on bacteria and dead cells. In time,

Table 3 Characteristics of some bacteria frequently found in wastewater (with information from Jiménez (2003) and Lenghton *et al.* (2005))

Characteristics and effects in humans

Escherichia coli is commonly found in wastewater at high concentrations. Different *E. coli* strains can cause gastroenteritis in both animals and humans and pose a high risk to newborns and children under 5 years of age. *E. coli* strains implicated with human diseases are: (1) enteropathogenic *E. coli*; (2) *E. coli* that is the common cause of traveler's diarrhea, which provokes a liquid and profuse diarrhea with some mucosity, nausea, and dehydration; (3) enteroinvasive *E. coli* that invades the intestinal mucus lining like *Shigella* spp., and (4) *E. coli* (EHEC) that produces a similar toxin to *Shigella* causing hemorrhagic colitis. Infective doses are relatively low (10² organisms).

Salmonella spp. is frequently present in wastewater at content always lower than that of fecal coliforms by 1–2 log. There is a wide variety of strains capable of infecting humans and animals. The incidence in humans is lower than in animals and has a seasonal variation.

The most severe form of salmonellosis is typhoid fever caused by *Salmonella typhi*. Typical symptoms are chronic gastroenteritis with diarrhea, stomach cramps, fever, nausea, vomiting, and headache. In severe cases, collapse and death might occur. Transmission is through ingestion of polluted water or food, and is very common in developing countries. Infective dose is of the order 10⁵–10⁸ microorganisms, but for *Salmonella typhi* doses as low as 10²–10³ have been reported.

Shigella is similar to *Salmonella* spp. but less frequent in wastewater. There are more than 40 strains, but *S. sonnei* and *S. flexneri* represent almost 90% of total wastewater isolations. It rarely infects animals and lives for a shorter period in the environment. One route of transmission is through swimming in polluted water. *Shigella* spp. produces bacillary dysentery or shigellosis. This is light watery diarrhea that can develop into full-blown dysentery. The symptoms are fever, nausea, vomiting, abdominal pain, migraine, and myalgia. The classic form of dysentery is characterized by the expulsion of feces containing blood with or without mucus. The infective dose is less than 10³ microorganisms.

Helicobacter pylori is found in wastewater. Its major habitat is the human gastric mucosa. Three species are human pathogens: *H. pylori*, *H. fennelliae*, and *H. cinaedi*. The pathway of transmission is not entirely clear but water could be involved. In developing countries, *H. pylori* is acquired early in childhood, and up to 90% of children are infected by the age of 5. This contrasts with the low infection rate during childhood observed in developed countries (0.5–1%).

Campylobacter jejuni usually is a pathogen to animals but it can cause severe gastroenteritis in humans. The main source of infection is nonchlorinated water supplies.

Mycobacterium tuberculosis along with *M. balnei* (marinum) and *M. bovis* causes pulmonary diseases and tuberculosis. For *M. tuberculosis*, contaminated water is the main source of infection.

Vibrio cholerae is the cause not only of epidemic but also eight pandemics, the last one between 1990 and 1995. Cholera epidemics are caused by *V. cholerae* group O1 and some non-O1. Symptoms are abundant liquid diarrhea with significant loss of hydro-electrolytes and severe dehydration associated with vomiting. *V. cholerae* is rare in developed countries but frequent in poor ones. Humans are the only known hosts. The most frequent pathway of transmission is water, either through direct consumption or when used to irrigate produce that is consumed uncooked. Fish grown in polluted water are another source of transmission. Since 2007, there have been outbreaks of cholera in India, Iraq, Congo, Vietnam, and Zimbabwe. In 2005, West Africa suffered more than 63 000 cases of cholera, leading to 1000 deaths.

Table 4 Protozoa related to sanitation problems and that are of interest for developing countries (with information from Jiménez (2003))*Characteristics and effects in humans*

Entamoeba histolytica is one of the most important parasites detected in municipal wastewater and is commonly known as Amoeba. Trophozoites measure 20–40 µm and t cysts 10–16 µm.

Amoebae usually lodge in the large intestine; occasionally they penetrate the intestinal wall, traveling and lodging in other organs. They are the cause of amoebic and hepatic dysentery. *Entamoeba histolytica* infects 10% of the world's population – mostly in the developing world – resulting in approximately 500 million infected persons; there are between 40 and 50 million cases of invasive amebiasis per year resulting in up to 100 000 annual deaths (placing it second after malaria in mortality caused by protozoan parasites). Ninety-six percent of these cases occur in poor countries, especially on the Indian subcontinent, West Africa, the Far East, and Central America.

Giardia spp. are common in wastewater as it frequently causes endemic diseases. It especially affects children under 5 suffering from malnutrition. The total number of sick people is of the order 1.1 billion, 87% of whom live in poor countries.

Giardia spp. is the most common parasite of humans but water is not necessarily the main pathway of transmission. Cysts (that are 8–14 µm long and 7–10 µm wide) can survive in water bodies for long periods, especially in winter. *Giardia* lives in the intestines of a large number of animals as trophozoites. The disease is characterized by very liquid and smelly explosive diarrhea, stomach and intestinal gases, nausea, and loss of appetite.

Cryptosporidium spp. is a parasite widespread in nature. Oocysts are resistant to chlorine and due to their small size (4–7 µm) are difficult to remove from water, as many other protozoan. *Cryptosporidium* spp. infects a large spectrum of farm animals and pets and was recently recognized as a human pathogen that is why it is considered as an emerging pathogen. *Cryptosporidium* spp. is capable of completing a life cycle within the same host and causing reinfection. Once an individual has been infected, the person carries the parasite for life and can be reinfected. The disease rate in developing countries has been poorly studied, in particular due to the higher occurrence of other types of diseases. Cryptosporidiosis in developing countries has shown a greater incidence among immune depressed people and in rural areas (Snelling *et al.*, 2007). The main symptoms of cryptosporidiosis are stomach cramps, nausea, dehydration, and headaches. Although it is known that the infectious dose varies between 1 and 10, outbreaks have always been associated with large concentrations in water.

trophozoites become once again cysts that are expelled in feces. Infected persons may or not display symptoms. Protozoa do not reproduce in the environment, only in their host. However, they are able to survive in the environment and remain active for periods ranging from some months to up to several years, depending on the environmental conditions. Most intestinal protozoa are transmitted through polluted water and food contaminated with polluted water or unsanitary handled (Jiménez, 2003). Table 4 shows the characteristics of some protozoa.

In the developing world, the more relevant protozoa because of their effects on humans are *Giardia* and *Amoeba*. *Cryptosporidium* is a threat to developed countries, as was unfortunately demonstrated in Milwaukee, US, when 403 000 people became ill and more than 50 died after an infection was transmitted through the drinking water supply (Hrudey and Hrudey, 2004).

4.06.4.1.4 Helminth eggs

Helminths are worms some of which are parasites in humans. Where helminths are the origin of waterborne diseases, they are mainly transmitted through the consumption of contaminated food (crops, meat, or fish). Helminths can also be transmitted through the oral–fecal route and, therefore, hygiene is important as a factor in their control. As helminths are associated with turbid water, they normally are not a concern in drinking water.

Helminths are pluri-cellular worms and because of this they are poorly addressed in environmental microbiology books. The eggs – their infective form – are microscopic and travel along with wastewater. Helminths occur in different types and sizes (from 1 mm to several m in length), and have diverse and complex life cycles compared to most of the microorganisms known in the sanitary field (Jiménez, 2008a).

Before infecting humans, in some cases, they may have an intermediary host as is the case for *Schistosoma* spp. that temporarily lives in snails.

There are three different types of helminths: (1) plathelminths or flat worms, (2) nemathelminths, nematodes or round worms, and (3) annelids. If plathelminths have their body formed by segments, they are called cestodes; if not, they are then called trematodes. Only the first two types are of sanitary importance. Although common in sanitary engineering literature, it is improper to use the terms nematodes, *Ascaris*, and helminths as synonyms. This misunderstanding comes from the fact that *Ascaris* (a nematode) is the most common helminth egg in wastewater and sludge. A list of helminth eggs found in wastewater and sludge and its classification can be found in Jiménez (2008a).

Helminthiasis are diseases of high incidence in developing countries compared with developed ones. Globally, there are around 1–2 thousand million people suffering of helminthiasis but most of them are from developing countries where it affects up to 10% of the population. The incidence rate may reach 90% in regions where poverty and poor sanitary conditions prevail. In contrast, in developed countries, helminthiasis' incidence is at the most 1.5% and affects mainly poor immigrants (Jiménez, 2008a). Helminthiasis have different manifestations but, in general, they cause intestinal wall damage, hemorrhages, deficient blood coagulation, and undernourishment. They can degenerate into cancer tumors. Helminthiasis affect mainly children, the elderly, and poor people (Jiménez, 2008). Around 94% of the more than 4 billion cases of diarrhea in the world are caused by helminths (Murray and López, 1996). There are several kinds of helminths with different local names (Annex 2). This along with the fact that it is hard to properly identify them clinically unless a costly laboratory analysis is performed, makes it difficult to track the actual incidence of all the

Annex 2 Examples of local names given to helminth and helminthiasis diseases

Common name	Technical name	Examples of local names given to diseases	Number of infected people (million)	Region affected
Foodborne trematodes and schistosomiasis	Trematode	Trematodiasis, clonorchiasis, schistosomiasis, fascioliasis	> 240	Found in 74 countries.
Blood fluke	<i>Schistosoma</i>	Schistosomiasis, bilharziosis or snail fever	200 half of which live in Africa (20 with severe consequences)	Asia, Africa, and South America. (80% of whom live in sub-Saharan Africa)
Liver fluke	<i>Clonorchis sinensis</i>	Clonorchiasis	40 (10% of the world's population thought to be at risk)	China, Russian Federation, Republic of Korea, Vietnam
Liver fluke	<i>Fasciola hepatica</i> and <i>F. gigantica</i>	Fascioliasis		Temperate areas of Africa, Europe and Central/South America
Intestinal Fluke	<i>Fasciolopsis buski</i>	Fasciololopsis		Kazakhstan, Lao Peoples's Democratic Republic, Poland, Russian federation, Thailand, Turkey, Ukraine, Viet Nam
Hookworms	<i>Ancylostoma duodenale</i>	Ancylostomiasis, anchylostomiasis, helminthiasis, miners' anemia, tunnel disease, brickmaker's anemia and Egyptian chlorosis	1300	Middle East, North Africa, India and (formerly) in southern Europe
	<i>Necator americanus</i>	Necatoriasis		
Tapeworm	All cestode			The Americas, Sub-saharan Africa, Southeast Asia, China, and Indonesia
Tape worm	<i>Taenia</i>	Taeniasis, Cysticercosis		Asia, Africa, South America, parts of Southern Europe and pockets of North America
Tapeworm	<i>Hymenolepis nana</i> and <i>diminuta</i>			
Roundworm	All nematode (<i>Ascaris</i> , <i>Toxocara</i> , <i>Trichuris</i> , <i>Enterobius</i>)	Nematode infection	4000	Latin America, Asia, Africa, far East
Roundworm nematode	<i>Ascariasis lumbriocides</i>	Ascariasis	1500	Africa, Asia and Latin America, Far East
Pinworm	<i>Enterobius vermicularis</i>	Oxiuriasis Enterobiasis	600	
Whipworm	<i>Trichuris trichiura</i>	Trichuriasis	1050	

helminthiasis. That is why frequently figures are underestimated. Technically, helminthiasis take their name from their causative agent. For instance, trichuriasis is named after *Trichuris*. Ascariasis, affecting nearly 1500 million people, is the most common of the helminthiasis and is endemic in Africa, Latin America, and the Far East. Even though the mortality rate is low, most of the people infected are children under 15 years of age with problems of faltering growth and/or decreased physical fitness. Around 1.5 million of these children will probably never bridge the growth deficit, even if treated (Silva *et al.*, 1997; Jiménez, 2008a).

The helminthiasis' infective agents are the eggs, not the worms. Actually, worms cannot live either in wastewater or in sludge because they need a host. Helminth eggs are transmitted through (1) the ingestion of crops polluted with wastewater or sludge, (2) direct contact with polluted sludge or fecal material, and (3) the ingestion of polluted meat or fish (Jiménez, 2008a). Each type of helminth has its own pathways of infection.

Eggs of different helminths generally occur in different shapes, sizes, and resistances (Figure 3). As a result of the higher incidence of ascariasis, in wastewater and sludge, these

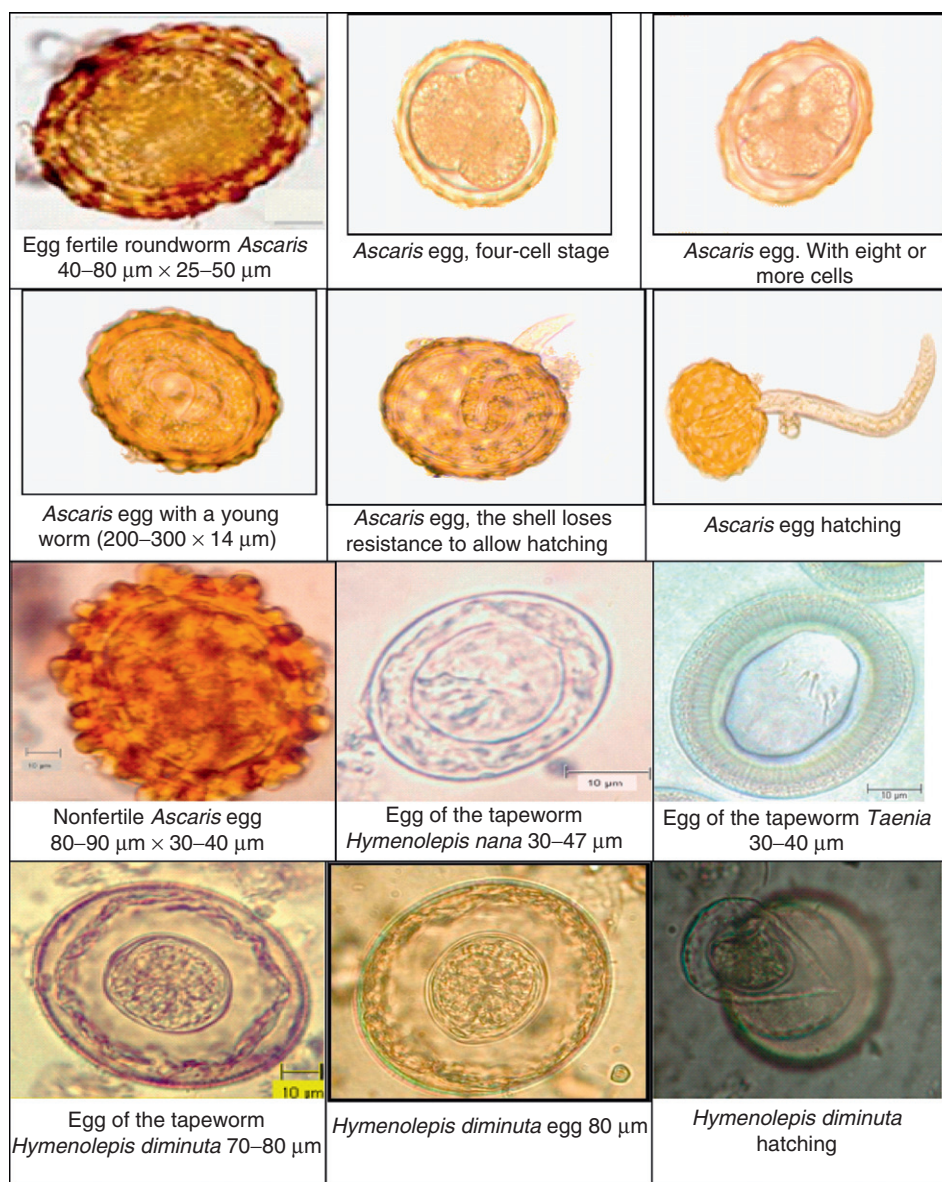


Figure 3 Examples of helminth eggs most frequently observed in wastewater and sludge, Photographs courtesy of Catalina Maya, Treatment and Reuse GROUP, UNAM.

are the eggs found in the highest concentrations (Figure 4). The percentage of types of helminths might vary from one region to another following the disease's pattern. Due to differences in health conditions in developed and developing countries, their helminth eggs content is very different in wastewater and sludge (Table 5).

Eggs contained in sludge are not always viable and infectious. To be infectious, the larvae need to develop, and, for that, a certain temperature and moisture are needed. The necessary conditions are frequently met in soil or crops, where eggs are deposited when polluted wastewater, sludge, or excreta is used as fertilizer. Under such conditions, the larvae develop in 10 days. According to previous information (that has not been updated using better analytical techniques), *Ascaris* eggs remain viable 1–2 months in crops and many

months in soil, freshwater, sewage, feces, night soil, and sludge – periods which are much longer than those for microorganisms (Jiménez, 2008a, Figure 5). This high resistance is due to a cover composed of 3–4 layers that gives mechanical resistance to eggs and protects them from desiccation, strong acids and bases, oxidants, reducing agents, detergents, and proteolytic compounds (Jiménez, 2008a). The resistance of different helminth eggs genera under environmental conditions has not been reported in literature.

To inactivate helminth eggs, it is recommended to raise the temperature above 40 °C for 10–20 days for *Ascaris* or to reduce moisture levels below 5%. These conditions are not easy to use during wastewater treatment; thus, helminths are usually removed from wastewater to be subsequently inactivated in sludge. Helminth ova of interest in the sanitary field

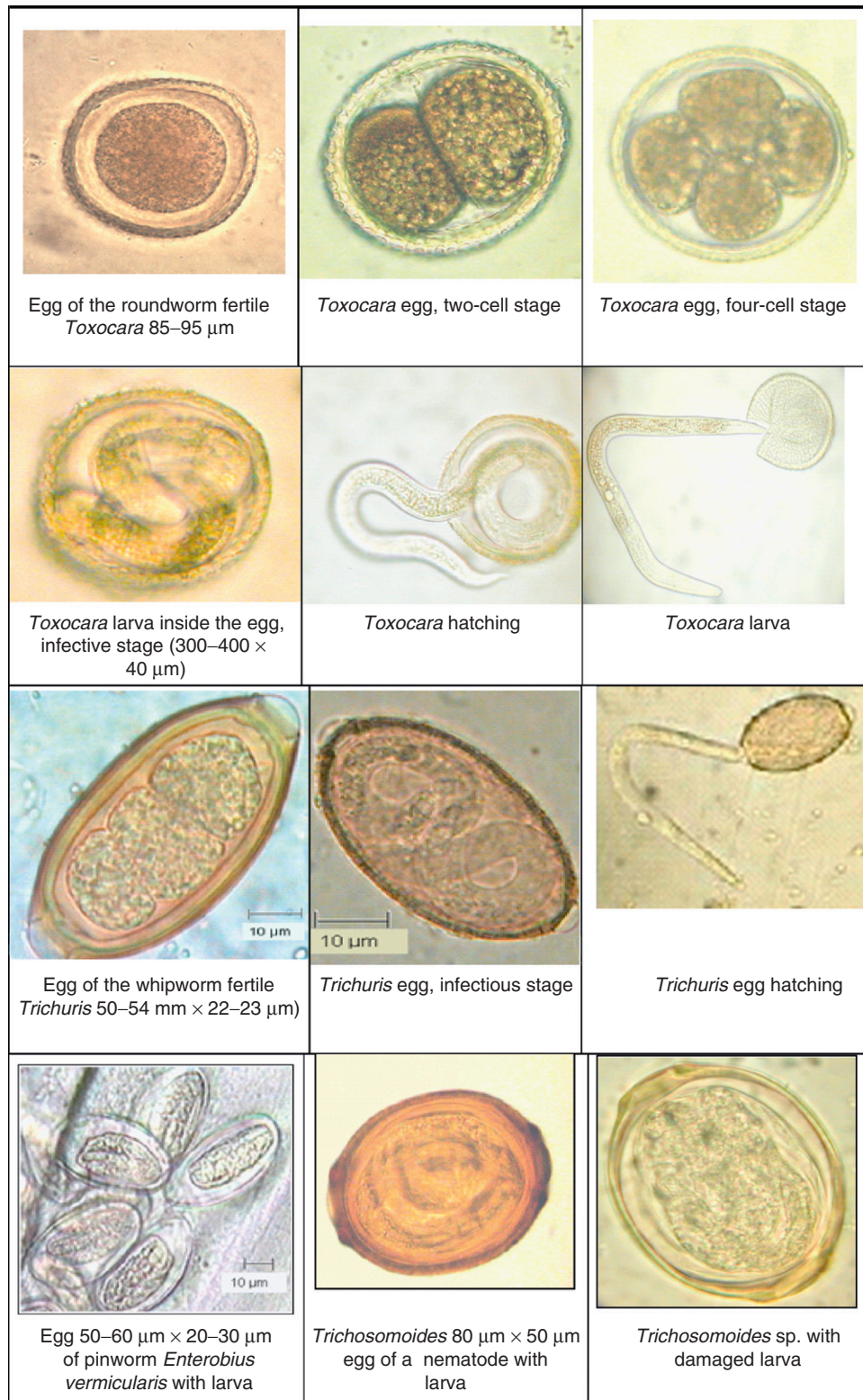


Figure 3 Continued.

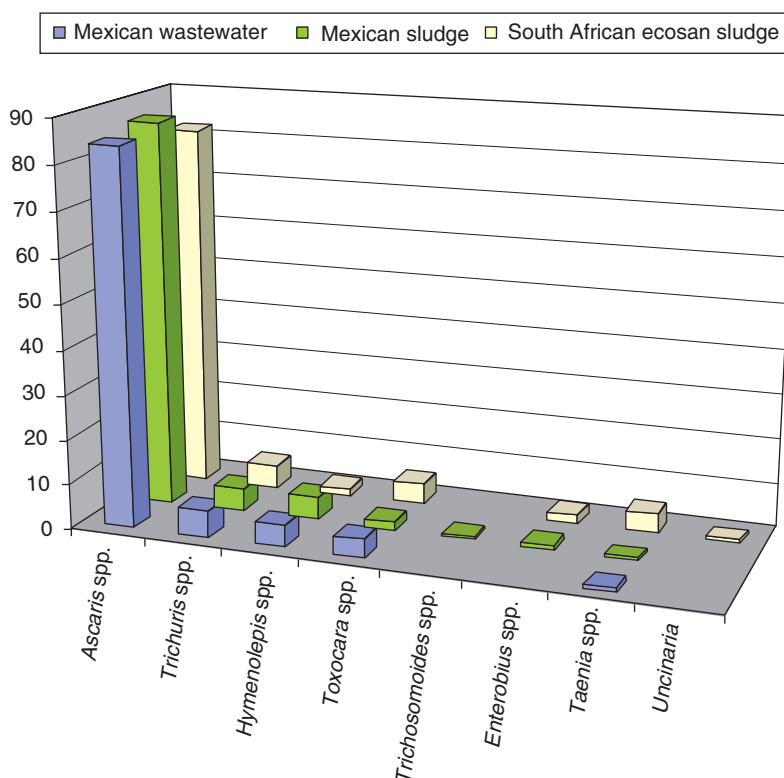


Figure 4 Content of different helminth egg genera in Mexican wastewater and sludge and from an on-site sanitation system in South Africa. Data from Maya C, Jiménez B, and Schwartzbrod J (2006) Comparison of techniques for the detection of helminth ova in drinking water and wastewater. *Water Environment Research* 78(2): 118–124 and Jiménez B and Wang L (2006) Sludge treatment and management. In: Ujang Z and Henze M (eds.) *Municipal Wastewater Management in Developing Countries: Principles and Engineering*, pp. 237–292. London: IWA Publishing.

Table 5 Helminth ova content in wastewater and sludge from different countries

Country/region	Municipal wastewater (HO l ⁻¹)	Sludge (HO g ⁻¹ TS)
Developing countries	70–3000	70–735
Brazil	166–202	75
Egypt	6–42	Mean: 67; maximum: 735
Ghana	No data	76
Jordan	300	No data
Mexico	6–98 in cities Up to 330 in rural and peri-urban areas	73–177
Morocco	840	No data
Syria	800	No data
Ukraine	60	No data
France	9	5–7
Germany	No data	<1
Great Britain	No data	<6
United States	1–8	2–13

From Jiménez B (2008a) Helminth ova control in wastewater and sludge for agricultural reuse. Water reuse new paradigm towards integrated water resources management. In: Grabow WOK (ed.) *Encyclopedia of Biological, Physiological and Health Sciences, Water and Health, Vol. II. Life Support System*, pp. 429–449. Oxford: EOLSS Publishers/UNESCO.

measure 20–80 µm, have a specific density of 1.06–1.2, and are very sticky. These properties are used to remove eggs from wastewater (Jiménez, 2008a).

Helminth ova criteria. As shown in Table 5, not all wastewater and sludge contain significant amounts of helminth ova. For this reason, they are not included in all countries' wastewater, sludge, or fecal sludge norms, as is the case with biochemical oxygen demand (BOD) or fecal coliforms, which are universal parameters used to design wastewater treatment (Jiménez, 2008a). Based on toxicological and epidemiological studies, the World Health Organization WHO (2006) suggested a value of $\leq 1 \text{ egg l}^{-1}$ in wastewater intended for the irrigation of crops that are eaten uncooked. Wastewater used for the culture of fish should contain 0 egg l^{-1} , since trematode eggs (*Schistosoma* spp., basically) may multiply in an intermediary host (a snail) before infecting fish and humans. For excreta, the recommended criterion is of 1 egg g^{-1} total solids (TS).

4.06.4.1.5 Biological indicators

Thermotolerant coliform bacteria (commonly referred as fecal coliforms) are the group most frequently used as indicators of fecal pollution because they behave in a similar way to most pathogenic bacteria in the environment, and, during treatment, they are abundant and easy to determine.

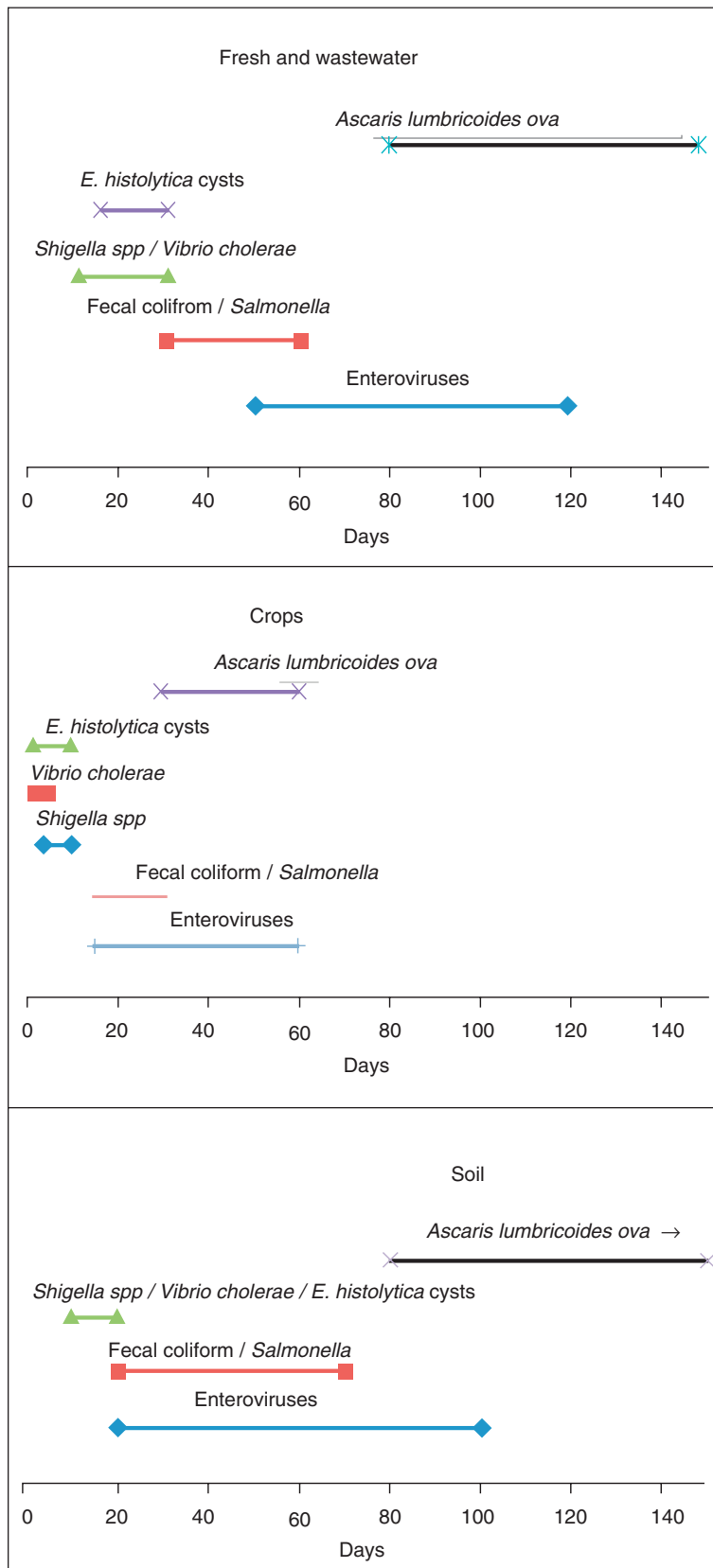


Figure 5 Survival time of different pathogens in fresh and wastewater, soil and crops at 20–30 °C. Data from Feachem R, Bradley D, Garelick H, and Mara D (1983) *Sanitation and Disease: Health*. pp. 349–356. New York, NY: Wiley.

Thermotolerant coliforms are less specific indicators of fecal contamination than *Escherichia coli*, since they may sometimes arise from nonfecal sources, especially in tropical climates (WHO, 2004). However, it is becoming increasingly evident that they are not useful to simulate the behavior of all enteric viruses, protozoa – in particular with regard to *Giardia* and *Amoeba* – and helminth eggs that are of concern in low-income regions. Despite this, it is frequently, but wrongly, assumed that fecal coliforms are indicators of all kinds of biological pollution. Even though they can be useful indicators of fecal pollution in developed countries' drinking water, this is not always the case for water and wastewater from developing ones, owing to the presence of a wider variety and larger quantities of microorganisms (Jiménez, 2009). This does not mean that fecal coliforms are not useful for developing countries; it simply means that care must be taken to select additional indicators for specific purposes, such as for wastewater and sludge reuse in agriculture and aquaculture. In these cases, the helminth egg content (WHO, 2006) needs also to be specified.

It is worth mentioning that the treatment procedures to inactivate helminth eggs are frequently developed using *Ascaris* eggs as models as they have been informally considered as indicators for all helminth eggs, although this has not been fully proven experimentally. In other cases, *Taenia saginata* or *Ascaris galli*, types of eggs that are rarely present in wastewater, are used to test treatment procedures.

4.06.4.1.6 Emerging pathogens

Some pathogens that are not usually followed during conventional monitoring have been linked to outbreaks in developed countries. These pathogens have been called 'emerging' pathogens. They have led to new regulations as well as to improvements in water and wastewater treatment procedures. Some of the microorganisms considered as emerging pathogens are *Giardia lamblia*, *Cryptosporidium parvum*, *Cyclospora cayatanensis*, *Blastocystis hominis*, *Legionella pneumophila*, *E. coli* 0157H7, *Campylobacter*, *Mycobacterium*, and *Norovirus* (Jiménez, 2009b). In developing countries, some of these pathogens are endemic, while others have either not been studied or not reported as disease-causing agents.

4.06.4.1.7 Biological analytical techniques

Assessing the biological quality of water is always a challenge due to the diversity of organisms and the need for different and proper methods to identify and enumerate them, some of which are complex, time consuming, and costly. In the following sections, a short description on the techniques used for different type of organisms is described.

Viruses. Identification and quantification of viruses in wastewater, sludge, or excreta is complicated due to the low level of recovery from wastewater and the need to use complex and costly techniques to analyze them. A laboratory requires 14 days, on average, to determine the presence or absence of a virus in water and another 14 days to identify them, using conventional procedures. Polymerase chain reaction (PCR) techniques have considerably speeded up the process, as they can be used to determine viruses online. These techniques are based on the amplification of a single or few copies of a piece

of DNA allowing the identification of different types of viruses. However, quantification with the precision required in the sanitary field remains a challenge. In addition, the method is sophisticated, and requires highly specialized equipment and highly trained personnel. Due to these difficulties, it is sometimes preferred to detect bacteriophages, that is, bacteria infected by viruses. Bacteriophages are used as informal indicators of viruses and not been linked to human diseases; therefore, their presence has no health significance (Jiménez, 2003).

Bacteria. As mentioned previously, thermotolerant bacteria are the common accepted indicator of bacterial fecal pollution. They are detected by using a selective medium and incubating it after inoculation at 35 or 37 ± 0.5 °C and/or 44 or 44.5 ± 0.25 °C, depending on the medium used. The materials and equipment used for this analysis are very common in most wastewater laboratories. PCR techniques to detect *E. coli* are useful as well.

Protozoa. There are enough accessible techniques to determine the presence of the main protozoan pathogens in wastewater and sludge; however, fewer techniques are available to quantify them with the required precision for the sanitation field. The presence of protozoa on samples does not necessarily always imply a risk, since this requires them to be also viable. To determine the viability, several days are required. PCR techniques for protozoa are not as well developed as they are for bacteria and viruses.

Helminth eggs. Helminths eggs require laborious techniques to detect them and even more so to enumerate them. Fortunately, the technique is readily available and does not use complex equipment, although it does require well-trained laboratory personnel. Currently, there is no standardized method and most of the few laboratories trained to detect them are using either different analytical procedures or similar ones with modifications. Moreover, most of the laboratories, instead of reporting the total content of helminth eggs, only report the *Ascaris* content, as is done in developed countries where it is frequently the single type of helminth eggs present (Jiménez, 2008a).

Analytical techniques for quantifying helminth eggs can be divided into two: direct and indirect techniques (Jiménez, 2008a). The first consists of separating helminth ova from the other particles contained in wastewater or sludge (where there are many) and then identifying and counting different genera using a microscope. Some examples of these techniques used the US-EPA (United States-Environment Protection Agency), the membrane filter, the Leeds I and Leeds II, and the Faust techniques. The most widely used technique seems to be the US-EPA (1992). A comparison of the performances of the above-mentioned methods has been made by Maya *et al.* (2006). The recovery rate among them varies from 20% to 80%. Sensitivity for each notably varies as well and not all are capable of measuring the criteria values set by WHO (2006) of 1 egg l^{-1} for wastewater and 1 egg g^{-1} TS for sludge.

The second types of techniques are indirect ones, and these have been applied only for wastewater. They are based on measuring either the total suspended solids (TSS) content or the particle size distribution (PSD), and then correlating the concentration to the helminth egg content. Calibration curves need to be established for each type of wastewater and

Box 1 Endocrine compounds. From Jiménez B (2009b) Wastewater risks in the urban water cycle. In: Jiménez B and Rose J (eds.) *Urban Water Security: Managing Risks*, p. 324. Paris: UNESCO Leiden: Taylor and Francis Group.

Endocrine disruptors are chemicals that mimic hormones or have antihormone activity interfering with the functioning of endocrine systems in various living species. They derive from many sources including pesticides, persistent organic pollutants, nonionic detergents, and human pharmaceutical residues. Some of them have been identified in municipal wastewater and many of them may persist in the environment for some time. Endocrine disruptors have been also found in drinking water. Their presence in recycled waters also raises broader questions about the risks and benefits of water recycling and our approaches to anticipating the emergence of new contaminants.

Human health effects potentially linked to exposure to these chemicals include breast, prostate, and testicular cancer; diminished semen quantity and quality, and impaired behavioral, immune or thyroid functions in children. Although direct evidence of adverse health effects in humans is lacking, reproductive abnormalities, altered immune function, and population disruption potentially linked to exposure to these substances has been observed in amphibians, birds, fish, invertebrates, mammals, and reptiles. Notably, feminization or masculinization on male or female animals, respectively, has been reported.

treatment process. Nevertheless, it is a worthwhile method because the helminth egg determination costs US\$7–12 if TSS are used, and US\$3 with the PSD, instead of US\$70, which is the cost of direct methods. It is important to distinguish between fertile viable and nonfertile eggs as only the viable eggs are infectious. This can be done visually using stains or by incubation at 26 °C for 3–4 weeks (Jiménez, 2008a).

4.06.4.2 Conventional Parameters

Conventional parameters as understood in this text are those commonly used to design or select wastewater and sludge treatment processes worldwide, and they refer mainly to the organic matter content (measured as BOD or COD – biological or chemical oxygen demand), or suspended solids. In general, they are similar worldwide except for the heavy metals content that in general –and especially for sludge – is notably lower in developing countries than in developed ones (LeBlanc *et al.*, 2008) as result of the difference at the industrialization level. However, at a local level, metal content in some industrialized areas of developing countries, notably where metal or tanning industries are placed, may be high. A detailed description of conventional parameters and their significance can be found in Jiménez (2009a).

4.06.4.3 Emerging Pollutants

The term (chemical) ‘emerging pollutant’ is used to describe a wide variety of complex organic chemical compounds that are candidates for future regulation and that have not usually been monitored. To detect them, complex and costly analytical equipment is needed, such as GC-MS or GC-MS-MS (gas chromatography coupled with one or two mass spectrometers) as these are the only ones capable to measure the very low concentrations at which the pollutants are present (in the order of micro- or ng l⁻¹) and to identify them. Emerging pollutants have been detected in untreated wastewater, treated wastewater, surface water, groundwater, and even in drinking water of both developed and developing countries (some). Among the countries that have measured and detect emerging pollutants, the following can be cited: Austria, Brazil, Canada, Finland, Germany, Italy, Japan, Mexico, the Netherlands, Spain, Switzerland, UK, and USA (Jiménez, 2009b).

The sources of emerging pollutants are diverse. They come from nonpoint sources, municipal wastewater (treated or nontreated), and industrial discharges. They are also the result

of the improper disposal of solid wastes. Two groups of compounds that are considered as emerging pollutants are: endocrine disrupter compounds (Box 1) and personal care and pharmaceutical products (PCPPs).

Wastewater treatment processes have not been designed to remove them; thus, they are randomly removed during conventional treatment. From the limited literature currently available, emerging pollutants – as other organic compounds – are concentrated in sludge during wastewater treatment. Initial risk studies suggest minimal ecological and health effects through biosolids recycling to soils (LeBlanc *et al.*, 2008). As most of these pollutants have only been recently studied, the knowledge of their fate, transport, behavior during treatment, and risks is still poor in the sanitary engineering field. Chemical emerging pollutants, in general, are not considered at the moment as a priority for the developing world as there are more pressing health and environmental pollutants of concern.

4.06.4.4 Risks

It is important to bear in mind that the simple presence of a pathogen or a toxic chemical in wastewater, sludge, or excreta does not necessarily mean that a negative effect will occur. For that, several other things need to happen. These include (1) the need for a compound/pathogen to reach a certain concentration; (2) the existence of a pathway for transmission to human or the environment; (3) the ingestion or presence of a certain dose to cause long- or short-term effects; (4) sufficient exposure times to the pollutant; and (5) sufficient sensitivity of a person or of the environment to pollutants. In addition, it should be remembered that, for humans, water is not the only source of risk, as food and air are also sources of pollutant ingestion and, in some cases, they may be the main ones. In terms of the differences of biological risks to humans in developing and developed countries, there are additional aspects to consider as humans develop immunity to pathogens depending on the type of environment they are exposed to, and thus infectious doses may be higher. Genetic history, nutrition, and the combination of social patterns also intervene. For these reasons, data developed for developed countries are not always applicable to developing ones to perform risk analysis.

In order to quantitatively assess risks, it is necessary (1) to establish the type and quantity of given microorganisms in a region, (2) to know the actual infectious dose, and (3) to define and evaluate the possible infection route. To

quantitatively evaluate the risk from a chemical or microbial pollutant, several methodologies are available in literature, but the data needed to apply them may be lacking for special cases in developing countries.

4.06.5 Sanitation in Low-Income Countries: A Complex Current Situation

4.06.5.1 Sanitation Needs a Definition

Sanitation is a term that has a clear meaning in the developed world. However, for the developing one, there is need to have a better definition. Traditionally, sanitation has been reported as the percentage of the population having access to the service. In practice, this service in low-income regions ranges from simple access to sewers that are discharging the wastewater just behind households or into the streets to sewers connected to sophisticated wastewater treatment plants coupled with water reuse projects and comprising safe sludge management practices. For basic sanitation – sanitation provided in rural or poor periurban areas, the term sanitation includes a wide variety of on-site sanitation options going from simple pit to highly comfortable package treatment plants, which may or may not be functioning. To overcome this, the Joint Monitoring Programme (JMP) from WHO-UNICEF proposed in 2000 to introduce the term ‘improved sanitation’. Improved sanitation is a system in which excreta are disposed of in such a way that the risk of fecal–oral transmission to users and to the environment is reduced (WHO–UNICEF, 2008). Table 6 shows which options qualify as improved sanitation and which do not.

Table 6 Improved and unimproved sanitation facilities according to WHO–UNICEF (2008)

<i>Improved</i>	<i>Unimproved</i>
Connection to public sewer or septic tank	Service or bucket latrine
Pour-flush latrine	Traditional latrine
Pit latrine with slab	Public latrine or shared toilet
VIP latrine	Open pit or pit latrine without a slab
Ecological sanitation	Open defecation in bush or field

In 2002, the World Summit on Sustainable Development (WSSD) provided a definition for basic sanitation that, besides considering the service itself, considered its impact on human health. This definition comprises the following:

- the development and implementation of efficient household sanitation systems;
- the improvement of sanitation in public institutions, especially in schools;
- the promotion of safe hygiene practices;
- the promotion of education and outreach focusing on children, as agents of behavioral change;
- the promotion of affordable and socially and culturally acceptable technologies and practices;
- the development of innovative financing and partnership mechanisms; and
- the integration of sanitation into water resources management strategies in a manner that does not negatively affect the environment (it includes protection of water resources from biological or fecal contamination).

As a result, the WSSD’s focus is not only on the construction of a particular number of toilets but also on the effective improvement of health and hygiene through basic sanitation. However, still new elements are needed to be added as problems caused by lack of sanitation are combined with those arising from the lack of economic resources and frequently also with lack of water in societies lacking even from social, economical, and political rights (Box 2).

4.06.5.2 Millennium Development Goals

The Millennium Development Goals (MDGs) are drawn from the actions and targets contained in the Millennium Declaration that was adopted by 189 nations and signed by 147 heads of state and governments during the UN Millennium Summit held in New York City on September 2000 (WHO–UNICEF, 2009). They comprise eight goals and 21 quantifiable targets. Water is part of the 7th Goal under Target 7c: “Reduce by half the proportion of people without sustainable access to safe drinking water and basic sanitation.” Fulfilling this target represents the challenge of providing safe water supply to 1.1 million people and safe sanitation to 2.6 million people within 15 years.

Box 2 What sanitation should include, with some information from Lenghton L, Wright A, and Davis K (eds.) (2005) *Health, Dignity and Development: What Will It Take? Millennium Development Goals*. London: Earthscan.

- Safe collection, storage, treatment and disposal, reuse, or recycling of human excreta (feces and urine).
- Drainage and safe disposal, reuse, or recycling of household wastewater (often referred to as sullage or grey water).
- Management, minimization, reuse, and recycling of solid wastes (trash or rubbish). Use of goods producing less solid wastes.
- Drainage, safe management, and even reuse or recovery of storm water.
- Treatment and disposal, reuse, or recycling of sewage effluents and wastewater by products.
- Collection and management of industrial waste products, and, the promotion of cleaner industries, vis-à-vis water.
- Management of hazardous wastes (including hospital wastes and chemical, radio-active, mining, petrochemical, and other dangerous substances).
- The use of sanitation as a way to properly reintegrating water, organic matter, and nutrients into the environment in order for them to be safely used again.
- Provision of water in a sufficient amount to maintain clean households and to allow proper hygienic habits.
- The recognition of a right for sanitation at the same level of the right to water.
- The sanitation as an instrument to differentiate social classes, gender, children, and ethnic groups.

Box 3 Some figures for global sanitation

- For each four persons that do not have access even to a simple pit latrine, six have it.
- For each one person that does not have access to sanitation, another one has it.
- In rural areas, for each two persons, only one person has access to a sanitation service.
- For each 7 l of wastewater that is nontreated, 1 l is treated.

4.06.5.3 Present Situation

Reporting figures concerning the state of sanitation in the developing world is a difficult task. First, there is a lack of information; second, the information available is generally presented in a heterogenic way; and third, different sources tend to contradict each other despite national and international efforts to produce consensus.

4.06.5.3.1 General overview

The worsening situation with regard to sanitation in developing countries can be described using different indicators (Box 3). Contaminated water and poor sanitation account for the vast majority of the 1.8 million child deaths each year from diarrhea – almost 5000 every day – making it the second largest cause of child mortality (UNDP, 2006). The expansion of water services is essential to reduce the burden of water-related diseases and to improve the well-being of a large part of the world's population. It is also vital for economic development and poverty alleviation (WHO, 2004). According to the figures presented by WHO-UNICEF (2006), despite the efforts made and due to population growth, between 1990 and 2004, the population with access to sanitation services has increased from 2569 million to 3777 million (47%), while the net number of people without improved sanitation decreased by only 98 million.

4.06.5.3.2 Regional situation

The difference between the level of sanitation in developed and developing countries is high: 99% versus 50% (Table 7). However, between 1990 and 2004, the percentage of people with access to improved sanitation increased from 35% to 50% with countries' variations ranging from 37% to 88% (WHO-UNICEF, 2006). The difference observed between rich and poor countries is also observed between urban (77%) and rural (33%) areas from developing countries and as well between rich and poor people living there following the inequities of wealthy distribution.

4.06.5.3.3 Situation at the national level

The sanitation coverage as percent of the population with service per country is presented in the map of Figure 6 for the year 2004. Annex 3 contains a table with countries with less of 60% of the total, urban, or rural population.

4.06.5.3.4 Low-income countries sanitation specificities

Sanitation in developing countries is quite a complex issue, because the lack of it is combined with other several problems, some of which are geographically described on the Maps 1–8

Table 7 Sanitation coverage per region for 2004

Region	Coverage as % of the population		
	Total	Urban	Rural
World	59	80	39
Developed regions	99	100	98
Commonwealth of independent states	83	92	67
Developing regions	50	73	33
Northern Africa	77	91	62
Sub-Saharan Africa	37	53	28
Latin America and the Caribbean	77	86	49
Eastern Asia	45	69	28
Southern Asia	38	63	27
South-eastern Asia	67	81	56
Western Asia	84	96	59
Oceania	53	81	43

Coverages below 60% are highlighted in red and those above 80% in blue.

Data from WHO-UNICEF (2006) *Meeting the MDG Drinking Water and Sanitation Target: The Urban and Rural Challenge of the Decade*. Geneva: WHO and UNICEF.

from Annex 4. By analyzing these maps, the following conclusions may be drawn:

1. Several low-income countries are located in arid or semi-arid regions; thus, besides sanitation problems, they face the problem of water scarcity.
2. Many of the areas under greatest stress (where people are already overexploiting rivers by tapping water that should be reserved for environmental flows) coincide with areas that are heavily developed for irrigation to provide water for food, that is, mostly in developing countries.
3. Water withdrawal for agriculture is mainly performed in developing countries as a result of low water availability and the high dependence of agriculture.
4. Areas where poverty and hunger are prevalent coincide with areas lacking sanitation.
5. In the future, it seems that the situation may worsen as water availability will decrease in the countries already experiencing water-related problems, including lack of sanitation.

As result of the past and present situations, sanitation has different aspects on developing countries that cannot be described simply using the percent of population-covered index. In the following, some of these aspects will be described.

Basic sanitation versus sanitation. Providing services for excreta management in poor rural or urban areas is frequently known as basic sanitation. Thus, it has to do with excreta management rather than with sewerage and wastewater treatment plants (Box 4 and Figure 7). The quality of the service is frequently associated with peoples' economic level, and thus, is

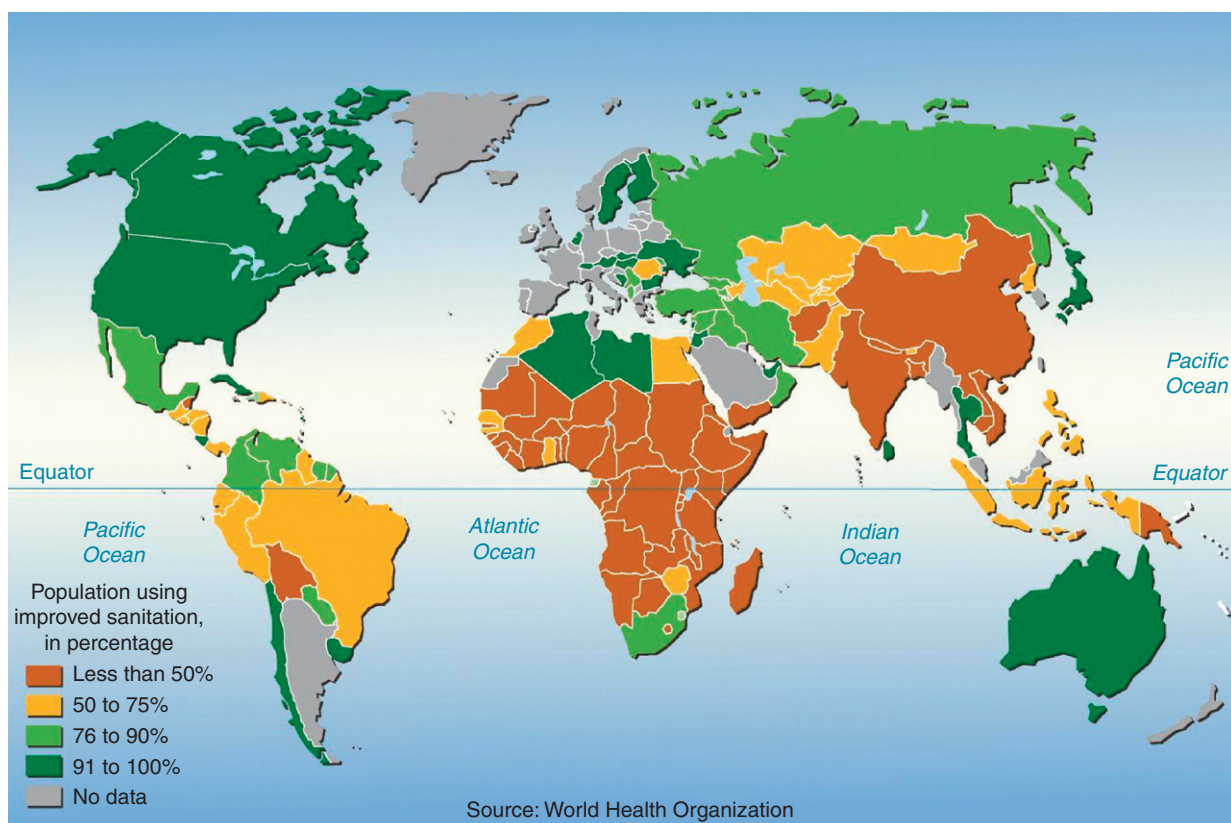


Figure 6 Sanitation coverage per country in 2004 (with information from WHO–UNICEF, 2006).

also a sign of status. Another aspect to consider is that the lack of basic sanitation frequently is associated with lack of water. LeBlanc *et al.* (2008) highlights that research and experience suggest the following hierarchy of risk to human health:

“living in a dense community without basic sanitation > (is more risky than...) irrigation of crops with untreated, pathogen-contaminated wastewater > use of untreated, pathogen-contaminated excreta or wastewater sludge on soils > use of untreated, pathogen-contaminated animal manures on soils > use of treated manures, wastewater, or biosolids on crops > use of these treated materials in accordance with strict modern regulations that address heavy metal and chemical contaminants.”

Differences on sanitation services. Possibly, one of the aspects that contributes the most to render sanitation in developing countries a challenge is the variety of needs and circumstances arising from social differences. As shown in Figure 8, for instance, poor people not only are less served but also the quality of the services is lower. One of the deepest disparities is between urban and rural areas as for the former the coverage is twice as much than for the latter in developing countries. Traceable differences in sanitation services have been reported as well among indigenous and nonindigenous people and minorities such as castes and women (Box 5). Among these differences, the following common challenges can be identified:

- The need to provide the service in poor areas with large population increases.

- For urban areas, a very fast service demand growth in slums that are spread out in cities, have high population density, and there is no land to place the infrastructure.
- For rural areas, the need to assist a population frequently dispersed and hence at higher cost.
- The need to fund projects combining liquid and solid waste collection and treatment infrastructure.
- The need to develop new or different management structures to provide services in social and political complex areas.
- The need to include health education and awareness programs on sanitation projects.
- The need to use public funding to provide services that are to be subsidized.
- The existence of regions having high income where services can be provided in a similar way to developed countries.

Sanitation versus wastewater treatment. As described previously, sanitation coverage does not necessarily result in wastewater being treated or safely disposed of. To illustrate this, figures for the situation in some developing countries are provided. Two comments on this figure are that (1) it is really difficult to find data on wastewater treatment, notably for the Asian and African regions and (2) although there should not be a full correspondence between the sanitation coverage and the wastewater treatment – as some people are served using basic sanitation facilities – the figures should not be as different as they are for some countries. In Latin-America, for instance, although the sanitation coverage was 78% in 2006, only 18%

Annex 3 Classification of countries per range of sanitation coverage, with information

Total	Urban	Rural
<i>Sanitation Coverage < 20%</i>		
Ghana		Cape Verde
Guinea		Solomon Islands
Cambodia		Togo
Burkina Faso		Micronesia, Federated States of
Ethiopia		
Niger		
Chad		
Eritrea		
<i>Sanitation coverage > 20% but < 40%</i>		
Afghanistan	Chad	Azerbaijan
Angola	Congo	Belize
Bangladesh	Eritrea	Brazil
Benin	Gabon	China
Burundi	Ghana	El Salvador
Central African Republic	Guinea	Lao People's Democratic Republic
Comoros	Sao Tome and Principe	Lesotho
Congo		Mongolia
Congo, Democratic Republic of		Nepal
Côte d'Ivoire		Peru
Gabon		Senegal
Guinea-Bissau		Timor-Leste
Haiti		Yemen
India		
Lao People's Democratic Republic		
Lesotho		
Liberia		
Madagascar		
Mauritania		
Micronesia, Federated States of		
Mozambique		
Namibia		
Nepal		
Sao Tome and Principe Solomon Islands		
Somalia		
Sierra Leone		
Sudan		
Timor-Leste		
Togo		
<i>Sanitation coverage > 40 but < 60%</i>		
Azerbaijan	Afghanistan	Colombia
Belize	Angola	Djibouti
Bolivia	Bangladesh	Egypt
Botswana	Benin	Fiji
Cameroon	Bolivia	French Guiana
Cape Verde	Botswana	Gambia
China	Burkina Faso	Guyana
Equatorial Guinea	Burundi	Honduras
Gambia	Cambodia	Indonesia

Annex 3 Continued

Total	Urban	Rural
Indonesia	Cameroon	Iraq
Kenya	Comoros	Kazakhstan
Kiribati	Central African Republic	Kyrgyzstan
Korea, Democratic People's R.	Côte d'Ivoire	Maldives
Kyrgyzstan	Congo, Democratic Republic of the	Marshall Islands
Maldives	Equatorial Guinea	Mexico
Mali	Ethiopia	Moldova, Republic of
Mongolia	Guinea-Bissau	Morocco
Nicaragua	Haiti	Palau
Nigeria	India	Panama
Pakistan	Kenya	Pakistan
Papua New Guinea	Kiribati	Papua New Guinea
Rwanda	Korea, Democratic People's R.	Philippines
Senegal	Liberia	South Africa
Swaziland	Madagascar	Tajikistan
Tajikistan	Mali	Turkmenistan
Tanzania, United Republic	Mauritania	Vanuatu
Uganda		
Vanuatu	Mozambique	Viet Nam
Yemen	Namibia	Venezuela
Zambia	Nicaragua	Zimbabwe
Zimbabwe	Niger	
	Nigeria	
	Somalia	
	Rwanda	
	Sudan	
	Sierra Leone	
	Swaziland	
	Tanzania, United Republic of	
	Uganda	
	Zambia	

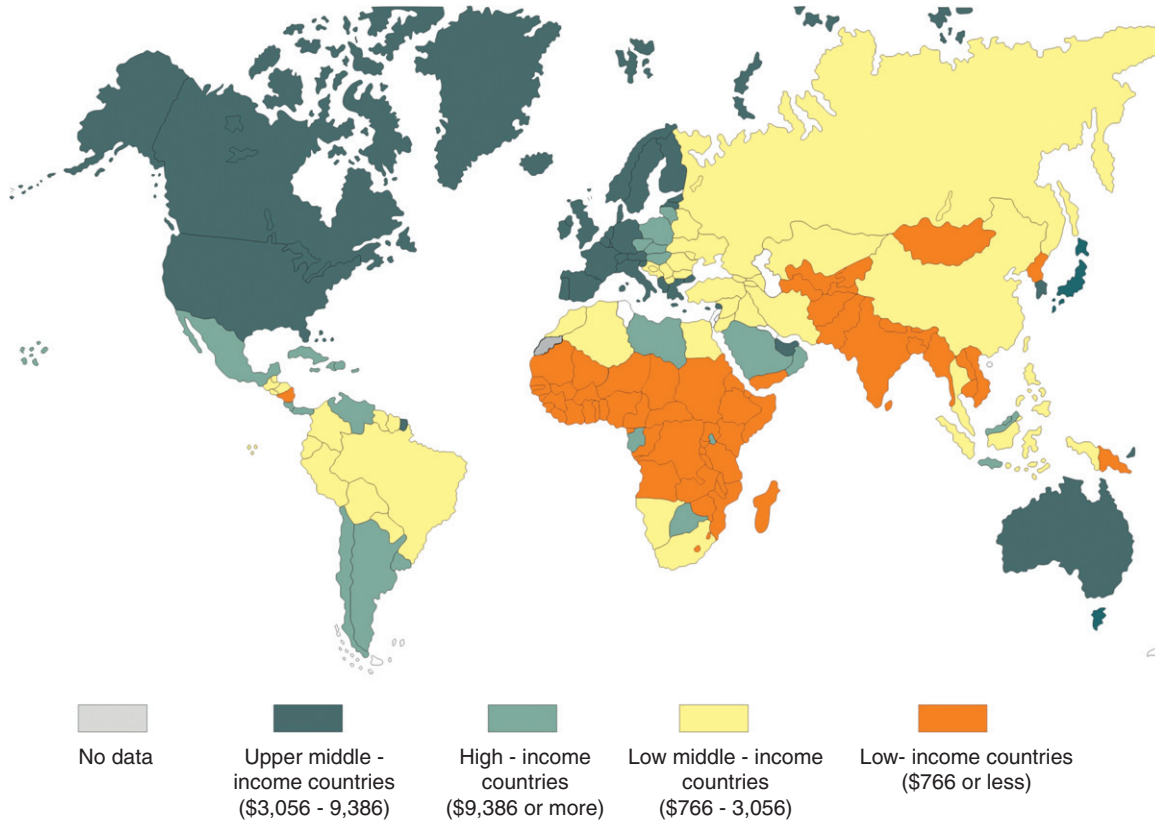
From WHO–UNICEF (2006) *Meeting the MDG Drinking Water and Sanitation Target: The Urban and Rural Challenge of the Decade*. Geneva: WHO and UNICEF.

of the wastewater was treated (CONAGUA and WWF, 2006). To give an idea of the situation in other regions, for the year 2004, when the Latin America and the Caribbean region reported a treatment capacity of 14%, this was of the order of 35% for Asia and nearly 0% for sub-Saharan Africa (WHO/UNICEF, 2000; Figure 9).

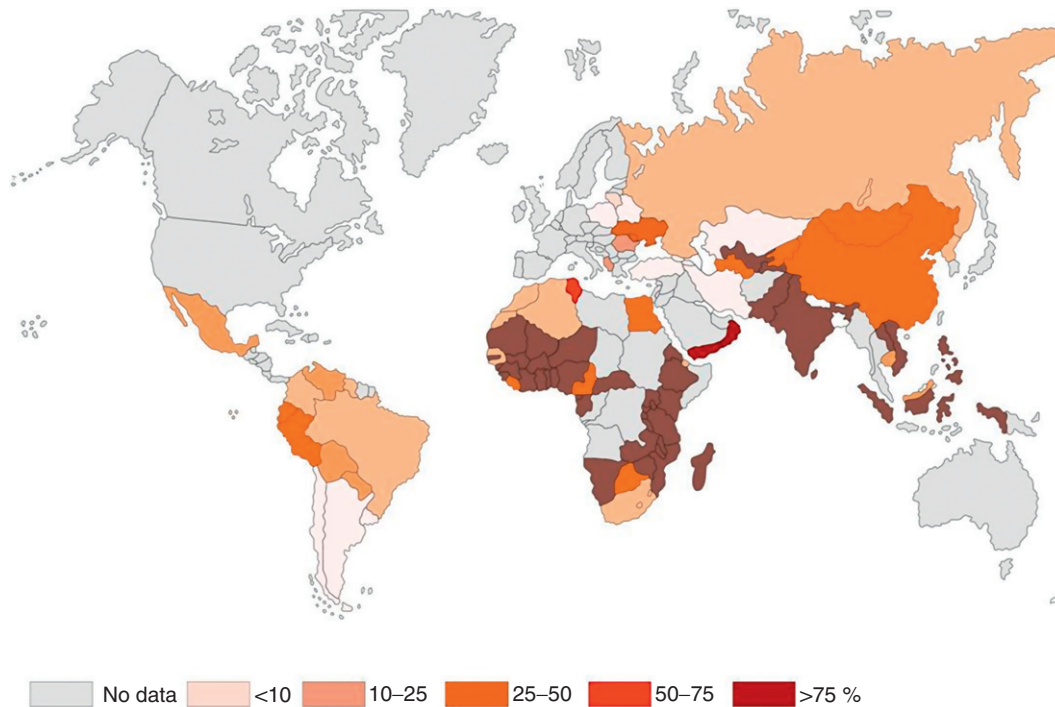
4.06.5.3.5 Sanitation Costs

According to Loughton *et al.* (2005), the amount of money needed to fulfill the sanitation MDGs ranges from US\$24 billion to US\$42 billion representing, in mean conditions, an annual average investment of US\$2.2 billion. To put these figures in perspective, the above-mentioned authors mention that each year Europe and the United States spend US\$17 billion on pet food and Europe spends US\$11 billion on ice cream. The overall cost estimation of the current water and sanitation deficit is of the order of US\$170 billion, equivalent to 2.6% of developing countries' gross domestic product (GDP). For each US\$1 invested for sanitation, the economic

Annex 4

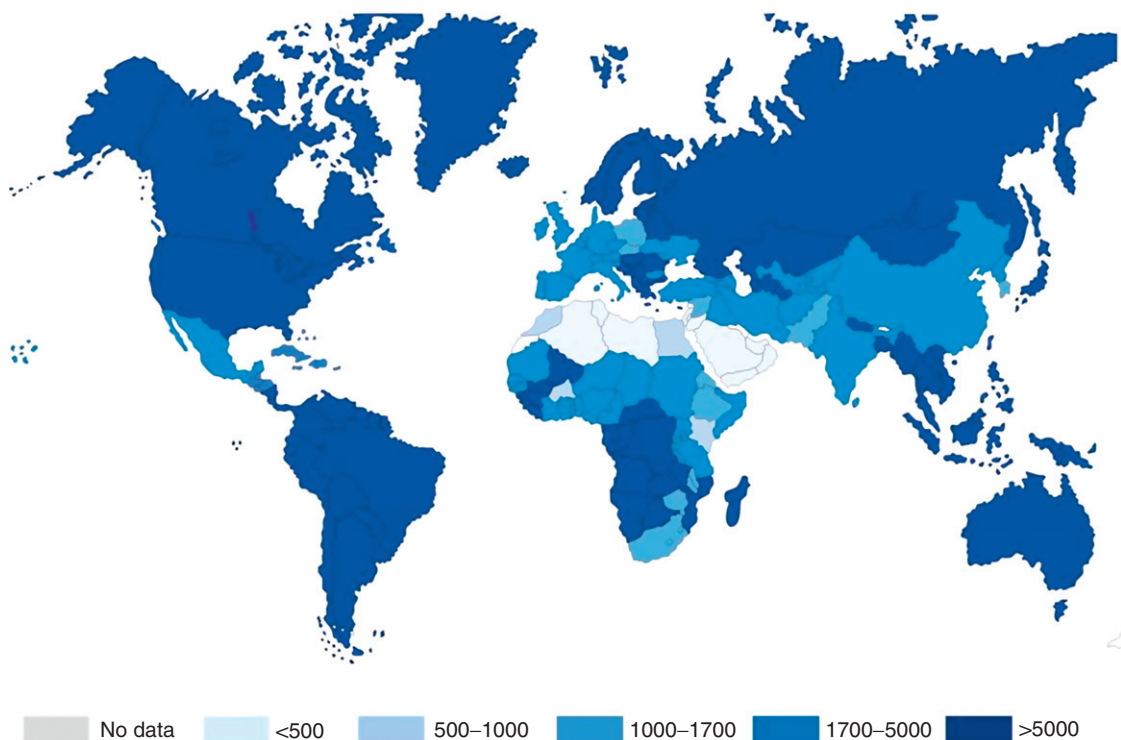


Map 1 Economic income per country, with information from World Bank 2009.

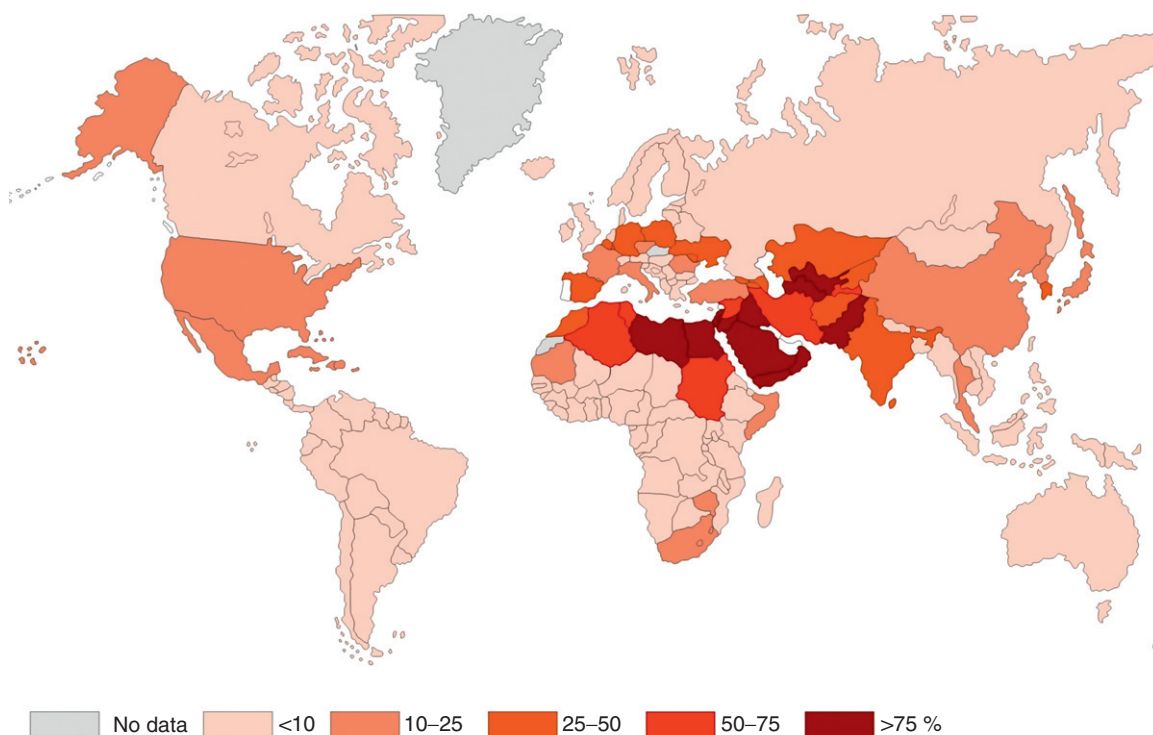


Map 2 People living at under 2 USD/day, UNDP, 2006 with data from <http://earthtrends.wri.org/povlinks/index.php>

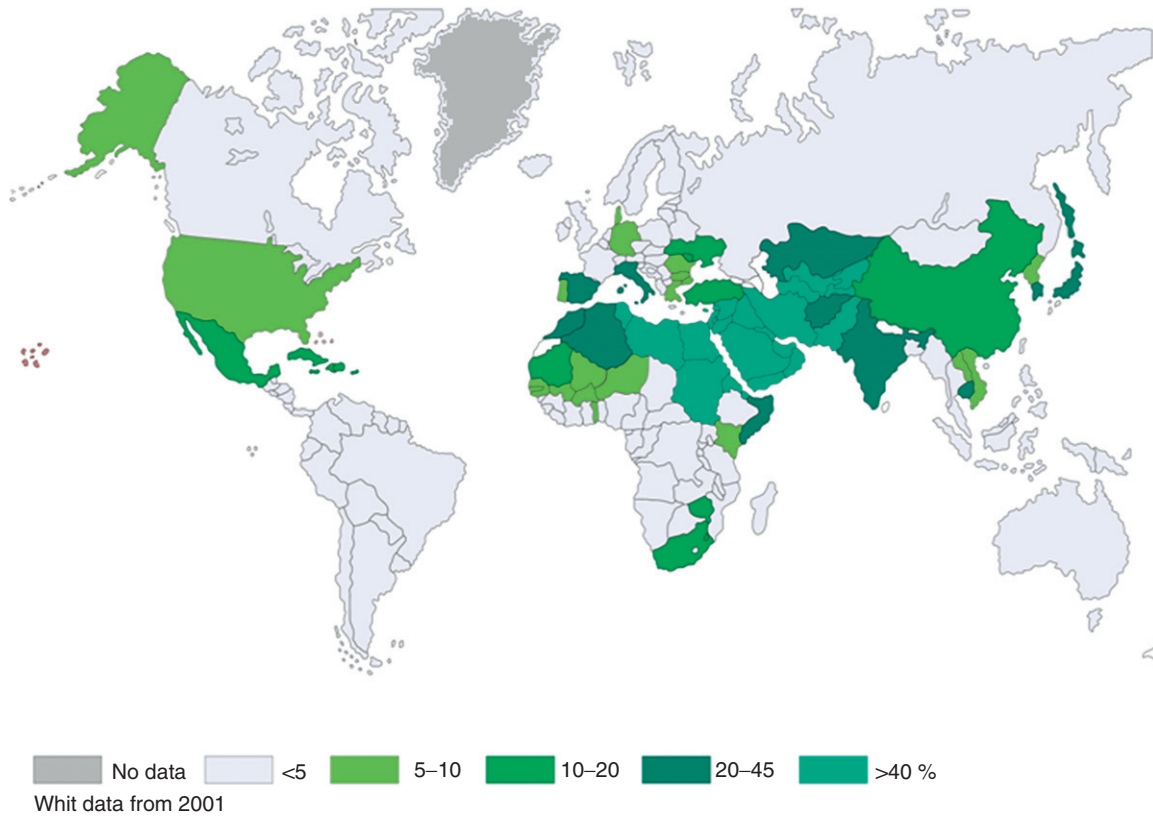
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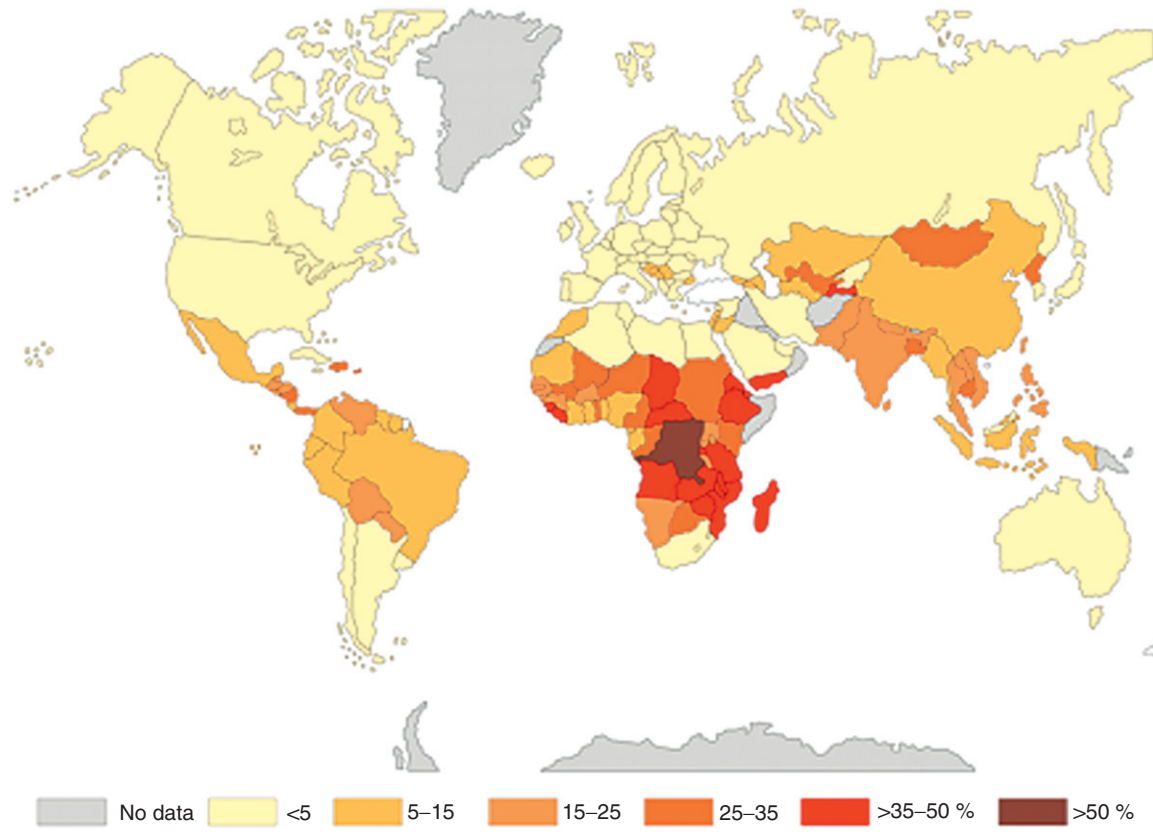
Map 3 Renewable water resources (surface and ground water) per inhabitant for 2005, with data from: FAO-Aquastat, 2009 <http://www.fao.org/nr/water/aquastat/globalmaps/>



Map 4 Water stress or water use intensity index (surface and groundwater withdrawal as percentage of the total renewable water resources) for 2001, with information from <http://www.fao.org/nr/water/aquastat>

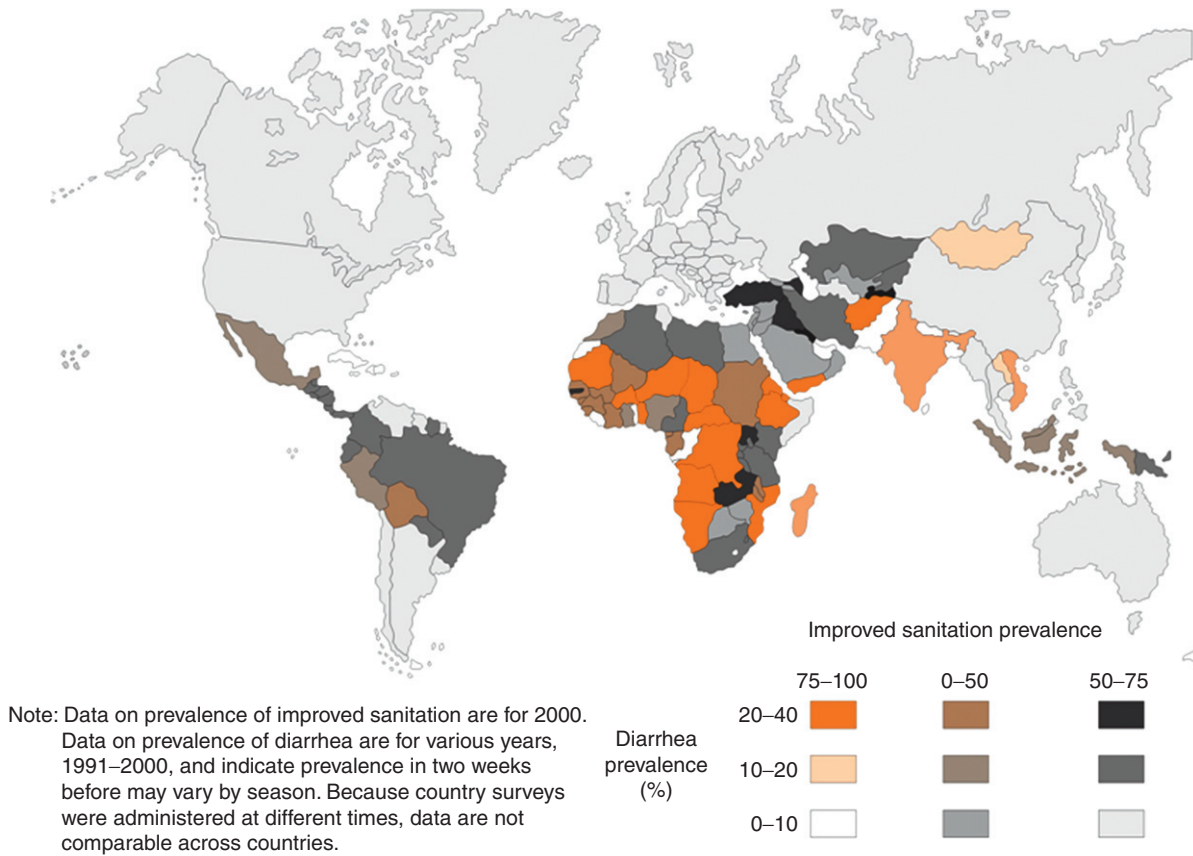


Map 5 Surface water and groundwater withdrawal for agricultural purposes as percentage of the total actual renewable water resources for 2001, with information from <http://www.fao.org/nr/water/aquastat/globalmaps>



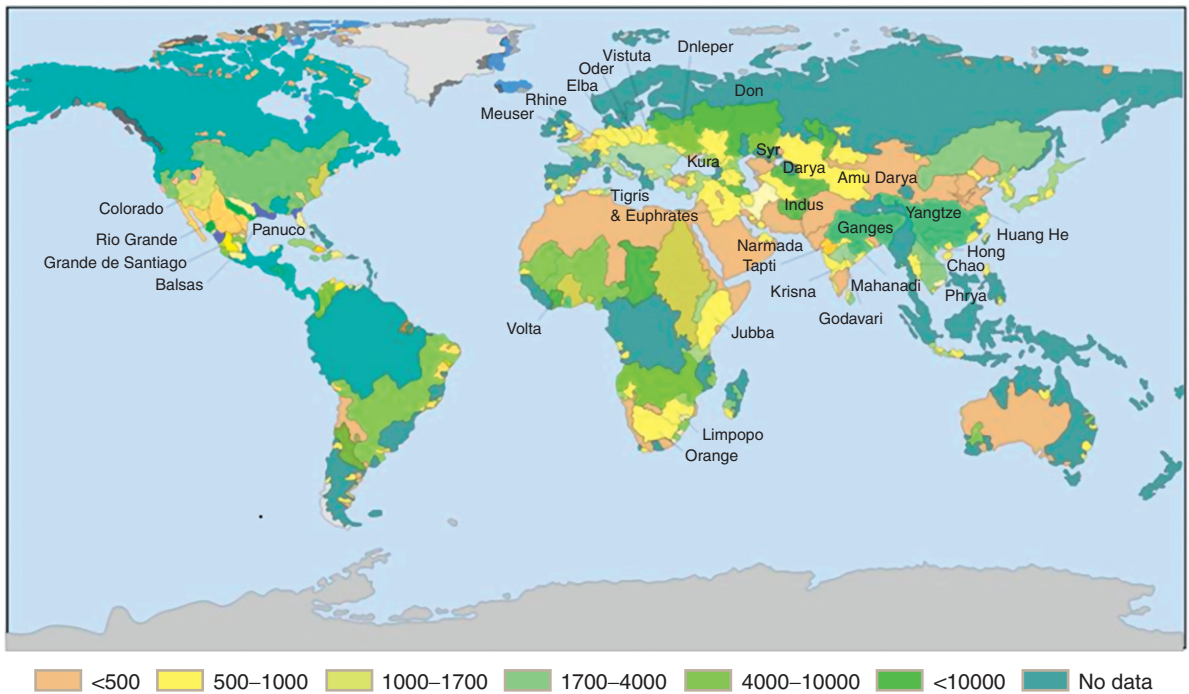
Map 6 Prevalence of undernourished people as percentage of total population for 2002-2004, with information from <http://www.fao.org/nr/water/aquastat/globalmaps>

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with data from FAO-AQUASTAT, 2007

Map 7 Prevalence of diarrhea and improved sanitation 2000 With information from: United Nation Children’s Fund Programme and The Joint Monitoring Programme Lenghton *et al.* (2005) UNPD Earthscan.



Map 8 Projected annual renewable water supply per person by river basin for the year 2025. With information from From: Water Resources eAtlas, 2007 http://earthtrends.wri.org/pdf_library/maps/2-4_m_WaterSupply2025.pdf

Box 4 Some challenges to provide basic sanitation in low-income countries

- Open defecation is practiced by 48% of the population in Southern Asia and 28% in sub-Saharan Africa.
- In Ouagadougou, the capital of Burkina Faso, the access to sanitation facilities is 53% while the figure for the country is 15.6%, a figure that reduces to only 10% for rural areas (Paskalev, 2008).
- In Yaoundé, Cameroon's capital with 2 000 000 inhabitants, the available facilities for most people (88%) are external and in shared proprieties (Figure 7).
- Basic sanitation and sanitation figures reported are not the same. For instance, for Cote d'Ivoire, a coverage of 45% is reported for rural areas, but, in fact, 36% refers to basic facilities and only 9% to adequate systems (Angoua, 2008).

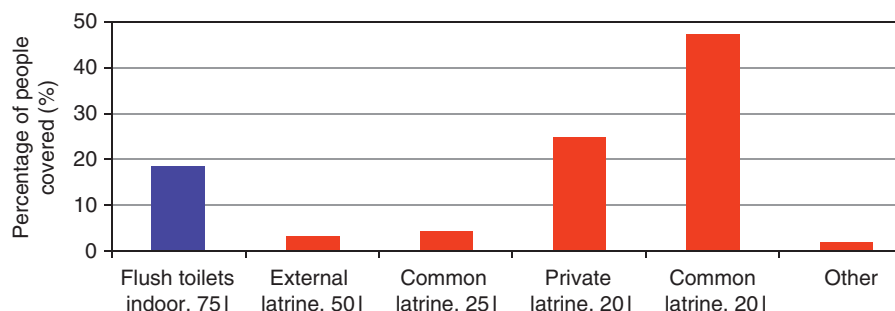


Figure 7 Type of toilets used in Yaounde indicating the amount of used water per day and inhabitant: estimation for 2007. Data from Mfoulu N (2008) Cameroon. In: LeBlanc RJ, Matthews P, and Richard RP (eds.) *Global Atlas of Excreta, Wastewater Sludge, and Biosolids Management: Moving Forward the Sustainable and Welcome Uses of a Global Resource: UNHSP*, pp. 169–179.

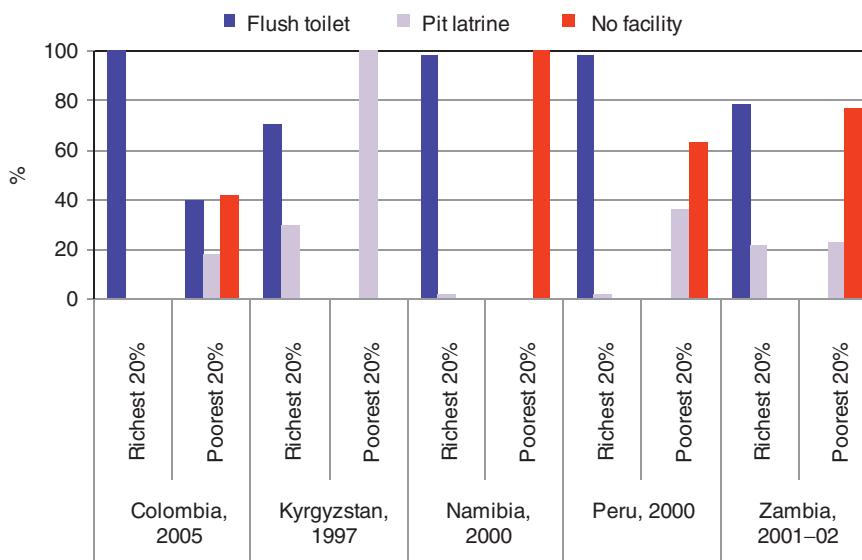


Figure 8 Type of facilities provided for the richest and poorest quintiles in some countries. Data from Lenghton L, Wright A, and Davis K (eds.) (2005) *Health, Dignity and Development: What Will It Take? Millennium Development Goals*. London: Earthscan.

return would be between 3 and US\$34, depending on the region and the type of technologies used (WHO-UNICEF, 2004). Studies performed in Egypt and Peru showed that just providing access to flush toilets reduced the risk of infant death by 57–59% (Lenghton et al., 2005).

4.06.6 Wastewater Management Systems

Even if sanitation represents an economic benefit, its cost is still important to societies in which this is not the only

requirement. Therefore, it is useful to combine options that involve building infrastructure with others that do not (such as washing or cooking produce that has been irrigated with polluted water) in order to improve health conditions while the sanitation services can be gradually provided. Such an approach is described in WHO (2006). In the next sections, options to build up wastewater management systems are reviewed. A wastewater management system (WWMS) is understood in this chapter as the combination of one or several of the following components: (1) basic sanitation facilities or toilets; (2) wastewater collection systems (sewers) or

Box 5 Women and sanitation (with information from Lenghton L, Wright A, and Davis K (eds.) (2005) *Health, Dignity and Development: What Will It Take? Millennium Development Goals*. London: Earthscan.)

One explanation for the low effective demand for sanitation is gender inequality. Women tend to place a higher value on household toilets than do men for a number of reasons, among them privacy, cultural norms, care-giving responsibilities, and the risk of sexual harassment and assault. In addition, the unique sanitation needs of women and girls (e.g., during menstruation and during and after pregnancy) receive little recognition when discussions about sanitation and hygiene occur. Yet, the limited political and personal power of women in many developing countries means that some of sanitation's strongest advocates are virtually absent from decision making and priority-setting processes.

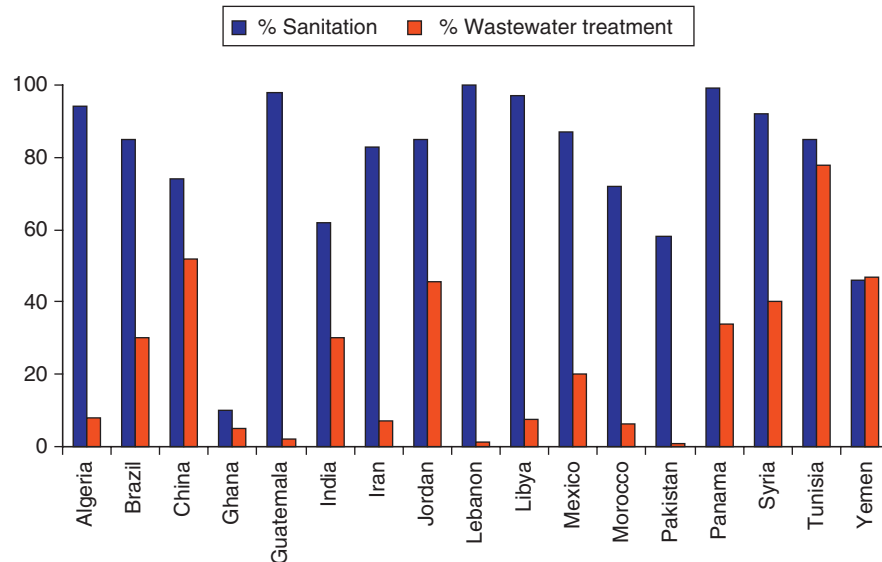


Figure 9 Percentage of sanitation coverage and treated wastewater. Data from CONAGUA and WWC (2006) Regional Document for the Americas Prepared for the 4th World Water Forum. Ciudad de México, Mexico, 16–22 March. Vienna: UN, Hashimoto (2009, personal communication), Wikipedia (2009), and Bahri A (2008) Water reuse situation on the Middle Eastern and North African countries. In: Jiménez B and Asano T (eds.) *Water Reuse: An International Survey of Current Practice, Issues and Needs*, pp. 27–48. London: IWA Publishing.

excreta extraction mechanisms; (3) wastewater treatment plants; (4) sludge management and disposal units; and (5) wastewater disposal or reuse facilities. Before presenting these components in detail, the two options in which they can be managed (centralized or decentralized) are discussed.

Conventionally, to handle wastewater, sewers connected to wastewater treatment plants have been used. This is known as a centralized system and is a well-mastered and well-managed technology approach applicable to cities, provided funds for its construction and operation are available. In terms of operation, centralized systems are often cheaper and easier to handle than decentralized ones.

For isolated slums and dispersed rural areas and even for cities where new sewerage systems is too costly, it is advisable to use decentralized wastewater management systems. In these, sewers of reduced size result in a lower capital cost (around 30%) due to the smaller diameter and length of the used pipelines. In addition, they offer the following benefits (Lenghton *et al.*, 2005; Correlje and Schuetze, 2008): (1) they allow investments to be made stepwise, in line with available funds, local development, and population growth; (2) they are used in smaller areas of service that are easier to manage; (3) they allow the use of different technologies to provide services to different socioeconomic groups; and (4) they facilitate the reuse of water on-site. Nevertheless, all these advantages need to be assessed in practice, as they cannot be taken for granted

universally. As for many water utilities, decentralized systems represent a higher number of systems to manage, which is difficult and complex; to overcome this limitation, centralized management of decentralized systems is recommended. This way it is possible to ensure high performance and reliable operation, reduce costs, and also ensure the need for specialized operators (Hughes *et al.*, 2006).

4.06.6.1 Basic Sanitation Facilities

From a technical point of view, there are four important components to consider when providing a basic sanitation service: (1) the type of toilet, (2) the storage facility for feces which frequently are associated to the toilet, (3) the way in which feces are extracted from the pit, and (4) their further management. This section deals with the first two components. Their main characteristics are discussed here; for design, it is recommended to consult specialized books. A good option to begin with is the United Nations Environment Programme (UNEP) website (see section titled 'Relevant websites').

4.06.6.1.1 Traditional latrines

Latrines are the most widespread type of on-site sanitation facility. They are used in rural settings and deprived areas in cities. They consist of a makeshift pit dug in the ground and

generally covered with any material (a wooden, plant, or metallic cover, whichever is available). When latrines are full they can be emptied (this is unpleasant and has an associated cost) or closed to build another one (this requires the availability of land).

4.06.6.1.2 Ventilated improved pit latrine

These latrines, instead of having a single vault, are made up of a shallow pit divided into two 1–2 m³ vaults. Their major advantage is that they are a permanent facility due to the alternate use of each pit. The name comes from the inclusion of a properly designed pipe allowing ventilation, which also requires a screen to avoid the accumulation of flies. The pit cover is made of precast concrete, wood, palm leaves, or metallic material, and is removable. Emptying is performed manually in low-income areas, but can be done mechanically every 3–4 years. The ventilated improved pit (VIP) latrine with multiple pits can be built for collective use, such as in schools, markets, fueling stations, and administrative buildings (Mamadou, 2008).

4.06.6.1.3 Septic tank

The septic tank is commonly used as primary treatment in rural areas, low-income urban settings, isolated households, or on sites where soil is not suitable for the installation of sewers (Jiménez and Wang, 2006). They are built where a constant water supply is available and are used to partially treat domestic wastewater and to digest the settled sludge. They remove around 50% of the organic matter and suspended solid content in 2–4 days. For sludge digestion, 0.5–1 year is required; during this time, sludge is mineralized and its volume is reduced. Septic tanks are made up of a series of communicating chambers. They must be water sealed to avoid underground infiltration and are built using bricks, mortar, or concrete. A variation of the septic tank is the Imhoff tank, having the advantage of a shape that allows the removal of suspended solids and the control of foul odors in a better manner. Septic tanks need to be periodically cleaned (1–2 times per year, leaving 20% of the mature sludge as inoculum for digestion). This represents an additional cost that cannot always be afforded by poor people. Septage (the slurry taken out of septic tanks) is sent to wastewater treatment plants or treated separately. To treat septage, lime is frequently added until a pH of 12 is reached, over a period of 30 min (Jiménez and Wang, 2006). Effluents from septic tanks are discharged into trenches for subsoil infiltration or diverted to the sewerage system (when available). Septic tanks are widespread sanitation systems but are often responsible for environmental pollution due to poor purification effects and leakages notably affecting groundwater.

4.06.6.1.4 Composting toilets

Composting toilets are characterized by the separation of urine and feces. For this reason, they are also referred to as urine diversion (UD) toilets. They are constructed with two vaults or chambers. When the first vault is full, the pedestal is moved over to the second vault, and the first hole is closed. When the second vault is full, the first vault is emptied and so on. The urine is diverted to a soakaway. In comparison to VIP

latrines, they have a lower cost associated with emptying the pits (Snyman, 2008). Urine is collected in small cans (10–20 l) and can be used to enrich the soil after a stabilization period of 30 days. Feces are treated using an aerobic composting process. To control odors and to assist in the mineralization of feces, materials, such as ashes or pieces of wood, are used daily to raise the pH. The pathogens in fecal matter are inactivated over time through the drying process so they can be safely removed by the owner at no cost to the municipality. Once the sludge is digested, disinfected, and removed, it is used as fertilizer.

UD toilets are seen as a viable option for rural applications. The main reasons are that they are cost-effective and, since the rural community is accustomed to the use of manure, the UD toilet is socially acceptable. However, its use in periurban areas is more problematic. The emptying of the vaults requires large-scale programs for which small businesses can contribute to the emptying of tanks (from UD or VIPs) either manually, using appropriate safety equipment, or by the use of a tanker. The disposal of the fecal matter in periurban areas is challenging due to the lack of land. If space allows, fecal sludge is buried on-site. Where this is not feasible, the sludge is blended into the waterborne system. This frequently leads to the complete overloading of the wastewater treatment plant (Snyman, 2008). There are several options of composting toilets (see section titled 'Relevant websites').

4.06.6.1.5 Pour-flush toilets

Pour-flush toilets have been developed based on traditional flush toilets, which rely upon a water seal to perform cleansing and to control odors and insect infestations. The system works via a manual flush, where 2–3 l of water are poured into the toilet. The water, urine, and excreta are collected in an anaerobic chamber, which works similarly to a septic tank. The chamber needs to be periodically emptied and the partially treated wastewater needs to be disposed of, normally to land (Hughes *et al.*, 2006). In the context of water-scarce areas, a very interesting option is combining graywater reuse with basic sanitation using pour-flush toilets. This concept was developed by United Nations International Children's Emergency fund (UNICEF) on a system called the Wise Water Management scheme (Godfrey *et al.*, 2007). This system was conceived to provide both water supply and sanitation services for water-scarce areas and can be used for both rural and low-income urban areas. It was conceived in Madhya Pradesh, India, a densely populated and poor area. The WWMS uses groundwater as the primary source of water and also includes rainwater harvesting, used to dilute groundwater when polluted with fluoride to reduce its content for human consumption (Figure 10). First-use water is employed for cooking, handwashing, and bathing. Water from these two activities is recovered and properly treated in a sand filter to be used for toilet flushing and kitchen garden irrigation. The graywater reuse system can be installed independently of the rainwater harvesting system. By matching water demands, in quantity and quality, to different conventional and nonconventional water sources, the WWMS increases water availability by nearly 60%. Sanitation using low-consumption reused water flush

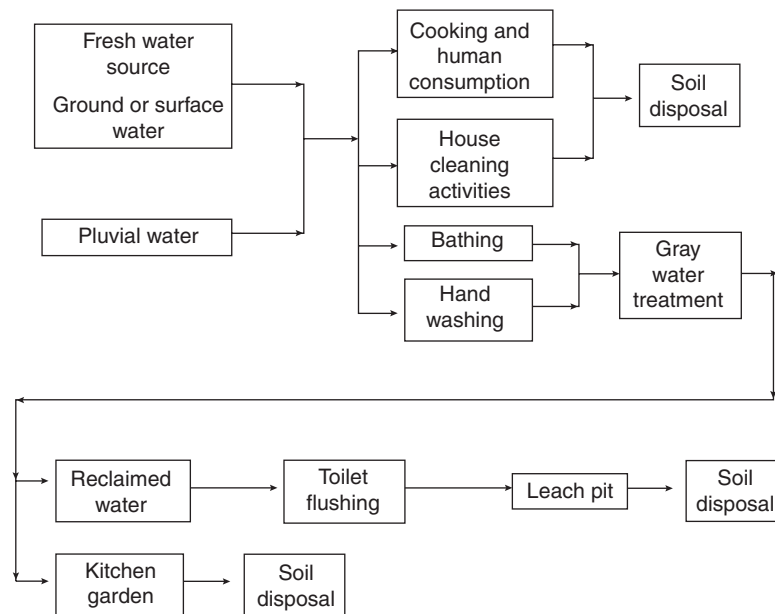


Figure 10 Flow diagram of the Wise Water Management Scheme.

Box 6 Poor people have a globalized attitude towards excreta management

As described for Senegal by Ba (2008), in most poor areas of the developing world, water from baths and in some cases from showers are routed to septic tanks from which the effluent is sent to infiltration wells or trenches. Kitchen and laundry water is generally poured directly into the street, discharge areas in the wild, a well, a nearby river, or riverbed. Wastewater and noncollected solids are also frequently mixed creating breeding sites, odor problems, and development of flies.

toilets has proven sustainable under the prevailing local conditions and has eradicated open defecation.

4.06.6.1.6 Additional recommendations to set up basic sanitation facilities

One important aspect to keep in mind when selecting the technology is that facilities need to be operational and, to achieve this, there is a need to sustain them under operation from the economical, technical, and cultural perspectives. Investment costs are linked to the type of sanitation system selected, the construction materials, and labor. Frequently, to reduce costs, cheap materials and the users are employed to build the facilities. However, this may result in failures, as cheap material frequently means low quality and the users are not people experienced enough, even if trained. It is thus preferable to invest in good and durable material and to use experienced workers. In India, for instance, sanitation programs using professional well-trained masons are being implemented in which the same masons for whom sanitation is a source of income become at the same time sanitation promoters.

Norms and institutional capacity to provide basic sanitation constitute another weak link in the complex chain needed to implement and provide services. How to build institutions, policies, and human resources to provide successful sanitation services is better known in high-income countries

than in developing ones. Each country/region needs to look for the proper way to solve their problems. Finally, concerning basic sanitation, it needs to be considered that in several places, providing basic sanitation means to change open defecation habits and to handle domestic solid wastes (Box 6). It means as well to properly dispose of the toilet paper.

4.06.6.2 Toilets

Under this section, only the toilets using less water or none at all are described as compared to the others (pour flushing toilets using > 15 l of water is a well-known technology widely spread commercially). Concerning these toilets, one aspect to highlight is that even if convenient from the point of view of the used water, care must be taken when designing treatment plants as wastewater will be not only lower in volume but also highly concentrated, notably in terms of its organic matter content.

4.06.6.2.1 Water-saving toilets

These toilets are based on the same working principles as common flush toilets but they are specially designed to fully operate with less water (6–8 l). In such toilets, it is possible to select either a full flush (with 4, 6, or 9 l depending on the model) for solids or a half flush (2–4.5 l) for liquids.

These toilets are also available with separate drainage for urine to reduce the impact of nutrients and pharmaceuticals on the sewage and to facilitate the reuse of urine as a fertilizer. However, most water-saving toilets available on the market are designed to be connected to typical drainage systems. There are several technological options on the market, some of which use a vacuum to transport feces at a much higher cost. The investment cost for low-volume toilets is comparable to high-volume toilets. However, dual flush toilets may cost more than common ones (nearly double). The installation of water-saving toilets must be stimulated by education (e.g., in the form of campaigns to raise awareness concerning water-saving issues), water metering, and pricing. Water-saving urinals, using 1–3 l, are also available (Correlje and Schuetze, 2008).

4.06.6.2.2 Toilets not using water

The idea of dry toilets is not new. They have been used for thousands of years in East Asia (China, Japan, and Korea). Dry toilets are available as industrial prefabricated products and can also be constructed in local workshops; however, know-how for its good operation and to avoid foul odors is required. Investment, construction, or installation costs vary significantly and depend on the specific system and design. The cost ranges from low investment for simple dry toilets to comparatively high cost for industrialized composting toilets. Due to the large size of the storage and composting chambers, these toilets require a large space underneath; if this is not possible, then they need to be regularly emptied and feces need to be transported to treatment facilities. User acceptance depends on cultural background and awareness. Generally, people who are already using flush toilets do not readily switch to dry toilets because the image of dry toilets is less attractive than that of flush toilets.

4.06.6.3 Sludge Extraction from On-Site Sanitation System

Equally important as the type of on-site sanitation system selected is the provision of all the services associated. Past experiences (Water Decade, 1980–90) have shown that massive sanitation infrastructure provision without a proper planning of the whole scheme can be a complete failure (Koné, 2010). Besides the technical aspects that are discussed later, the most worrying aspect is the lack of financial, institutional, and regulatory framework in most of the developing countries to establish the network required. Management of on-site sanitation infrastructure comprises on-site sanitation systems emptying, fecal sludge haulage, treatment, and safe reuse or disposal (Koné, 2010).

Fecal sludges refer to sludge collected from on-site sanitation systems such as latrines, nonsewered public toilets, or septic tanks. The criteria to select an extraction method – a task that is never pleasant – depend on (1) the TS content and (2) the funds available. Sludges with less than ~2% TS, such as those produced in septic tanks, can be pumped; but, for the rest of facilities producing all sludge with 10% TS, pits need to be emptied using cesspit trucks or manually by laborers (Koné, 2010). Even though when mechanically emptied and water is used for toilet cleansing, 20–50% of the contents in the lower pit part need to be manually emptied to extract the thicker

sludge. The use of mechanical equipment allows carrying away the sludge several kilometers for disposal on controlled sites or on treatment facilities, but this is often expensive and needs proper equipment and skilled laborers. In contrast, when sludge is manually emptied, this is deposited in nearby lanes or on open spaces representing a source of risk. According to Koné (2010) 30–50% of the on-site sanitation facilities from West African countries are emptied manually. In addition, in almost every developing country, fecal sludge collection and haulage are conducted by private entrepreneurs. However, their important role and responsibilities as key stakeholders are not yet fully recognized and legalized (Koné, 2010).

4.06.6.4 Sewerage Systems

4.06.6.4.1 Small sewers

In many low-income areas, the sanitation problem begins with the lack of sewerage. One option is to build sewers of small extent coupled with on-site sanitation systems. Sewers carry the treated effluent to disposal (usually to soil for infiltration, to irrigation canals, or into water receptors), to wastewater treatment plants, and/or to reuse sites located within a short distance. As these sewers frequently convey partially treated wastewater (such as septic tank effluents), they are designed for self-cleaning using a high wastewater velocity and/or a steep slope. This option is applicable for rural areas or urban ones where adequate land is available.

Another option is to use simplified sewers. These are recommended where an uncertain population increase is occurring, as normally happens in periurban areas or slums. Small sewers are built to reduce the infrastructure and maintenance costs, as well to allow high operational flexibility. Inspection chambers such as manholes are replaced by inspection cleanout. The life expectancy of such sewers is in the order of 20 years rather than the 30 years quoted for conventional sewers. Such sewers are short and shallow (Hughes *et al.*, 2006). One example of simplified sewers are condominium ones in which pipelines are laid through housing lots instead of on the side street, in a way that allows isolated and stepwise construction (UNEP, 2002). Condominium sewers were developed in the 1980s in Brazil with the aim of extending sanitation services to low-income communities. This technology has now become a standard sanitation solution for some urban areas in Brazil, irrespective of income levels. Condominium sewers reduce the per capita costs of service by replacing the traditional model of individual household connections to a public sewer with a model in which household waste is discharged into branch sewers, and eventually into a public sewer through a group (or block) connection (Watson, 1999 cited in Lenghton *et al.*, 2005).

4.06.6.4.2 Conventional sewers

These are structures that are bigger and deeper than those previously discussed. Details for design can be found in conventional literature on sewers.

4.06.6.4.3 Pluvial sewers

Many developing countries are located within regions subject to tropical storms, or in areas where there are only two seasons per year: wet and dry. Therefore, urban hydraulic infrastructure

needs to be designed accordingly to have sewers that can handle large peaks of stormwater and the normal wastewater flows (wastewater treatment plants should also be capable of dealing with the varying wastewater characteristics in quantity and quality, at least in large cities). Sewers in tropical areas produce a high amount of sediments to be disposed off, which turns out to be a peculiar and difficult-to-solve problem not frequently commented upon in specialized literature but that needs proper methods to extract sludge and handle it. In addition, when conveyed in sewerage systems, stormwater must be treated in treatment plants at the same time as wastewater; but, if transported separately, it can be discharged to surface water or into wells for groundwater infiltration receiving treatment in soil. In this case, it must be kept in mind that stormwater quantity and quality are determined by rainfall, catchment processes, and human activities, which cause its flow and composition to vary in space and time. Normally, for the first rains of the year, stormwater has higher suspended solids, heavy metal content, and bacterial numbers than nontreated wastewater, and lower dissolved solids, nutrients, and oxygen demand than secondary-treated sewage effluent.

4.06.6.5 Wastewater Treatment

Wastewater treatment is the typical method applied for sanitation, and is the predominant option used in developed countries for that purpose. Although it cannot be considered a caveat for all the negative impacts produced by wastewater, it is still a very important option, and, in many cases, the only one. There are several steps to treat wastewater. The primary step basically serves to remove easily decantable and floating solids. The secondary one, generally a biological process, is used to remove biodegradable (mostly) dissolved suspended material. The tertiary step is used to refine the quality of the effluent produced by a secondary treatment. It may have different purposes, most commonly being the removal of nutrients (N and P). As the treatment steps were conceived following treatment needs, in practice, they are usually implemented in separate tanks or in well-defined sections of wastewater treatment facilities; however, it is possible to use compact processes eliminating physical separation among steps and thus reducing costs (Jiménez, 2003). Wastewater treatment plants are not common facilities in low-income countries. In contrast to developed countries, in developing ones, the sanitation figure (50% according to WHO-UNICEF (2006)) does not include the treatment of wastewater, which barely reaches 15% (US-EPA, 1992). Moreover, when available, the treatment merely consists of a primary step or including eventually a secondary step that is not always properly functioning. In many developing countries, the main issue concerning treatment is still the proper disposal of feces, particularly in low-income urban or rural areas. This, combined with a high content of pathogens in wastewater, sludge, or fecal sludge, implies the need to properly select the treatment process in order to effectively control disease dissemination. In general, coupling any kind of secondary wastewater treatment process (biological or physico-chemical) with a filtration step before disinfection will considerably reduce the pathogen content. However, this is rarely feasible for economic reasons and therefore it is sensible to consider the use

of other technologies alone or combined with other type of intervention methods to build up a multiple barrier system to control wastewater risks (Jiménez, 2009b). In the following sections, guidance will be provided to support the selection for treatment options, based on the type of pollutants.

4.06.6.5.1 Conventional pollutants treatment

To address problems caused by suspended solids, organic matter, nutrients, and fecal coliforms, there is a wide variety of available technologies supported by literature and practical results. Their affordability in economic terms and the suitability of the processes for local conditions are among the important aspects to consider for developing countries. It is beyond the scope of this chapter to provide a full description of treatment technologies for conventional pollutants, which can be found elsewhere in the literature. Table 8 shows the removal of pollutants by different processes so that it is possible to identify those acting upon the same type of pollutants.

4.06.6.5.2 Pathogens treatment

Table 9 presents organisms' removal or inactivation achieved by different wastewater treatment processes. This table is a guide for selecting a process. However, to design complete treatment schemes, the operating conditions need to be properly selected as well as the pre-and post-treatment. Table 9 differs from the one presented by WHO (2006) in showing the removal efficiency data for helminth eggs in terms of a percentage instead of log removal. This is because helminths eggs' content is by far much lower and log units are meaningless. For developing countries, the removal of protozoa and helminths eggs is the main concern, considering their content and the occurrence of diseases caused by these types of agents. To remove protozoa, filtration is a good treatment option. Conditions used to remove *Cryptosporidium* oocysts – the targeted protozoan for developed countries – can be used as well to remove protozoa relevant to developing countries.

Helminth eggs are not affected by conventional disinfection methods (chlorination, ultraviolet (UV) light, or ozonation); thus, they are first removed from wastewater using sedimentation, coagulation–flocculation, or filtration processes to be subsequently inactivated in sludge (Jiménez, 2008a). Removal occurs because eggs are particles 20–80 μm in size. It is estimated that for contents of 20–40 mg l^{-1} of TSS in treated wastewater, the concentration of eggs is around 3–10 eggs l^{-1} , while for values below 20 mg l^{-1} it is around 1 egg l^{-1} or less (Jiménez, 2008a). However, for a process to be reliable, besides the removal efficiency attained, it is important for it to produce an effluent with constant concentration.

4.06.6.5.3 Emerging chemical pollutants

The removal efficiency of emerging chemical compounds during conventional treatment can be found in Jiménez (2009b). It is recommended that experimental tests be performed under laboratory conditions, prior to treatment selection.

In the following, a description of main wastewater treatment processes is made, highlighting aspects that are relevant to developing countries, notably concerning their efficacy to control pathogens.

Table 8 Removal of pollutants by different wastewater treatment process that can be used to buildup a multiple barriers treatment scheme (with information from Jiménez (2003); Jiménez (2009), and Correlje and Schuetze (2008))

Pollutant	Process			Process																							
	ONSS	PS	BT	BT + NR	CF	FI	CI-D	UASB	LmP	UV-D	O-D	NPh	SAT	WT	CI-O	Oz-O	UV-O	Pp	Ads	MF	UF	NF	RO				
Suspended solids	NO	NO	2	2	2	2	NO	2	2	NO	NO	NO	2	2	NO	NO	NO	2	15	2	2	2	2	2			
Dissolved solids	NO	NO	NO	NO	NO	NO	3	NO	3	NO	NO	NO	3	NO	NO	NO	NO	3	NO	2	2	2	2	2			
BOD	NO	NO	2	2	2	2	NO	2	2	NO	NO	NO	2	2	NO	NO	NO	2	2	2	2	2	2	2			
TOC	NO	NO	2	2	2	2	NO	2	2	NO	NO	NO	2	2	NO	NO	NO	2	2	2	2	2	2	2			
Volatile organics	NO	NO	2	2	2	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO			
Heavy metals	NO	NO	2	2	2	21	NO	2	2	NO	NO	2	2	2	NO	NO	NO	2	NO	2	2	2	2	2			
Nutrients	NO	NO	2	2	2	21	NO	2	10	NO	NO	2	2	2	2	2	2	2	2	2	2	2	2	2			
Viruses*	NO	NO	2	2	2	7	2	NO	11	2	2	2	2	9	2	2	2	2	No on AC	NO	NO	2	2	2			
Bacteria*	NO	NO	2	2	2	7	2	NO	11	2	2	2	2	9	2	2	2	2	No on AC	2	2	2	2	2			
Protozoan*	NO	NO	2	2	2	2, 10	2	9	2	2	2	2	2	9	2	2	2	2	2	2	2	2	2	2			
Helminth eggs	NO	NO	2	2	2	NO	9	2	2	NO	NO	?	2	9	2	2	2	2	2	2	2	2	2	2			
Pesticides	NO	NO	NO	NO	NO	NO	NO	NO	NO	11	11	11	11	11	12	12	12	12	12	12	12	12	12	12			
Disinfection by products	NO	NO	NO	NO	NO	NO	8	NO	NO	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8			
Chemical emerging pollutants	NO	NO	3,4,5	3,4,5	5	6	8, 12	NO	NO	11	12	20	19	?	12,13	12	14	5	16	NO	17	17	18	18			

Processes: AC, activated carbon; Ads, adsorption; BT, biological treatment (any technology); BT+ NR, biological treatment with nutrient removal; CF, coagulation–flocculation (any technology) CI-O, chlorine oxidation CI-D, chlorine disinfection; FI, filtration; Clo, chlorine oxidation; Lmp, lime precipitation; MF, microfiltration; UF, ultrafiltration; NF, nanofiltration; NPh, natural photolysis; O-D, disinfection with ozone; ONSS, on-site sanitation systems; Oz-O, ozone oxidation; PS, primary sedimentation; Pp, precipitation; RO, reverse osmosis; UV-O, UV light oxidation; UASB, upflow anaerobic sludge blanket; SAT, soil aquifer treatment and river bank filtration; UV-D, UV-light disinfection; WT, wetlands.

Low removal Medium removal High removal

- | | |
|---|---|
| <p>1 Depending on the treatment level (primary, secondary, or tertiary).</p> <p>2 Depending on the type of technology used.</p> <p>3 Might increase the content.</p> <p>4 Mostly in biological secondary treatment plants; widely depending on the chemical composition of the pollutant; removal might represent only the transformation of the compound or its adsorption into.</p> <p>5 Depending on the specific compound.</p> <p>6 If coupled with chemicals.</p> <p>7 Produce the pollutant as by-product or increase its value.</p> <p>8 With low reliability.</p> <p>9 For phosphorus.</p> <p>10 Depending on the operating conditions.</p> | <p>11 Noxious by-products can be formed.</p> <p>12 If there is no competition with organic matter (BOD or COD).</p> <p>13 Doses are several orders of magnitude higher than those used for disinfection.</p> <p>14 If granular carbon is used.</p> <p>15 High for nonpolar organic compounds with $\log K_{OW} > 2$ and when there is no competition with organic matter.</p> <p>16 Medium to high depending on the presence of cations and organic matter.</p> <p>17 High but not for low molecular weight uncharged compounds.</p> <p>18 Effective for several EC but not for carbamazepine, primidone, and iodinated X-ray contrast media.</p> <p>19 High for some EC, as it depends on the strength of solar irradiation removal will be different for different latitudes, or conditions.</p> <p>20 Can be enhanced with photosensitizers.</p> <p>? Unknown or insufficient information</p> <p>*, Can be removed or inactivated.
NO, not applicable for the pollutant.</p> |
|---|---|

Table 9 Reduction or inactivation of different biological pollutants in wastewater

Treatment process	Log unit microorganisms removal			Removal (%)
	Viruses	Bacteria	Protozoan (oo)cysts	Helminth eggs
<i>Natural systems</i>				
Waste stabilization ponds, WSP	1–4	1–6	1–4	90–100 ^{a, e, HR}
Wastewater storage and treatment reservoirs	1 to 2/4	1 to 3/6	1–2	70–95 ^{a, d, LR, g}
Constructed wetlands	1–2	0.5–3	0.5–2	90? ^{a, e, L, R}
<i>Primary treatment</i>				
Primary sedimentation	0–1	0–1	0–1	90 ^{a, LR}
Chemically enhanced primary treatment or advanced primary treatment	1–2	1–2	0.5–2	90–99 ^{a, e, HR}
Anaerobic upflow sludge blanket reactors, UASB	0–1	1–2	0–1	60–96 ^{a, e, LR}
Filtration	0–1	0–0.5	0–1	90–95
<i>Secondary treatment</i>				
Activated sludge + secondary sedimentation	0–2	1–2	0–1	90–95 ^{a, L, R}
Trickling filters + secondary sedimentation	0–1	1–1	0–0.5	85–90 ^c
Aerated lagoon or oxidation ditch + settling pond	1–2	1–2	0–1	95–100 ^c
Slow filtration		1–2		90 ^c
<i>Tertiary treatment</i>				
Coagulation/flocculation	1–3	0–1	1–3	95–99 ^{a, e, HR}
High-rate granular sand filtration	1–3	0–3	0–3	90–99 ^{a, f, HR}
Dual-media filtration	1–3	0–1	1–3	100 ^c
Membrane bioreactors	2.5 to >6	3.5 to >6	>6	100 ^c
<i>Disinfection</i>				
Chlorination (free chlorine)	1–3	2–7	0–1.5	0 ^{a, f, b}
Ozonation	3–6	2–6	1–2	30–70 ^b
UV irradiation	1 to >3	2 to >4	>3	0 ^c

^aHave been tested at full scale.

^bFrom laboratory data.

^cTheoretical efficiency based on removal mechanisms.

^dTotal helminth egg removal is only achieved when wetlands are coupled with a filtration step.

^eTested with high helminth egg content.

^fTested only with low helminth egg content.

^gEfficiency highly depends on size and operating conditions, notably the hydraulic retention time.

LR, low reliability; HR, high reliability.

Based on Shuval HI, Adin A, Fattal B, Rawitz E, and Yekutieli P (1986) Wastewater irrigation in developing countries: Health effects and technical solutions. World Bank Technical Paper No. 51. The World Bank, Washington; WHO (1989) *Guidelines of the Safe Use of Wastewater and Excreta in Agriculture and Aquaculture*. Prepared by D. Mara and S. Cairncross: Geneva: WHO. Von Sperling (2003, 2004); Rose (1999); Jiménez B (2009b) Wastewater risks in the urban water cycle. In: Jiménez B and Rose J (eds.) *Urban Water Security: Managing Risks*, p. 324. Paris: UNESCO Leiden: Taylor and Francis Group; WHO (2006) *Guidelines for the Safe Use of Wastewater, Excreta and Greywater, Vol. 2: Wastewater Use in Agriculture*. Geneva: WHO.

4.06.6.5.4 Slow filtration

Slow filtration is recognized in water potabilization as an efficient method to control microbial pollution in rural and low-income communities. The few studies carried out on slow filtration of wastewater have demonstrated a removal range of 60–80% of suspended solids and 1–2 *E. coli* log, with coarse sand (Jiménez, 2003). In rural areas, it may be coupled with absorption wells, irrigation reuse, or a soil aquifer treatment (SAT) system.

4.06.6.5.5 Waste stabilization ponds

Waste stabilization ponds (WSPs) are shallow basins that use natural factors such as biodegradation, sunlight, temperature, sedimentation, predation, and adsorption to treat wastewater (Mara, 2004). WSPs are capable of removing organic matter with efficiencies similar to the activated sludge process and all kind of pathogens. They are easy to design and operate but require long retention times (several weeks). WSP systems

comprised several ponds connected in series. Lagoons are made through the shallow excavation of around 1–2 m, and they are frequently unlined to reduce investment costs. After a period of time, soil percolation and sedimentation form an impermeable barrier. If the water table is very high at the site, ponds need to be impermeable from the beginning. WSPs remove up to 6 bacteria log, up to 5 viruses log, and almost all the protozoa and helminth ova. To control *Cryptosporidium* spp., almost 38 days' retention time is needed (Jiménez, 2008).

In developing countries with wet warm climates, the use of stabilization ponds is recommended if land is available at a reasonable price. For arid and semiarid regions, high evaporation rates limit their application as there is a net loss of water of 20–25% due to evaporation. This, in addition, increases the salinity of the effluent limiting its use for agricultural irrigation (Jiménez, 2008). Sludge production in ponds is low but if extracted it needs disinfection as helminth ova remain viable in ponds for more than 9 years (Nelson *et al.*, 2004).

WSPs can be coupled with aquaculture systems that are shallow ponds or wetlands where fish, duckweed, or aquatic vegetables are produced as is frequently done in Indonesia, China, and Thailand. Ponds can be used to produce only one crop such as duckweed that is used as food for the next pond where grass carp are grown. Different species can also be cultured in the same pond, as happens in nature. To operate the system, wastewater is applied to ponds at the required rate (estimated in terms of the organic load applied per hectare of ponds per unit time), and the organic matter and the nutrients contained serve as food for plant and animal production (Hughes *et al.*, 2006). In order to avoid health problems, wastewater needs to be previously disinfected according to WHO guidelines (2006).

4.06.6.5.6 Wetlands

Constructed wetlands are used to naturally remove organic matter, pathogens, and nutrients from wastewater through biodegradation, adsorption, or filtration in a similar way to WSPs. Nutrients are also removed by plant uptake and pathogens by competition and sun UV-light inactivation (Jiménez, 2003). Wetlands are shallow ponds where aquatic macrophytes are planted in soil, sand, or gravel. There are three main types: surface-flow, horizontal-flow subsurface, and vertical-flow systems. *Juncus* spp. or *Phragmites* are commonly used plants but any local plant can be employed. Construction requires expertise and skilled labor. Once installed, operation is relatively easy. Wetlands remove nitrogen, phosphorus, and heavy metals. Up to 90–98% of thermo-tolerant coliforms, 67–84% of MS2 coliphages, and 60–100% of protozoa are inactivated or removed using hydraulic retention times of 4–5 days. In practice, pathogen removal is highly variable and depends on climate, type of wetland, and the kind of plant used. To completely remove helminth ova, it is necessary to couple wetlands with filtration, otherwise effluent with variable content may be produced. Breeding of mosquitoes and unpleasant odors can be a problem if wetlands are not operated correctly. Subsurface wetlands are used to avoid mosquito breeding (Correlje and Schuetze, 2008).

Wetlands are a good solution for wastewater treatment in urban or rural areas where space is available; as a rule of thumb, 0.5–2.5 m² per person is required for the treatment of graywater and 1–3 m² per person for domestic wastewater. They are considered environmentally sound technology by UNEP for the treatment of graywater and stormwater urban runoff. They are used as secondary or tertiary treatment units, in which case, they treat effluents from septic tanks, anaerobic ponds, upflow anaerobic sludge blanket (UASB) reactors, or conventional wastewater treatment plants. Treated wastewater can be reused for agricultural irrigation, although its nutrient content is low. Wetlands have been used in Bangladesh and China to treat wastewater and to cultivate fish and ducks. In addition, they have the advantage of producing a low quantity of sludge.

4.06.6.5.7 Land treatment

Soil can be used to treat wastewater by infiltration. It has a greater depollution capacity than water receptors, as there is no limit for the oxygen transfer needed for biodegradation.

Land-based treatment is recognized as an environmentally sound technology by UNEP (2002) that has a low cost when used for primary effluents. Among its disadvantages is the high demand for land (Jiménez, 2003). In the case of land treatment, depollution takes place in the unsaturated zone through biodegradation, adsorption, ion-exchange filtration, and precipitation. For the removal of organisms, in addition to predation and humidity, the temperature also plays a role. Heavy metals and trace organic compounds (such as emerging pollutants) are removed mainly by adsorption. To operate, wastewater is to be applied at specific rates; if pretreatment is needed primary sedimentation or sand filtration might be used (Brissaud and Salgot, 1994; Jiménez, 2003; Bouwer, 2002). In developed countries, pre-treatment usually consists of a secondary treatment.

Wastewater application occurs in cycles at a rate that depends on the soil infiltration characteristics. In a typical situation, the cycle involves 1 week of wastewater flooding where infiltration is reduced by organic buildup, and 1 week of drying where bacteria consume the organic matter and soil drying takes place. There are several types of land treatment options in specialized literature that can be consulted. For efficient functioning, hydraulic loads (29–111 m³ m⁻² yr⁻¹) and mass loads should be limited. To avoid aquifer pollution, application of wastewater (preferably partially treated) is restricted to sites where groundwater is a minimum of 3 m in depth. Applied as primary or secondary treatment, land treatment produces a consistently high-quality effluent (TSS <1 mg l⁻¹, organic carbon 3 mg l⁻¹, and total nitrogen 6 mg l⁻¹, with a phosphorus removal of almost 50% with minimal pre-treatment). As tertiary treatment, it removes >92% of BOD, 85% of COD, 100% of TS, >55% of detergents, >99% of ammoniacal nitrogen, 55% of total nitrogen, and 98% of phosphorus. Land treatment is effective for the removal and/or inactivation of helminth eggs, protozoa, bacteria, and even viruses (Jiménez, 2003). Treated wastewater can be used for irrigation or any other use and can be collected on the surface or underground.

4.06.6.5.8 Reservoirs and water storage tanks

Reservoirs or wastewater storage tanks can be used as well to treat wastewater. While wastewater is stored during the wet season to provide water for irrigation during the dry season, pathogens are removed or inactivated via sedimentation, UV-sunlight inactivation, predation, and other similar processes, which also occur in WSPs. Nevertheless, the efficiency is lower. Procedures for designing wastewater storage and treatment reservoirs are detailed in Juanicó and Milstein (2004) and Mara (2004). Reservoirs and storage tanks are easy to operate and maintain, and if considered as part of the irrigation system, they result in a low investment cost. However, they facilitate vector breeding if they are not well maintained and operated, and algal development in effluents may interfere with irrigation applications.

Effluent storage reservoirs remove 2–4-log of viruses, 3–6-log of bacterial pathogens, and 1–2-log units of protozoan (oo)cysts. If treatment reservoirs are operated as batch systems with retention times over 20 days, the complete removal of helminth eggs can be achieved (Juanicó and

Milstein, 2004). In addition to large storage reservoirs, small storage ponds can be utilized for pathogen removal when used for urban agriculture irrigation as intermediate water storage reservoirs. Such reservoirs reduce the helminth ova content by around 70% (Keraita *et al.*, 2008).

4.06.6.5.9 Upflow anaerobic sludge blanket

The UASB is used to remove organic biodegradable matter. A UASB is a kind of attached system where microorganisms adhere to themselves, forming flocs. UASBs are considered as the most successful anaerobic process applied to treat wastewater due to low hydraulic retention time compared to other anaerobic processes thanks to the high density of biomass attained in the blanket (Campos, 1999). The reactor is designed to not only produce the biological reaction but also to sediment and filter suspended solids from wastewater. In addition, sludge retained in the bottom part of the reactor is anaerobically digested (Campos, 1999). The UASB produces better results when the wastewater has a high organic matter content. As by-products, it produces methane and partially treated sludge. The gas can be used as a source of energy, while the sludge remaining, after proper treatment to control the pathogen content, can be used to fertilize soil. UASBs remove 65–75% of BOD and COD and helminth eggs through filtration in the sludge blanket and through sedimentation. However, their efficiency with regard to the removal of helminth eggs is very variable. From wastewater containing 64–320 eggs l⁻¹, they produce effluents with 1–45 eggs l⁻¹ (60–96% removal). Therefore, UASBs are frequently coupled with other treatment process such as stabilization ponds or filtration to completely and reliably remove helminth ova and to inactivate other pathogens. Several stand-alone UASB plants or those coupled with WSP are currently under operation in Curitiba, Brazil. UASB reactors require careful design and operation to avoid bypasses (Campos, 1999). The construction, operation, and maintenance of improved anaerobic technology such as biogas installations require considerable expertise and skilled labor as well as space (Correlje and Schuetze, 2008). UASB reactors have a low capacity for tolerating toxic loads, need several weeks to start up the process, and require a post-treatment step.

4.06.6.5.10 Activated sludge

It is the most common way to treat wastewater in developed countries. Compared to other secondary biological processes, activated sludge is effective for pathogen control as it removes 10% more than trickling filters. Both sedimentation and aeration play an important role in this. Sedimentation eliminates heavy and large pathogens, while aeration promotes antagonistic reactions between different microorganisms, causing their elimination. As a result of becoming entrapped within the flocs (which are subsequently sedimented), there is fairly good removal of small nonsedimentable microorganisms, such as *Giardia* spp. and *Cryptosporidium* spp., which remain concentrated within the sludge (Jiménez, 2003). Helminths eggs are also removed, but due to continuous difficulties in achieving efficient and reliable sedimentation of suspended solids in secondary decanters, protozoan and helminths eggs may be found in effluents along with flocs. For an

initial helminths egg content of 20–120 eggs l⁻¹, effluents with 3–10 eggs l⁻¹ are produced (Jiménez, 2008).

Other biological secondary treatment options include aerated ponds, oxidation ditches, and trickling filters. Much specialized literature exists describing the processes that are used to treat effluents before discharge into water bodies.

4.06.6.5.11 Coagulation–flocculation

This is a process that was almost abandoned for the treatment of municipal wastewater in the 1960–70s due to the high sludge production, which considerably increased the overall wastewater treatment cost. The introduction of new chemical products, in particular flocculants, combined with the possible reuse of treated effluent for agricultural irrigation and ocean disposal, has been instrumental in its reintroduction. Coagulation–flocculation removes helminths eggs while preserving nutrients and organic matter in contents suitable to grow plants. When this process is applied using low coagulant doses combined with a high molecular weight and high charge density flocculants, it is called chemical enhanced primary treatment (CEPT). If a high-rate settler is used instead of a conventional settler, it is referred to as advanced primary treatment (APT). As a result, CEPT has a total hydraulic retention time of 4–6 h while, for APT, this is only 0.5–1 h. Among the coagulants that have been used, iron and alum compounds are the most common. APT removes 50–80% of protozoan cysts (*Giardia*, *Entamoeba coli*, and *E. histolytica*) and 90–99% of helminths eggs. From a content of up to 120 eggs l⁻¹, an APT can consistently produce an effluent containing 0.5–2 eggs l⁻¹. This process produces an effluent with a low content of suspended solids or turbidity, which leads to greater disinfection efficiency, either with chlorine or with UV light. Likewise, the process allows the use of sprinkler irrigation in high-tech countries or countries where water is scarce. The effluent quality is improved by the soil effect, and aquifers can be used as water supply storage (Jiménez, 2003, 2008).

APT and CEPT are useful in middle- and high-low-income countries on large urban areas as an economical alternative to an activated sludge process as the treatment cost for APT is one-third of this process when considering sludge treatment and disposal within 20 km. Coagulation–flocculation can also be applied as a tertiary treatment after a biological process. This is a very good method to remove enteric viruses (Jiménez, 2003).

4.06.6.5.12 Rapid filtration

Rapid filtration (at rates over 2 m³ m⁻² h⁻¹) is very efficient in removing protozoa and helminth eggs from wastewater, primary effluents, and biological or physicochemical effluents. It removes 90% of fecal coliforms, *Salmonella*, *Pseudomonas aeruginosa* and enteroviruses, 50–80% of protozoan cysts (*Giardia*, *Entamoeba coli*, and *E. histolytica*), and 90–99% of helminths eggs. Efficiency can be increased to easily reach >99% if coagulants are added (Jiménez, 2008). For helminth ova removal, rapid filtration is performed in silica sand filters with 0.8–1.2 mm media size, a bed depth of at least 1 m and filtration rates of 7–10 m³ m⁻² h⁻¹. The helminth ova content

in the effluent is constantly $<0.1 \text{ HO l}^{-1}$ in filtration cycles of 20–35 h for primary effluent (Jiménez, 2003, 2008).

4.06.6.5.13 Disinfection

The challenge for any disinfection method is that microorganisms respond differently. Efficiency depends on the disinfecting agent, the type and content of microorganism, the dosage, and the exposure time. The water matrix has as well a relevant influence, which becomes more important as its concentration and complexity increase. The most common disinfection processes for wastewater are chlorination, ozonation, and UV-light disinfection.

1. *Chlorination.* It is the most widely used process to control microorganisms. It is effective for the inactivation of bacteria, less so for viruses and protozoa, and not at all for helminth eggs. With regard to virus and bacteria, chlorine has inactivation efficiencies of up to 5–7 log. However, chlorine is a very reactive agent and, therefore, before attacking microorganisms, it reacts with many substances contained in wastewater, in particular with organic matter, hydrogen sulfide, manganese, iron, nitrites, and ammonia. As a result, chlorination is a process that, in order to be efficient, needs to be applied at the end of treatment schemes to avoid interferences. If, in treated wastewater, ammoniacal nitrogen and organic matter are still presented, chloramines and organo-chlorinated compounds are formed. These are compounds that increase cancer risks. Notwithstanding such risks, it is always preferable to chlorinate wastewater as microbial diseases have faster and often more dramatic health effects (Jiménez, 2003).
2. *Ozonation.* Ozone is very effective at inactivating viruses and bacteria. It inactivates 3–4 log concentration units in a very short time, provided there is a low demand for oxidizing agents by wastewater. There is abundant information in the literature concerning the design and operation of the processes. Required ozone doses for several microorganisms are also available in the literature but, frequently, they are not affordable. As happens with chlorine, by-products generated during ozonation are a source of concern as many of them have been reported in the literature as toxic (Jiménez, 2003).
3. *UV light.* Nowadays, UV-light disinfection closely competes with chlorination because it does not generate by-products that are too costly to remove from wastewater. Besides, compared to chlorination, UV light does not need storage facilities, does not imply the handling of hazardous chemicals, and uses very small-size treatment tanks as disinfection contact times are very small (in the range of seconds or minutes). Furthermore, due its simplicity of operation and high adaptive potential, it is suitable for rural and isolated communities.

4.06.6.6 Sanitation and Wastewater Treatment Costs

Figure 11 presents estimated cost for different sanitation options, including from basic sanitation system to wastewater treatment plants. Simple services certainly are much cheaper to provide, but they do not necessarily represent what the society wishes to have due to the comfort level. As cost is an

important barrier to spread sanitation services, one would expect that these data is a well-known parameter. Despite this, in many developing countries there are no reference costs, as exist in developed ones. As result of this situation, in many bids, costs are established using international data that do not necessarily reflect the local conditions (Table 10). Differences are due not only to build the sanitation facilities but also for the use of fuel and electricity, two important inputs to operate wastewater treatment plants. Sludge management and disposal (Figure 12) is another source of different affecting costs (Figure 12). Table 10 also shows that the cost of emptying on-site sanitation systems is not negligible.

4.06.6.7 Criteria for Selecting Wastewater Treatment Processes

The selection criteria for wastewater treatment processes are presented in Table 11, emphasizing the needs of developing countries.

4.06.7 Wastewater Disposal versus Reintegration

After treating wastewater, the next step is its disposal. Recently, some researchers have suggested (Asano, 2009) to use the term 'dispersion' instead of 'disposal' in order to change the perception of getting rid of used water, but this term has to an extent the connotation of wanting to dilute a problem. In this chapter, the term 'reintegration' is introduced in order to emphasize that water needs to be returned to the environment or used once again (reuse). By reintegrating the water to the environment, the responsibility of using it and then restoring it back to the environment in a proper way may be realized. As, well water can be reintegrated into the hydraulic cycles in which is been used by the society, thus reducing the negative impact of extracting water from the environment beyond the amount needed for ecological use (environmental flow). Water can be reintegrated to the environment by discharging it to the soil or into water bodies. In the following, different ways to reintegrate used water are discussed. This is followed by discussing the reintegration of water through reuse.

4.06.7.1 Soil Disposal or Reintegration of Used Water to Soil and to Groundwater

Soil reintegration (disposal) consists of discharging treated or nontreated water into land. As discussed in the Section 4.06.6.5 the soil may act as a treatment step if a proper management is provided. The options to reintegrate treated wastewater into the environment are presented below. After discharging used water to soil, it will be evaporated, infiltrated, or will percolate to reach surface or groundwater bodies. The extent of each of these will depend on the soil and local conditions.

4.06.7.1.1 Leach drains

They are used mostly for on-site sanitation effluents. They consist of a trench in which partially treated wastewater is discharged to allow its infiltration to the subsoil. The seepage in the trench allows uniform disposal of the wastewater over a given area. The leach drain is often filled with gravel or highly

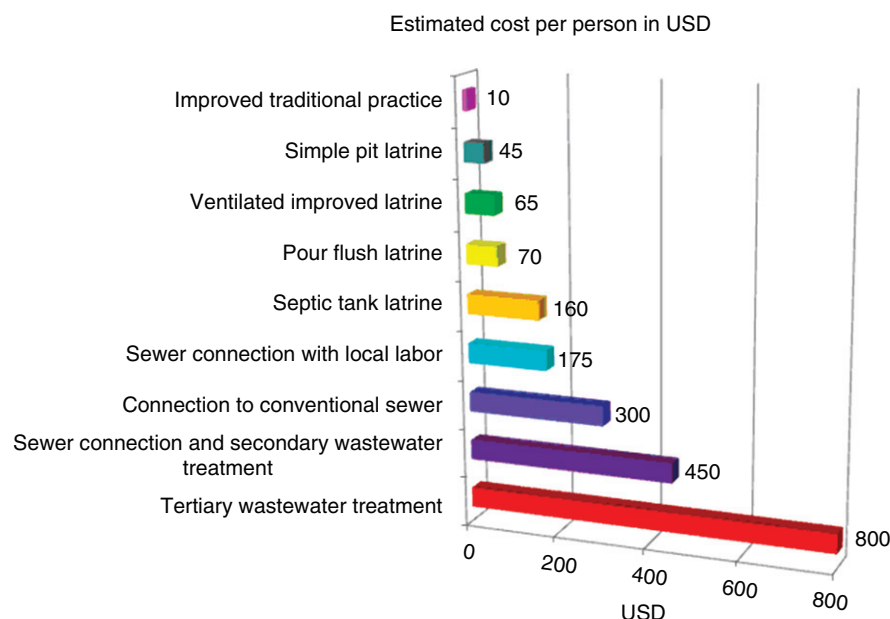


Figure 11 Estimated cost for different options (with information from van de Guchte, and Vandeweerd, 2004).

Table 10 Comparisons of costs for wastewater treatment, diesel, and electricity in selected countries for the year 2008 (with information from LeBlanc *et al.* (2008))

Country	USD per m ³ of wastewater	USD per 1000l diesel fuel	USD per kWh ⁻¹ of electricity
<i>Countries with high sanitation coverage</i>			
England	2.98	2152	0.29
Norway	2.92	2292	0.07
Austria	1.24	1897	0.18
Australia	1.14	1234	0.11
USA	0.92	753	0.04
New Zealand	0.73	990	
Russian Federation	0.42	800	0.12
Canada	0.39	1073	0.08
Italy	0.39	1899	0.26
<i>Countries with low sanitation coverage</i>			
Czech Republic	2.93	1752	0.26
Jordan	2.30	700	0.06
Slovakia	1.47	1764	0.14
Hungary	1.39	1697	0.14
Turkey	0.59	3588	0.17
Senegal	0.35	1044	0.17
Bulgaria	0.31	1298	0.59
China	0.08	834	0.09
Iran	0.05		0.03
	<i>Per truckload to empty latrines</i>	<i>USD per 1000l diesel fuel</i>	<i>USD per 1 kW h⁻¹ of electricity</i>
Cameroon	120	1120	0.12
Nigeria	45	935	
Mali	38.2	1061	0.21
Ethiopia	16.50	742	0.06

permeable material and a perforated pipe – from which used water is distributed – is placed in the centre at about 0.2 m beneath the soil surface. The perforated pipe is typically around 0.1 m in diameter (Hughes *et al.*, 2006). The size of the trench depends on the wastewater load and the soil type, groundwater depth, and precipitation. Leach drains are not recommended disposal options if the groundwater table is close to the surface (e.g., < 0.5 m depth) or the soil has low permeability (e.g., < 3 mm d⁻¹).

4.06.7.1.2 Evapotranspiration beds

They are convenient where soil is highly impermeable (e.g., clay) but can also be used in permeable soil from where water is both evaporated and infiltrated. In each case, plants are positioned to increase evapotranspiration and to remove nutrients from wastewater. If a limited area is available, evapotranspiration beds can be used in conjunction with a seepage trench. To increase dispersal of the wastewater throughout the whole bed, perforated pipes surrounded by gravel are used. The design of the bed should ensure it is large enough to hold wastewater loading and pluvial precipitation while, at the same time, providing sufficient water and nutrients to plants (Hughes *et al.*, 2006).

4.06.7.1.3 Soil aquifer treatment and aquifer storage recovery system

Soil disposal can be coupled with soil treatment in the soil aquifer treatment–aquifer storage recovery system (SAT-ASR). An aquifer storage recovery system (ASR) consists of holding water in an appropriate underground formation, where it remains available in such a way that it can be recycled by extraction when needed. An ASR can have several objectives, some of which are (Dillon and Jiménez, 2008; Jiménez, 2003) temporary or long-term storage; decrease of disinfection by-products; reestablishment of underground water levels;

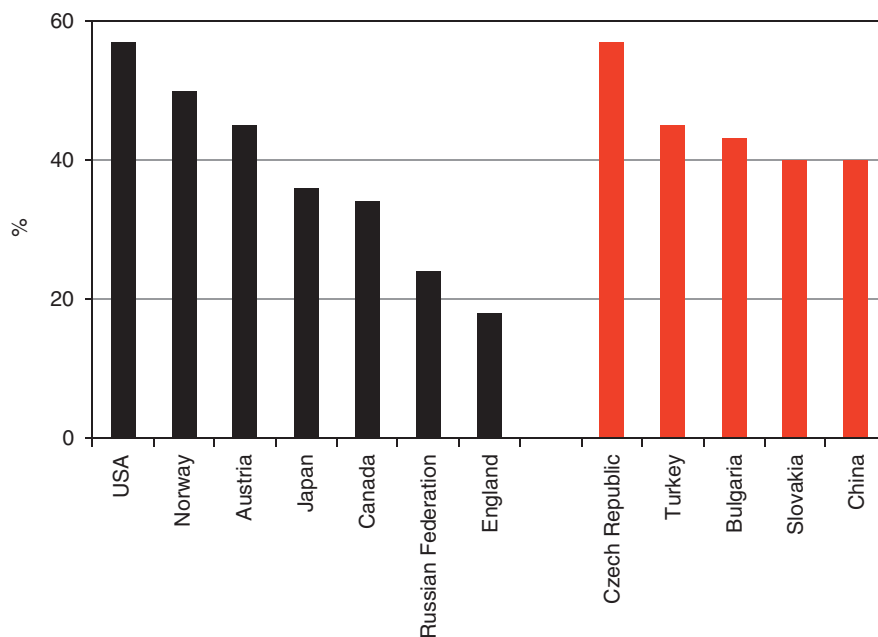


Figure 12 Estimated percentage of total wastewater treatment costs required for wastewater sludge treatment and management (with information from LeBlanc *et al.*, 2008).

maintenance or improvement of underground water quality; prevention of saline intrusion; deferment of expansion of water supply systems; aggressive water stabilization; hydraulic control of contaminant plumes; and compensation of soil salinity lixiviation. The major advantages of underground storage is that evaporation losses are considerably lower than dams (~1%) and do not have the eco-environmental problems associated with them (Dillon and Jiménez, 2008). Aquifers can be an economical option to reintegrate water to the environment in arid and semi-arid countries where it remains available for future use. They are also convenient in densely populated urban areas where, besides storing treated water, aquifers can store stormwater runoff.

4.06.7.2 Disposal into Surface Water Bodies or Reintegration of Used Water to Surface Water Bodies

Effluents from treatment plants can be used for the augmentation of surface water bodies, in which the effluent is diluted with freshwater and reused as a source for water. The water quality of receiving water should be preserved to facilitate a safe water supply. For this, it is important to control pollutant content in the effluent, notably pathogens, organic matter, and nutrients (especially for surface water bodies with slow flow). Two aspects need to be monitored: oxygen depletion in rivers and eutrophication in dams and lakes. To avoid oxygen depletion, biodegradable organic matter needs to be removed before introducing the wastewater. There is considerable literature available concerning this aspect as it has been the main target for most wastewater treatment processes. Control of eutrophication is achieved by removing N and/or P from effluents; this is an operation costly to perform in wastewater treatment plants for most developing countries. As an

alternative, land treatment can be used or treated wastewater used first for agricultural irrigation recovering it from the agricultural drainage before sending it to on lakes. Eutrophication of dams and lakes is a frequent problem in developing countries; alternatives for its control are discussed in Box 7.

4.06.7.3 Reuse

Reuse is another option to reintegrate water to the environment but through its use. Due to the increase in the human population and the increased use of water for almost all human activities, water is becoming scarce and new tools are needed to use it better. Such tools are (1) the efficient use of water (using less water for the same activity – this is beyond the scope of this chapter) and (2) water reuse. Water reuse is a key component to alleviate the mismatch between water supply and water demand.

At the global level, water availability is of around $8500 \text{ m}^3 \text{ inhab}^{-1} \text{ yr}^{-1}$ but with important variations at a regional, national, and local level. For instance, it is estimated that around 700 million people (11% of the total population) in 43 countries live in areas with less than $1000 \text{ m}^3 \text{ inhab}^{-1} \text{ yr}^{-1}$. By the year 2025, 38% of the total world population will live under such water stress, increasing to 50% (in 149 countries) by the year 2050 (UNDP, 2006). As shown in Maps 3, 4, and 9 (Annex 4), most of the affected people live in developing countries. For these countries, three aspects can be highlighted concerning water stress and water demand. First, water is needed for economic development and a better quality of life (even if industrialized countries are not completely making an efficient use of water; they use 30–50 times more water than developing ones (UN/WWAP, 2003)). Second, agriculture is the dominant user of water worldwide, but, in addition, for developing countries, agriculture is usually the

Table 11 Criteria for selecting wastewater treatment operation and processes*Process applicability*

- Must be evaluated based on past experience, data from full-scale plants, published data, and from pilot and full-scale plant studies.
- If few data or unusual conditions are encountered (atypical wastewater characteristics) pilot plant studies are essential.

For developing countries:

- Since much less experience is available, a good wastewater characterization is needed as well as a request during bids that the applicability of the processes should be demonstrated before construction.
- Bids should encourage operating at lower costs at the same pace the process is optimized.
- Technology complexity need to be in agreement with the type of community being served: rural areas, rural isolated areas, small urban towns, large towns, and megacities (low-, middle-, and high-income urban and periurban areas densely or dispersed populated).
- Possibility to combine treatment technologies with soft intervention methods (management).

Performance

- Performance needs to be expressed not only in terms of the effluent quality but also on its allowed variability, and both must be consistent with the effluent discharge requirements and the possible use of treated wastewater.
- Performance needs also to be considered in terms of its reliability, as it may vary according to the process type. Reliability is very important when the effluent is to be reused or treated water is to be discharged into sensitive aquatic environments.

For developing countries:

- Performance should be verified in terms of the disinfection needs locally required.

Influent wastewater variability

- Consider wastewater characteristic variations in probabilistic terms.
- Consider wastewater variability in terms of climate change impacts and climate variability.

For developing countries:

- It is important to have a statistically representative wastewater characterization considering parameters not only defined in norms but also those that might interfere with the treatment processes or the future use of treated water.
- Design data should not be based on bibliography data, especially that coming from other countries.
- Since segregation and pretreatment of industrial discharge is not common, there are high chances that the wastewater to be treated will contain inhibiting constituents. An evaluation of these is important but not as intensive as the one required for the characterization of the targeted treatment parameters.
- Consider wastewater quantity and quality possible variation if programmes to reduce water consumption (such as the use of water less toilets) are to be implemented.

Reliability

- Achievable performance needs to be expressed in statistical terms and in short and long terms, taking into account water flow and wastewater quality variations.

For developing countries:

- Unusual situations and emergencies are common. Selecting robust albeit more expensive processes might be cheaper long term, both economically as well as in terms of the negative effects that malfunctioning can produce.

Process sizing

- Reactor sizing is based on the governing reaction and kinetic coefficients. If kinetic data are not available, process loading criteria are used, but not always with good results, even in developed countries.

For developing countries:

- Most of the available information used in the design of biological process comes from the developed world, where wastewater and climatic conditions, among others, are different, and so bibliographic kinetic data and load criteria use should be avoided as much as possible.
- For coagulation–flocculation process doses and mixing conditions determine at laboratory conditions are essential to minimize cost and sludge production.
- For disinfection processes conditions need to be determined or checked up using laboratory data
- If experimental data are not available, the adjustment of published data to local conditions, such as pressure and temperature, should always be checked in bids.

Applicable flow range and flow variations

- The process should be matched to the expected ranges of flow rates. Moreover, whenever possible, considering the presence of stormwater, notably considering impacts of climate change.

For developing countries:

- For those located in regions with high pluvial precipitation concentrated in short periods of time, treatment processes must be able to deal with flow and major variations in quality.
- Alternatively, the use of flow equalization tanks and their cost should be considered.
- Processes that can be operated as modules than can be easy to start should be preferred to match variable influents in terms of quantity and quality.

Residual treatment and disposal

- The types and amounts of solid, liquid, and gaseous residuals produced must be estimated. Use pilot plant studies to identify and quantify residuals.

Table 11 Continued*For developing countries:*

- By-products and wastewater treatment residues are often disregarded in proposals in order to offer a lower operating cost. To avoid this, it is important to clearly state in bids that any residues must be quantified and the management options considered within costs.

Sludge processing

- Design, operation, and maintenance must have the same degree of investment and complexity of its management as that of the wastewater treatment.

For developing countries:

- Revalorization of sludge as biosolids (treated sludge) for soil fertilization, erosion control, or land remediation are to be considered as a priority.
- For urban areas, use of biosolids to cover landfill cells can be an interesting disposal option.

Climatic constraints

- Temperature affects the reaction rate of most chemicals and biological processes; therefore, local water temperature should be taken into account when selecting a processes.

For developing countries:

- In most developing countries temperature is relatively high, so problems arise due to high temperatures not low ones. High temperature may accelerate odor generation and also limit solubilization of gases such as oxygen. In densely populated urban areas, temperatures may rise even more than expected due to the 'heat islands' phenomena.

Environmental constraints

- Environmental factors, such as prevailing winds, may restrict or affect the use of certain processes, especially where odors are produced near residential areas.
- A wastewater treatment plant may have negative impact on the environment if not properly designed.
- The disposal site restrictions of the treated wastewater need to be considered regardless of the norms to be met.

Water and sludge reuse

- Water reuse can be a way of making wastewater treatment more attractive in economic terms.
- For countries located in water-stressed areas, besides being ecologically sound to reintegrate water to the environment as disposal option, reuse serves to alleviate water scarcity.

For developing countries

- Land degradation is costing 5–10% of their agricultural production (Young, 1998) and fertilizers have often a prohibitive cost for farmers; in both cases, biosolids can be used to remedy these problems.

Ancillary processes

- Wastewater treatment plants are often accompanied by ancillary (complementary) processes that do not necessarily directly relate to the wastewater treatment process, such as power plants, special storing facilities for reagents, etc. It is important therefore to know, before selecting a process, what are those needs, their cost and viability to obtain them from the local market.

Chemical requirements

- The type and amount of chemicals to be used need to be considered as well as their cost and market availability, both now and in the future.
- If chemicals are added during the treatment of wastewater or sludge and these are to be reused, their selection needs to be compatible.

For developing countries:

- Although the use of chemicals is often prohibited, an economic comparison is worth making, especially if chemicals are locally available.

Energy requirements

- The present and future cost of the energy used is something to consider.
- In selecting and designing wastewater treatment plants, the location, efficient use of energy, and the possibility of recovering/producing energy for in-plant use must form part of the selection criteria that in the long term will contribute to properly closing the urban water cycle.
- The energy foot print of the wastewater and sludge treatment plant should be minimized to contribute to the reduction of GHG (greenhouse gases).

Personnel requirements

- The amount of people as well as their skill levels need to be well defined.

For developing countries

- The most common situation is a high availability of low-skilled personnel working for low salaries. Thus, selected processes may have a high labor demand but cannot be very sophisticated. Alternatively, intense training programs should be considered; nevertheless, high indexes of personal rotation are frequently experienced in developing countries when personnel are trained.

Complexity and compatibility

- Define operational needs under routine and emergency conditions.
- Define the type and need for repairs.
- It is important that the items selected be compatible for efficient operation.

For developing countries:

- It should be considered that cheap or obsolete equipment may become costly if frequent repair is needed.
- Equipment and spare parts must be available within an appropriate period of time. Obsolete equipment is very difficult to repair.

(Continued)

Table 11 Continued

– Normally, few items are produced or available locally, therefore overall equipment selection needs to consider compatibility between different equipment traders.

Adaptability

- Many treatment plants will need to adapt to future conditions and not all systems have the same capability to be adapted.

Economic life-cycle analysis

- Cost evaluation must consider initial capital cost and long-term operating and maintenance costs. The plant with lowest initial capital investment may not be the most effective with respect to operating and maintenance costs.
- The nature of the available funding will affect the choice of the process.

Land availability

- It is important to consider the size of the selected treatment process with respect to available land, including buffering zones for future expansions.

For developing countries:

- There is not always land or cheap land available, as frequently believed.
- Considering the fast growth of cities in the developing world and the possibility of building plants in modules, it is very useful to consider buffering zones to increase treatment capacity, complete the treatment process or even to avoid building human settlements near to the facilities.

Public acceptance

- Communities reject systems producing foul odors or vector breeding. Communities also tend to more readily accept natural process that are integrated with the landscape.
- Low-income communities accept better technologies that are a source of jobs for local people than rich ones.

Adapted from Jiménez B (2009b) Wastewater risks in the urban water cycle. In: Jiménez B and Rose J (eds.) *Urban Water Security: Managing Risks*, p. 324. Paris: UNESCO Leiden: Taylor and Francis Group.

Box 7 Eutrophication Control (with information from Jiménez B (2009b) Wastewater risks in the urban water cycle. In: Jiménez B and Rose J (eds.) *Urban Water Security: Managing Risks*, p. 324. Paris: UNESCO; Leiden: Taylor and Francis Group.)

Eutrophication is a process in which plants (such as water lilies or hyacinths (*Eichornia crassipes*), hydrilla (*Hydrilla verticillata*), cattail –(*Thypha* sp.), and duckweed (*Lemna* sp.)) proliferate in surface water bodies due to the presence of high concentrations of phosphorus and/or nitrogen that may come from wastewater, treated effluents, or agricultural runoff. It is commonly observed in polluted lakes or dams, but problems in low flow rivers and agricultural canals have also been observed. Aquatic plants cover the water surface preventing sunlight and oxygen from entering the water. Other negative effects that are provoked are (1) oxygen depletion in the hypolimnion; (2) release of Fe, Mn, NH₄, and heavy metals from the sediments; (3) vector breeding, such as *Schistosomas* and mosquitoes; (4) loss of biodiversity, especially in higher trophic levels; (5) displacement of native species, (6) obstruction of hydroelectric plants and irrigation canals and drains; and (7) restrictions on tourist, recreational, and fishing activities. To reduce aquatic weed density (plants m⁻²), five methods are available:

- **Biological control.** It consists of using living organisms to control weeds. In theory, it is a cheap option as no equipment or chemicals are required but it has an associated labor cost in order to perform maintenance. To be completely effective, the rate of grazing needs to be higher than the plant growth rate, which is very difficult to match in practice. A wide variety of fish, arthropod, fungi, and bacteria have been used for this purpose.
- **Mechanical Control.** These methods remove or cut weeds into pieces using mechanically or manually operated equipment. It is an expensive option that can play a role in quickly reducing the extent of infested areas prior to the application of another control method.
- **Chemical control.** Pesticides are also used to control weeds. Some substances that have been used are terbutryn, diquat, 2,4-D, glyphosphate, paraquat, and simazine. However, due to their toxicity, they can only be applied under controlled conditions and for a limited period of time.
- **Water level control.** In this method, the water level is decreased so the weeds located close to the edges of the water body dry out. The applicability of this method is limited to dams where water levels can be controlled, and to the dry season in which rain would not convey plants once again to the water.
- **Nutrient control.** Weed growth is caused by high N or P content in water, and so, lowering their concentration through wastewater treatment is another alternative. Unfortunately, the cost remains high.

Due to their low efficiency or cost implications, in practice, two or more methods are often used to control weeds.

main source of income and the main mean to feed a growing population. Third, the increasing demand for water by municipalities and industries is increasing the competition for its use with farmers. It is estimated that, in developing countries, water withdrawals will increase more (27%) than in developed ones (UNDP, 2006). Among the uses demanding water, sanitation needs to be considered and, in that respect, water reuse may be a component in some areas to promote it through the alleviation of water demand, saving water for

sanitation facilities or through coupling projects to treat wastewater with reclamation ones.

4.06.7.3.1 Types of water reuse

Two types of water reuse can be distinguished: nonintentional and intentional or planned. As, in several developing countries, lack of sanitation is generating nonintentional reuse, national policy will need to encourage controlled options

instead of promoting practices to start up water reuse. This is the biggest difference with developed countries, where reuse is being promoted once wastewater is treated.

4.06.7.3.2 Unintentional reuse

In literature, water reuse is considered merely as an activity where wastewater is intentionally treated to be used once again. Therefore, water reuse is understood as an artificial man-made practice. However, unintentional reuse also exists as part of the natural hydrological cycle, but this is frequently not acknowledged. (Jiménez, 2009a). 'Nonintentional', 'nonplanned' or 'incidental' water reuse describe situations where used water is mixed with (or becomes part of) the water supply. In most cases, this unplanned reuse is difficult to identify, although it would be important to acknowledge it in order to properly control it. The nonplanned use of water is at the origin of the presence of emerging chemical pollutants in water sources and the reason why drinking water standards are becoming increasingly comprehensive and stringent and more sophisticated technologies to treat water are needed (Jiménez, 2009b). Nonplanned reuse of wastewater is happening for agricultural irrigation, aquifer recharge, and human consumption.

1. *Nonplanned reuse for agriculture.* Three-quarters of the total irrigated area worldwide is located in developing countries, and, as a consequence, there is a high dependence on water for food production. Frequently, due to lack of sanitation in these countries, wastewater is used to irrigate land. This is a practice that happens almost naturally because of the combination of the high demand for water for irrigation (81% of total use compared to only 45% in developed countries, Figure 13), the availability of wastewater, the productivity boost that the added nutrients and organic matter provide, and the possibility to sow crops all year round (Jiménez, 2006).

It is estimated that at least 20 million hectares in 50 countries (around 10% of irrigated land) are irrigated with raw or partially treated wastewater (WHO, 2006).

Approximately one-tenth of the world's population consumes crops irrigated with wastewater, diluted or not. As an example, in Hanoi, Vietnam, wastewater is used in the production of 80% of the vegetables consumed locally (Ensink *et al.*, 2004). The use of nontreated wastewater is also common for urban agriculture, which is practiced in urban and periurban areas of arid or wet countries where there is local demand for fresh food products, and people live on the verge of poverty with no job opportunities (Jiménez, 2009b). For urban agriculture, wastewater flowing in open channels is used to irrigate very small urban plots of land where trees, fodder, or any other product that can be introduced to the market in small quantities (flowers and vegetables) or be used as part of the family diet are grown (Ensink *et al.*, 2004). In terms of volume, reuse of nontreated wastewater is at least 6 times higher than of treated wastewater (Jiménez, 2006; Jiménez and Asano, 2008). As a consequence, any sanitation project in localities using wastewater should consider its actual use.

2. *Unintentional reuse for water recharge.* Since groundwater is not water that can be observed as in lakes or dams, very often its pollution and nonintentional recharge is not perceived. Infiltration may result from agricultural irrigation, leakages from wastewater and water urban networks, unlined dams, tanks or reservoirs, and on-site sanitation systems. Little information on the extent of this problem is reported in literature, but some cases (a summary is presented in Table 12) have been described highlighting the importance of this phenomenon as a source of water supply. For the one referring to the Tula Valley, it has been the best documented (Jiménez, 2008b) that recharge with wastewater amounts to at least $25 \text{ m}^3 \text{ s}^{-1}$, and the aquifer is used to supply 500 000 people. Infiltration and pollution of groundwater supplies varies from negligible to severe, and the recognition of unplanned reuse is needed in order to advance understanding of how to manage the risks. This may involve continuing groundwater recharge with water of improved quality and/or separating the

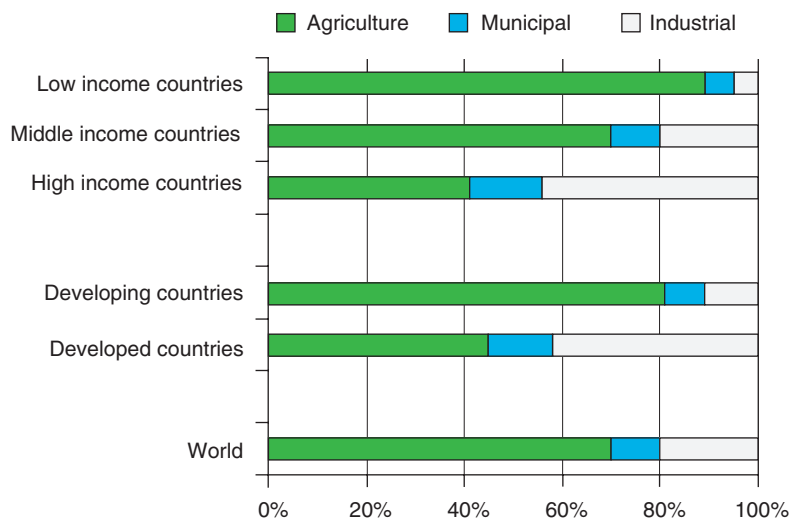


Figure 13 Water use in developing and developed countries (with information from Earth Trends, 2009).

Table 12 Examples of unintentional indirect potable reuse via aquifers

City	Recharged water	Groundwater uses
Hanoi, Vietnam	Sewer, storm water	Irrigation and drinking
Hat Yai, Thailand	Drainage canals, on-site sanitation facilities	Drinking
Ica Valley, Peru	Primary effluent	Drinking
Leon, Mexico	Mix industrial effluent	Irrigation and drinking
Merida, Mexico	Sewer, storm water	Drinking
Mexico City (southern part), Mexico	On-site sanitation facilities	Drinking
Santa Cruz, Bolivia	On-site sanitation facilities	
Sana'a, Yemen	Cess pits	Drinking
Tula Valley, Mexico	Untreated effluent	Irrigation and drinking

Adapted from Dillon P and Jiménez B (2008) Water reuse via aquifer recharge: Intentional and unintentional practices. In: Jiménez B and Asano T (eds.) *Water Reuse: An International Survey of Current Practice, Issues and needs*. London: IWA Publishing.

recharge areas further from points of water abstraction. Appropriate monitoring information will allow the most cost-effective investments to be identified (Dillon and Jiménez, 2008).

3. *Nonintentional reuse for human consumption.* Nonintentional reuse for human consumption occurs as described previously, not only through aquifer recharge but also through surface water sources when effluents, treated or nontreated, are discharged into them. This has been documented in developed countries. For instance, in the River Thames in England, during dry periods, 70% of the water used as supply downstream comes from treated effluent. In California's Santa Ana River, a large part of the supply consists of treated wastewater (Gray and Sedlak, 2003) and in Berlin, 17–35% of the city's water supply comes from an advanced treated effluent that is discharged to a nearby water supply (Jekel and Gruenheid, 2008). The increasing evidence of the presence of emerging contaminants in water sources is an indication of the nonintentional reuse of water. Information on this subject for developing countries is very poor, and possibly only reported as pollution cases. Recognizing the nonintentional reuse of water for human consumption will help society to acknowledge that water reuse is unavoidable in the future and also to understand that, to properly reintegrate used water to the environment is needed. For this, tools other than wastewater treatment plants will be needed.

4.06.7.3.3 Intentional or planned reuse

According to Asano (1998), wastewater reclamation involves the treatment or processing of wastewater to make it reusable; and wastewater reuse or water reuse is the beneficial use of treated water. Planned reuse may be performed for agricultural

irrigation, industrial purposes, environment restoration, and municipal uses.

1. *Reintegrating water for irrigation.* Most of the world's poorest people, 800 million to 1 billion rural people, live in arid areas and depend directly on natural resources, including water, for their livelihoods (Dobie, 2001). In such a context, safe wastewater reuse can be a sanitation option that could also be coupled with food security and economic development goals. Under prevailing land and water management practices, a balanced diet represents a depleting water use of $1300 \text{ m}^3 \text{ inhab}^{-1} \text{ yr}^{-1}$, which is 70 times more than the $50 \text{ l inhab}^{-1} \text{ d}^{-1}$ required for basic household water needs (SIWI-IMWI, 2006). For several middle- and low-income countries, agriculture is currently, and will continue to be, a key sector representing 80% of export earnings. Limited and unreliable access to water is a determining factor in agricultural productivity in many regions, a problem rooted in rainfall variability that is likely to increase with climate change (Lenghton et al., 2005). To feed this sector, water reuse can be one option.

Planned reuse of water for agricultural irrigation in developing countries is a convenient strategy for many reasons (Jiménez and Garduño, 2001; Jiménez, 2006, 2009a; WHO, 2006; Keraita et al., 2008), such as

- It is an easy option to increase controlled reuse when nontreated wastewater is already in use as it allows more profitable and safe products.
- It can be a low-cost option to manage wastewater and to reintegrate water into the environment.
- It allows the reclamation of nutrients (N and P, to increase soil fertility) and organic matter (to improve soil characteristics) at no cost.
- Particularly in (but not limited to) arid and semi-arid areas, it permits higher crop yields, as it allows crops to be sown year-round due to higher water availability.
- Due to the availability and reliability of water, crops with better profitability can be selected.
- It avoids discharging pollutants to surface water bodies (which have a considerably lower treatment capability than soils).
- It is possible to recharge certain type of aquifers through infiltration.
- It can be part of a strategy to secure food and increase poor people's income in water-scarce areas.

To obtain all the advantages from reusing wastewater for agriculture in planned projects, it is important (1) to control possible negative effects (Jiménez, 2006; WHO, 2006) such as those related to health; (2) to keep in mind that in many cases nontreated wastewater is being reused at low or even no cost by poor farmers and, hence, they will be unable to afford reuse costs; and (3) from the legal aspect, the historical use of nontreated wastewater by farmers confers riparian rights.

2. *Reintegrating water for industrial reuse.* Industrial reuse (reclamation of wastewater from a different use, i.e., reuse of a municipal effluent for industrial cooling) differs from municipal and agriculture reuse as it involves the private sector that has its own rules and well-defined needs driven

by economic factors (Jiménez and Asano, 2008). Before reusing water, industries always prefer to implement water-saving projects as these immediately reflect on their budgets; for reusing water, investments to provide proper treatment and monitoring programs are needed. To promote industrial reuse, the best government strategy is to provide incentives rather than setting compulsory regulations (Jiménez and Asano, 2008). Among the different industrial reuse options, cooling is the most popular due to its high water demand, and the possibility of using secondary-treated municipal effluents, sometimes coupled with filtration or softening processes. As a consequence, power plants located near urban areas are potential sites of industrial water reuse.

3. *Reintegrating water to the environment.* More than 1.4 billion people live in river basins where the intense use of water threatens freshwater ecosystems (Smakhtin *et al.*, 2004). Reintegrating water to the environment is a practice that is gaining momentum, as it is being recognized that (1) the environment needs water and (2) the environment has the same entitlement to water as other uses. Unfortunately, these two aspects are better recognized by developed countries than developing ones. Overuse of water tends to occur in regions heavily dependent on irrigated agriculture or where there is rapid growth of densely populated areas (UNDP, 2006), two characteristics common in developing countries. Among the more prominent examples (UNDP, 2006) of water overuse, the exploitation of the Yellow River basin, in northern China, can be cited: Human withdrawal currently leaves less than 10% of the flow remaining in the river. The river ran dry 600 km inland for a record 226 days in 1997. The drying up of the river caused a drop in agricultural production averaging 2.7–8.5 million tons a year, with losses estimated at US\$1.7 billion for 1997. The purified effluent from sewage treatment plants can be used for the augmentation of river flows, to raise the level of wetlands or lakes, to recover dried lakes, or even to create new lakes or wetlands. In doing so, biodiversity may recover. Care must be taken when restoring water into water bodies to preserve or improve the actual quality of water. Used water reclamation can be combined with rainwater reclamation. Water reuse with environmental restoration can be coupled with projects of urban image improvement or programs to provide better facilities at recreational areas.
4. *Restoring water to aquifers.* Aquifer recharge is not, itself, a use of reclaimed water but is often part of the pathway to reuse. It is a convenient way to reintegrate water into the environment but can be used only under certain circumstances related, in particular, to the type of soil and groundwater. Aquifer recharge can be performed to recover groundwater levels, to control saline intrusion, to augment drinking water sources, to protect and, in some cases, to improve underground water quality, to protect surface water bodies from contamination by effluents, to increase water availability for any use, and simply to store water for the future (Dillon and Jiménez, 2008; Corleje *et al.*, 2008). Intentional recharge with reclaimed water can play a role in providing balanced storage and supplemental treatment for water (Bouwer, 2002; Dillon and Toze, 2005). It also provides low-cost storage that occupies a minimum of

valuable urban land, while stored water is protected from pollution and evaporation. There are two methods to recharge aquifers. The first is known as land-spread infiltration where treated wastewater infiltrates through soil by gravity. This option has relatively low operating and maintenance costs. The second method for recharge is direct well injection. In this option, wells are used to convey a highly treated effluent directly to aquifers. Regulation to recharge aquifers are very different from one country to another; some are set at a national level while others are defined using a case-by-case approach (Jiménez, 2003). Most of the projects to recharge aquifers are found in developed countries. In developing ones, some examples are found in Atlantis, South Africa (for drinking and agricultural purposes, using pond infiltration), in Windhoek, Namibia (for drinking purposes and using injection wells), in New Delhi, India (for irrigation using infiltration ponds for treated urban wastewater and stormwater), in Beijing, China (for drinking purposes using wells and recharge basins), and in Mexico City, Mexico (for drinking purposes on a limited scale and using infiltration ponds; Dillon and Jiménez, 2008). In all these cases, wastewater is treated to at least a secondary level (see section titled 'Relevant websites').

5. *Reintegrating water for municipal use.* In 20 years, 60% of the world's population will be living in cities (UN, 2006). This being the case, more water will be needed for municipal use and, at the same time, more municipal wastewater will be produced. This situation, therefore, represents an opportunity to increase municipal wastewater reuse. Water reuse in cities represents an opportunity to conveniently treat wastewater, with environmental and even economic advantages. Opportunities to reuse wastewater in cities are classified into two groups: (1) those demanding relatively low-quality water and involving low health risks, and (2) those demanding high-quality water where health risks are high. In the first group, there are several types of uses, such as: (a) the filling of recreational lakes or the operation of fountains; (b) car, truck, or street washing; and (c) green area irrigation. Options demanding high water quality include reuse for drinking supply. Around the world, there are successful examples of both types of reuse, low risk options being the most common. Water reuse for human consumption, although less common, is no less important. Moreover, the only two examples of the reuse of water for human consumption in the world are notably from two countries from the developing world: Namibia and Singapore (Box 8).

4.06.7.3.4 Graywater reuse

Graywater (i.e., domestic wastewater not containing toilet wastewater) is more accessible for reuse as it is less contaminated than wastewater, notably in terms of (but not limited to) pathogens. Typical sources of graywater are bathing, laundry, dishwashing, and food preparation. Due to its comparably low and easily degradable contamination, it can be relatively easily treated for reuse. Graywater reclamation entails the production of less wastewater to be treated in

Box 8 Reuse of wastewater for human consumption in Namibia and Singapore

Windhoek, Namibia, has been reusing wastewater for human consumption for more than 40 years (Van der Merwe *et al.*, 2008) as result of an original idea in 1956. Since its operation, no measurable health risk has been observed and neither have people drinking reused water displayed associated health problems. The reclamation plant has undergone several modifications to improve the technology used. The quality of the water supplied can be consulted every day in the local newspaper. The amount of water reused is around 250 l s⁻¹, which is distributed after dilution by a factor of 1–3 with first-use water. The monitoring program for the facility represents 20% of the operating costs, and is performed by the wastewater treatment plant and also by three independent laboratories. The system is operated using a multiple barrier concept that goes beyond the wastewater treatment plant. The astute words “Water should be judged by its quality; not its history” are attributed to Dr. Lucas van Vuuren (van der Merwe *et al.*, 2008), one of the pioneers of the Windhoek reclamation system. This refers to the fact that fear of reused water should be based on rational aspects.

The other example of direct reuse of wastewater for human consumption comes from Singapore (Funamizu *et al.*, 2008) and is known as the NEWater project. It started in 2003 and uses a secondary effluent that is further treated with a membrane system (microfiltration (MF) and reverse osmosis (RO)) and UV-light disinfection. The water produced is cleaner than tap water as it fulfills all the requirements set by US-EPA and WHO for drinking purposes. Treated water is channeled to a reservoir, from which it is taken as supply after dilution with first-use water. Water is distributed through the network for use for domestic and industrial purposes. When the NEWater project was launched, it operated at a rate of 870 l s⁻¹. This will be progressively increased to reach 2400 l s⁻¹ by 2011 (~0.5% and 2.5% of total water consumption, respectively). In both cases, Namibia and Singapore, before the implementation of the reuse programs, stringent industrial pre-treatment programs and segregation of industrial effluent from the sewer were put in place.

centralized plants. Graywater reuse is performed at the same facilities where it is produced and, as a result, a short storage time is needed (1 day retention time). Graywater reuse can be performed individually (for a single home) or collectively (several groups of houses or larger buildings). Treated graywater may be used for watering plants, kitchen gardens, and for the safe augmentation of ground- or surface water. Treatment can be very simple or highly sophisticated, ranging from simple manually operated sand filters to biomembrane reactors, hence, covering the needs for rural areas or buildings located in upmarket areas in megacities. Further details on design and operation can be found in Correlje and Schuetz (2008). Graywater reuse can be as well an important component for basic sanitation, as described in Section 4.06.6.1.

4.06.8 Sludge and Excreta Management

As the quantum of wastewater treatment is still low in developing countries, little information is available concerning the actual situation. LeBlanc *et al.* (2008) performed a survey in some countries showing that the tendencies are the following:

1. *For middle-income countries.* From information coming from 10 middle-income countries, including Africa (Namibia and South Africa), the Middle East (Iran, Jordan and Turkey), Asia (China and Russian Federation), and Latin America (Brazil, Colombia and Mexico), it is shown that wastewater treatment facilities serve mostly urban areas using preliminary, primary, and, in some cases, secondary processes. For rural or poor periurban areas, basic sanitation facilities are provided. Although sludge is produced in these facilities, this is not always managed as part of the sanitation service. The disposal options for the sludge from wastewater treatment plants produced are landfill dumping, dumping into sewers, storage at wastewater treatment plants, land application, and agricultural reclamation. Land application and agricultural reclamation are options

limited by space problems, while the use of landfills is restricted in densely populated urban areas, where solid wastes compete for space with sludge. As sludge production is still low in the few wastewater treatment plants available, sludge management policies are novel, and are still in a maturation phase. Some of these policies offer new approaches different to those used in developed countries (LeBlanc *et al.*, 2008). With regard to fecal sludge, the main constraint for their management is the cost to empty on-site sanitation systems as these are often located in inaccessible areas, are large in number, and are frequently highly dispersed. It is noted that the high cost of latrine emptying is not sustainable, even for large municipalities. Extracted fecal sludge is often buried on-site, dumped into landfills or sewers or sent to uncontrolled discharge sites. Discharge of sludge and fecal sludge in sewers often lead to surpass the wastewater treatment plants' capacity when available.

2. *For low-income countries.* Data from different African countries (Burkina Faso, Cameroon, Côte D'Ivoire, Ethiopia, Mali, Mozambique, Namibia, Nigeria, Senegal, and South Africa) demonstrated a similar situation focused on the need to provide basic sanitation services either in rural or urban areas. Few cities have complete sewerage systems and, when available, sewers frequently feed into partially functioning wastewater treatment plants. In these countries, the use of on-site sanitation systems, such as septic tanks, bucket latrines, pit latrines, and dry latrines, produces fecal sludge, which is often 'contaminated' with domestic waste. In dense informal settlements, the challenges to properly handle fecal sludge are significant as besides the technical constraints other factors related to the social, political, and cultural aspects come into play. Fecal sludge handling includes the need to provide reliable and low-cost options to emptying the facilities, to provide proper and affordable treatment and transportation, and to have suitable sites for safe disposal.

Literature exists concerning the alleviation of sludge and fecal sludge disposal and revalorization problems, not all of which is relevant for developing countries. Common issues in

properly managing sludge and excreta in developing countries are as follows (LeBlanc *et al.*, 2008; Jiménez, 2006, 2008):

- Conventional sludge and excreta treatment options used in industrialized countries do not necessarily achieve the levels of pathogen inactivation required for its safe reuse.
- Nutrients, organic matter, and energy are resources available in fecal and wastewater sludge that should be utilized as best as possible. There are examples around the world showing the feasibility and convenience of reclaiming them.
- Applying properly treated excreta and biosolids to soils in a safe way can contribute to soil fertility and with it to food security; it can also raise income for poor farmers.
- Proper management of excreta and wastewater sludge can significantly reduce releases to the atmosphere of potent greenhouse gases such as methane and contribute to carbon sequestration in soils.

4.06.9 Policy

The MDG Target 10 stating “Reduce by half the proportion of people without sustainable access to safe drinking water and basic sanitation is considered under Goal 7: Ensuring environmental sustainability” (Box 9). Therefore, sanitation is to be provided in a sustainable framework which, in practice, means to provide a service comprising much more than was expected in the past. To implement it, a proper policy is needed.

4.06.9.1 Integrated Water Resources Management

In order to consistently provide sustainable water services, it is recommended that an integrated water resources management (IWRM) approach is used. This approach is useful to analyze situations such as when

- multiple barrier system comprising solutions that go beyond the construction of wastewater treatment plants need to be implemented to protect health and the environment;
- sanitation needs to be provided as a tool (sometimes indispensable) to have clean water supplies and to provide a safe water supply (Box 10);
- sanitation is coupled with projects contributing to food security, job opportunities, increases in exportation, soil erosion control, efficient use of water, etc.;
- sanitation needs to be provided over a wide area rather than to a single section of it to effectively control negative environmental impacts;
- sanitation needs to be part of a three R concept system (reduce, reuse, and recycle);
- sanitation is considered as part of a cycle in which wastewater is properly reintegrated to the environment;
- sanitation needs to consider the impacts caused by climate change;
- projects need to be designed, operated, and/or managed by different institutions, sectors, basin agencies, or even countries;

Box 9 What does sustainability mean?

“A process that promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems”, UN-Water, 2008

According to LeBlanc *et al.*, 2008, elements defining sustainability are

- dealing transparently and systemically with risk, uncertainty, and irreversibility;
- ensuring appropriate valuation, appreciation, and restoration of nature;
- integrating environmental, social, human, and economic goals in policies and activities;
- providing equal opportunities and community participation;
- conservation of biodiversity and ecological integrity;
- ensuring inter-generational equity;
- recognizing the global integration of localities;
- a commitment to best practice;
- avoiding net losses of human or natural capital;
- implementing principles for continuous improvement; and
- providing good governance.

Box 10 The Bissau case, with information from Correlje AF and Schuetze T (2008). *Every Drop Counts: Environmentally Sound Technologies for Urban and Domestic Water Use Efficiency*. Division of Technology, Industry and Economics, TU Delft. India: United Nations Environment Programme.

Bissau, Guinea, in West Africa is a city attracting huge numbers of people from the surrounding countryside. Most of them have settled in squatter new areas around the old colonial center. During a study performed in the 1990s, it was found that the newly piped water taps ran dry several times per day. As a result, many people returned to the old wells. These were often more contaminated than before because the new pit latrines installed close to the wells polluted the groundwater. Groundwater quality was also impacted by solid waste thrown into the pits dug for the production of adobe blocks to build new houses. Moreover, the new network of gutters was now efficiently removing most of the clean rainwater that used to recharge the groundwater. The gutters caused an extra problem. On the edge of the settlements, where the gutters ended, storm water peaks caused serious soil erosion. This created problems for a newly developed scheme of vegetable gardens on the urban fringe, and even threatened houses. The original problem – the lack of water in piped water taps – was related to electrical power failures causing water pumps to stop. Similar situations can be encountered in many developing countries and they cannot be easily solved as long as their roots are not properly and integrally tackled.

- good technical solutions needing proper social, economic, and political policies are to be put in place; and
- wastewater, treated or not, is being nonintentionally reused.

4.06.9.2 Need for an Own Policy for Developing Countries

Developed countries, through experience, research, and technological innovations have progressively improved their sanitation services and have developed systems that are what they need. However, as described in this chapter, the problems they have faced and the problems they are now facing, although similar, are not the same as those confronted by developing countries. Thus, there is a need for low-income nations to develop their own processes using part of the developed countries' experience. To contribute to this process, a definition of the issues to address and the challenges to face is provided in the following.

4.06.9.2.1 Issues to address

The issues that need to be addressed are as follows:

- Low sanitation coverage lagging behind population growth, needing an intense effort in order to be tackled.
 - Need/importance to couple sanitation programs with others addressing problems such as food security, low income, and soil erosion control. In practice, this requires increased efforts of coordination.
 - Lack of sanitation as a component of poverty, and therefore, as a problem that cannot be completely solved if its roots are not properly addressed (**Box 11**).
- Lack of sanitation, particularly in vulnerable groups that, due to their own characteristics, are often more difficult to provide services for.
 - A growing population, notably in urban areas and, within them, in slums.
 - Higher vulnerability to the negative impacts of economic and climatic change on sanitation needs.
 - For low-income countries, lack of economic capacity to deal with the cost of covering the sanitation MDG targets and, for middle-income countries, the need to mobilize funding required to put sanitation above other needs.
 - The proper management of sludge and excreta, two by-products often not considered as part of sanitation targets of funding programs.

4.06.9.2.2 Challenges to face

The challenges to be encountered are listed below:

1. The lack of political will and commitment at the highest level (**WHO/UNICEF, 2000**) is a barrier that is greater than, for instance, the lack of economic resources, the capacity for building, or the acquisition of appropriate technology, since all these may be overcome by a strong political support. In order to develop political will, politicians and society need to appreciate the value of sanitation. An understanding that it is through the provision of water supply and sanitation that industrialized countries build up strong societies with good health and good economic conditions is needed (**Box 12**).
2. The second challenge is to put in place accountability mechanisms to ensure that resources provided to fulfill

Box 11 The sanitation problem in Cameroon (with information from Mfoulu N (2008) Cameroon. In: LeBlanc RJ, Matthews P, and Richard RP (eds.) *Global Atlas of Excreta, Wastewater Sludge, and Biosolids Management: Moving Forward the Sustainable and Welcome Uses of a Global Resource: UNHSP*, pp. 169–179. Vienna: UN).

In Cameroon, some houses are equipped with a 2-m-deep hole for a latrine, surrounded by pieces of timber. When the hole is full, it is covered with earth and medicinal or aromatic plants, and another facility is built. If the family has no land to dig another hole (as frequently happens), they call the tanker to empty it at a cost of US\$120. Sometimes, while the family saves up the money, excreta overflows and pollutes the nearby area where wells and boreholes are located, threatening drinking water quality. When feces are removed by tanker trucks, they are often dumped into rivers or the forest, because there are no treatment facilities.

Houses in modern residential areas have septic tanks, and their effluents are directed into wells for filtration. Often, this does not happen in the correct way because builders have not mastered the technology. Some collective residential areas, universities, and hospitals are connected to sewers that convey wastewater to a treatment plant, from where treated water is directed to a river.

But still, there are people without access to any of the facilities described above who go into the bush to relieve themselves on the spot. Villagers continue to use this practice because they have no choice.

Box 12 Clean means healthy?

Mexico City produces 21% of Mexico's gross domestic product (GDP) (US\$12 500 per capita). After the swine flu (H1N1 flu) outbreak in May 2009, a loss of US\$144 million was experienced solely due to the shutting down of restaurants, and US\$35.2 million were lost due to the closure of public transport for just 10 days. To allow the city to return to normal conditions, health experts advised constant handwashing and the disinfection of school toilets. At this point, politicians realized that 200 public schools had no water at all, 195 had malfunctioning toilets and 90 more had no facilities at all. Before the swine flu epidemic, politicians had not understood the link between water, sanitation, and health and had not addressed this problem, although on many occasions parents' associations had requested the services. The president of one parents' association commented on the news that, in contrast to most Mexicans, he believed that the swine flu had been a blessing as it was the only way to ensure proper sanitation facilities at schools. The Mexico City government invested US\$56 million on the school program 'Clean means healthy'.

Box 13 Need for new type of institutions, with information from Lenghton L, Wright A, and Davis K (eds.) (2005) *Health, Dignity and Development: What Will It Take? Millennium Development Goals*. London: Earthscan.

Water and sanitation service agencies are typically modeled after utilities in industrial countries, and as such are organized around the goals of maximizing operational efficiency for public sanitation components (trunk sewers and treatment plants) rather than providing services to poor people, slums, disadvantaged groups, etc. As result, in, in developing countries, experience and institutional structures to provide the type of services needed is deficient. As a result, services are being provided by other means. Data from India indicate that as much as 8% of rural households across the country invest their own money and use small private providers to construct latrines. Self-provision accounts for about 1 million privately installed septic tanks in Manila and in Jakarta. Research in Africa confirms that the role of the small-scale private sector in sanitation provision is significant. These findings are further supported by data from the JMP (WHO-UNICEF Joint Monitoring Programme): between 1990 and 2000, the increase in the number of people served by sanitation reported by the JMP was much larger than the expected impacts of the public investment that occurred during this period. The reorientation of public programs to either modify their structures or to promote and assist the provision of sanitation services by small private and even familiar companies is needed. This does not currently occur in developed countries.

the MDGs (public and private from donors) will be used wisely and for what they were originally intended for.

3. The third challenge involves a broader aspect. Even if sanitation programs are put in place, if poverty is not properly addressed, most of the solutions provided will be unsustainable. This will possibly lead in the future to adding addressing poverty to the already lengthy list of reasons why sanitation has failed in developing countries (this list already comprises financing, institutions, education, the need for decentralization, and the need for private participation).

4.06.9.2.3 Strategies that can be used

Although there is no recipe for success, strategies that can be considered when developing plans for sanitation include the following (Jiménez and Garduño, 2001; Jiménez, 2003, 2006; Lenghton *et al.*, 2005; UNDP, 2006; WHO, 2006; LeBlanc *et al.*, 2008; Correlje and Schuetze, 2008):

To develop policies:

- Take time to perform proper planning in order to identify the resources (human and economic) needed to design, build, operate, and maintain facilities, and to develop policies and institutions. Do not initiate projects for which this has not been previously defined, otherwise there is a risk of losing any investments made (a case in point is the existence of many facilities installed around the world, which have been subsequently abandoned).
- Take time to define how much money is needed, supported by experts with no commercial interest, specifically not those from companies that are potential participants in bids.
- Define needs and priorities using the best available information even if it does not come from the water sector. Priorities can be set by using the methodology proposed by Lenghton *et al.* (2005), which considers actual water service coverage, and mortality due to gastrointestinal diseases and density of settlements, considering urban and rural areas. Evaluate risks using quantitative methodologies to properly identify and prioritize problems, and select solutions accordingly (in terms of size, and economic and human resource investments).
- As much as possible during the planning stage, involve sectors related to the solutions other than the water sector

(e.g., the federal, regional, and local governments, ministers of the environment, urbanism, agriculture, land use, transport, economic development, social development, finance, etc.).

- Couple sanitation programs with programs related to food security, soil remediation, and economic development.
- Produce efficient, affordable, and enforceable norms and set goals for them that are easy to understand.
- Promote innovation at all levels (institutional –Box 13–, financial, regulatory, and technological).
- Combine different intervention methods to control problems; consider not only of sewers, latrines, and wastewater treatment plants.
- Consider water reuse and the safe reintegration of sludge and fecal excreta as an important part of the overall sanitation program.
- Promote the management of the environment in an integrated way, even considering climate change effects.
- Design monitoring programs that wisely use resources by including information that WILL be used. Use the new information obtained to evaluate and improve the program.
- Review the program to ensure it covers the specific targeted population sectors (women, the poor, rural areas, etc.) and meet the defined goals.

For funding:

- be creative in finding solutions to funding needs;
- extend financial support to the poorest households to ensure that sanitation is an affordable option;
- discern whether there is an absolute lack of resources for expanding water supply and sanitation coverage, or if there is a need to redistribute potentially sufficient existing resources; and
- develop and put into practice transparent mechanisms to easily and rapidly transfer monetary resources from central to local institutions.

For institutional design:

- Develop national and local political institutions that reflect the importance of sanitation in terms of social and economic progress.
- Promote institutions throughout government that use or at least understand concepts of integrated management, not only for water.
- Develop institutions where innovation and solidarity are considered as a virtue.

- Consider the need to have as part of the institutions well-trained and highly professional personnel.

For norms and regulations:

- Identify which problems should be addressed by using norms (compulsory), criteria (recommendations), or other type of tools (such as incentives and education).
- Set appropriate and affordable sanitation risk-based standards, designed to contribute to solving local problems that can be reviewed over time to integrate experience. These should be able to be adapted to new and better conditions in order to move progressively to an ideal situation.
- Allow the development of norms that are adapted to local needs and capabilities (Table 13). Sanitation systems are often adopted from other developed countries without sufficient adaptation and users tend to put in place an idealized solution in which a uniformly high level of service is provided and the technology to be used is already set.
- Set up regulations that combine different intervention methods to control risks that are not based only on wastewater treatment plants.
- Keep in mind that parameters selected are to be enforced and they will demand economic and human resources for.
- Review the whole legal framework related to the standard so they can fit in and be implementable.
- Set up standards using a participatory approach, which includes stakeholders and expert participation, notably coming from local universities.
- Where noncontrolled reuse is already in place, regulations need to maintain the benefits already obtained while

progressively controlling drawbacks; this can be done by promoting controlled reuse rather than adopting vanishing current practices.

- Incorporate reuse as part of the sanitation standards.

To set up programs:

- Perform a national inventory of the actual needs and solutions to be implemented to manage wastewater, excreta, and sludge, include a survey on water reuse possibilities to couple them with sanitation solutions when feasible.
- Implement policies by promoting incentives rather than imposing rules and fines; but when rules are to be observed, be firm on decisions, and inform society in order for it to be perceived that jeopardizing the health of others is important.
- As there is no universal solution, support a wide range of sanitation technologies and service levels that are technically, socially, environmentally, and financially appropriate.
- Promote innovation to have both technically and economically feasible technologies to deal with local pollutants, notably for the high and varied pathogen content.
- Implement pilot plant programs to test policies and use the information obtained to retrofit your program before scaling it up (Box 14; Spaliviero and Carimo, 2008).
- Empower local authorities and communities with the authority, resources, and professional capacity required.
- In order to fund the maintenance and expansion of services, local governments and utilities should ensure that users who can pay, do so.
- Carry out training programs addressing all stakeholders needs, from plumbers to politicians.

Table 13 Some aspects to consider when setting regulations

<i>Aspect</i>	<i>Advantages</i>	<i>Disadvantages</i>
Definition of fixed treatment option(s) to use and inclusion of predefined treatment design and operating criteria.	<ul style="list-style-type: none"> – Reduces the need for monitoring and surveillance. – Renders project implementation easier. 	<ul style="list-style-type: none"> – Limits innovation – Encourages bias in regulators who will be responsible for both selecting the method of control and meeting objectives. – May lead to nonviable schemes from an economic point of view.
Selection and use of the best indicators as parameters.	Reduces monitoring and surveillance cost.	<ul style="list-style-type: none"> – Introduces the idea that indicators are the best and ideal parameters to define pollution. – Most of the current best indicators have been proven effective for developed countries but have not been tested for all conditions in developing countries. – May give a false impression of safety. – Cannot be universal or static over time. – Increases supervision costs.
Selection of normal monitoring parameters and establishment of limits for each one.	– Facilitates surveillance.	
Use of epidemiological local data.	– Introduce protection for local problems.	– Information not always available for all of the diseases currently present.
Use of toxicological tests.	<ul style="list-style-type: none"> – Data available internationally. – Helps to establish cause–effect relationship. 	<ul style="list-style-type: none"> – Often render norms too stringent. – For diseases originating from microbial pollution do not correspond to local conditions when diseases are endemic.
Use of risk evaluation models.	– Help governments to make rational decisions.	– Difficult to explain their meaning to the population.

Adapted from Jiménez B (2003) Health risks in aquifer recharge with recycle water. In: Aertgeerts R and Angelakis A (eds.). *State of the Art Report Health Risk in Aquifer Recharge Using Reclaimed Water*, pp. 54–172. Rome: WHO Regional Office for Europe.

Box 14 Development of a stepwise program in Mozambique (with information from Spaliviero M and Carimo D (2008) Mozambique. In: LeBlanc RJ, Matthews P, and Richard RP (eds.) *Global Atlas of Excreta, Wastewater Sludge, and Biosolids Management: Moving Forward the Sustainable and Welcome Uses of a Global Resource: UNHSP*, pp. 431–437. Vienna: UN.)

Following Mozambique's independence in 1975, the government identified sanitation as one of the key components to improve health conditions. As such, in 1976, the Ministry of Health launched an intensive national campaign for the self-help construction of latrines. Many thousands of latrines were constructed during a relatively short period. However, there were numerous problems, including insufficient awareness about environmental conditions, a lack of technical guidance in latrine design and construction, and shortages of critical building materials. Consequently, many of the latrines became structurally unsafe and unusable. In response, a research project was initiated in 1979 to "identify and develop a suitable technology and method for large-scale implementation of improved sanitation in periurban areas." The result was the development and successful pilot testing of an appropriate and cost-effective technology. From 1979 to 1994, around 135 000 improved latrines were produced. In addition, an awareness campaign was carried out on the use of the latrine, hygiene promotion, and capacity building. In 1996, the program was extended to the rural areas. Prior to 1998, more than 230 000 latrines were constructed and installed. In December 1998, the program was formally transferred to the National Directorate of Water Affairs. Overall, it has been a long and steady scaling-up process over more than 10 years that ended by ensuring a progressive withdrawal of the government from latrine production. The emphasis now is given to decentralization and privatization for the services, although the responsibility for the program remains with the government. From this experience, some lessons learned, are

- Although technology must be simple, it is important for massive use to ensure its local production and commercialization. There must be several types of sanitation facilities with different prices in order to commercialize.
- A good network needs to be established between users (periurban communities, the government, nongovernmental organizations (NGOs), small private companies, and donors) to ensure that the program progressively developed its own dynamism.
- Latrines need to be emptied and the service needs to be provided.

- Implement programs to segregate and/or pre-treat industrial discharges to sewers to render municipal wastewater treatment more affordable and to avoid the presence of noxious compounds in treated wastewater and sludge that will limit their revalorization options.
- As wastewater, sludge, and excreta management regulation compliance often depend on the work of different ministries, coordinate the work of such institutions taking care that the objectives of each are compatible.
- Develop public indicators to follow up progress globally and also consider the implementation of indicators to follow specific targets such as wastewater treatment coverage, safe reintegration of treated water to the environment, and sludge and fecal excreta management. Attention should also be provided to deprived sectors (women, poor people, slums, dispersed rural areas, etc.)
- Seek to validate your indicators by a third independent party such as a university or a non-governmental organization (NGO).
- Verify that the same information is provided international, nationally, and locally.

To raise support for the program:

- Make it understandable to all that lack of sanitation means a barrier for economic development is an unsustainable way to manage the environment, is at the origin of local pollution problems, contributes to water scarcity as it reduces water availability, and increases vulnerability and reduces the capacity to adapt to climate change. All of these issues have broad support among society and different groups, not all of which are concerned by sanitation for the poor.
- Build community-level initiatives through government interventions aimed at scaling up best practice.

- Create awareness of the nonplanned reuse of wastewater and the importance of investing in it as an option to make clean water accessible for any use.

4.06.10 Funding

Figure 14 shows the investments made for water supply and sanitation from 1990 to 2000; it can be observed that, in the past, most efforts were orientated to water supply and cities, leaving sanitation (only about one-fourth of investments made for water supply) and rural areas far behind. Figure 15 shows the origin of investments. In the case of Asia and Latin-America, almost all the finances have come from governments, while, for Africa, it represented nearly a half.

From the previous analysis, it is evident that there is need to invest money to catch up with the level of services needed. Before calling for funding, it is convenient to analyze (preferably only within each country, without the input of donors or enterprises) what the money should be used for. To sustainably increase sanitation coverage, economic resources are needed not only to build sanitation infrastructure, but also for planning according to local needs and possibilities, developing research and technology, and developing institutional capacity in a local context. Unfortunately, most of the time, funding is provided only for some of these activities (mostly for infrastructure); one major reason being that, often, this is the only type of funding that is sought.

4.06.10.1 Funding Options

There are two funding options: public or private, each of which has different modalities. For public funding, the money comes from federal or local governments either directly from tax revenues or user charges, or, indirectly through cross-subsidies from users who can afford to pay, private-sector investment, or international and national loans. Private sector

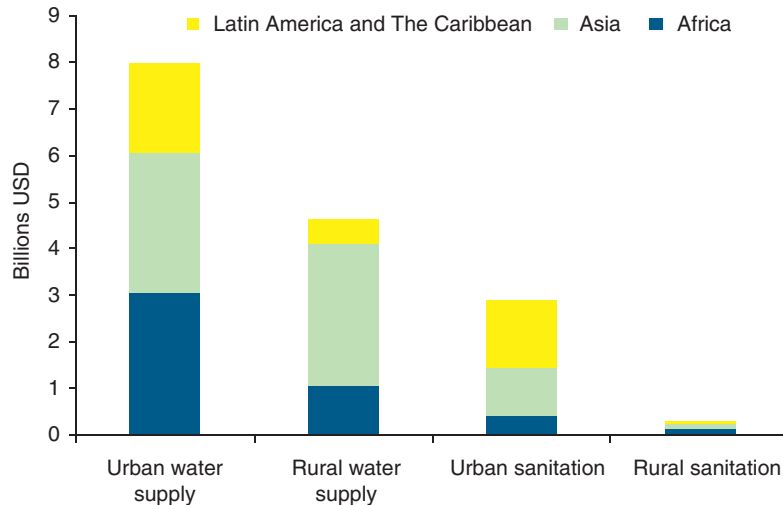


Figure 14 Investments made in billions of USD between 1990 and 2000 per region for rural and urban water supply and sanitation. Data from WHO/UNICEF (2000) *Global Water Supply and Sanitation Assessment Report, Joint Monitoring Programme for Water Supply and Sanitation*. Geneva: WHO.

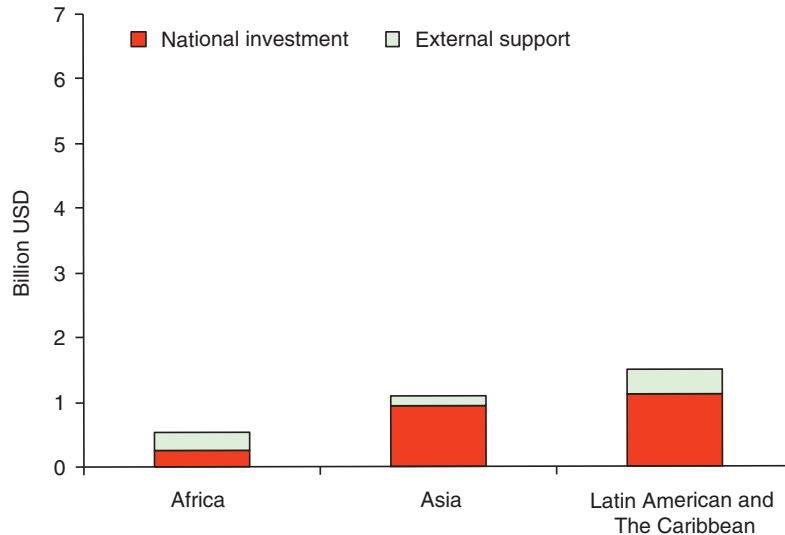


Figure 15 Origin of the investments made in billion USD between 1990 and 2000 for sanitation per region. Data from WHO/UNICEF (2000) *Global Water Supply and Sanitation Assessment Report, Joint Monitoring Programme for Water Supply and Sanitation*. Geneva: WHO.

investments and national and international loans are to be paid from taxes, the difference is only that payments differ in time and are used simply because it is very difficult to finance sanitation projects directly from users. As a result, people who pay for the services are not always the same who will be using them.

Private aid is made available by private enterprises or NGOs. Private funding is used simply because developing countries have greater needs than economic resources. The participation of private enterprise cannot be taken for granted as there are several factors that actually inhibit their participation. These include low accessibility to loans from towns and municipalities, the need to organize projects that have payback periods of 20 years, and the need to recover costs through water tariffs (Lenghton *et al.*, 2005). Private funding includes not only international or national firms, but also self-

provision schemes provided by nonconventional private enterprise. These nonconventional private enterprises have been called by some 'informal' although for several developing countries, they have in many cases proven to be more formal, useful, and to provide more reliable services than formal ones. For example, in India, an NGO named Sulabh has installed 5500 pour-flush toilets that are operated on a fee-paying basis and are maintained by attendants who live at the facilities. Through providing good reliable service, Sulabh's facilities have become a model for sustainable public sanitation services. This shows that there is growing knowledge and capacity provided by small and even family-run companies that are capable of producing significant and innovative improvements in access to sanitation.

Financing strategies are specific for each country and situation and depend on the political will, the compatibility with

existing institutional arrangements, the degree of community involvement in decision making, the available economic and financial resources, and the prevailing social and cultural preferences, among other aspects. When either private or public funding is used, some key elements to make a good use of it according to [Lenghton *et al.* \(2005\)](#) are

- *Maximum scalability.* The selected financing strategy needs to be one that can be scaled up quickly and in a straightforward manner to allow for rapid increases in the population served.
- Minimal transaction costs.
- Full financial accountability.
- Closed revenue cycle, that is, financially viable in the sense that all capital and operating costs are fully covered – either through user fees, government subsidies, or external finance.

4.06.10.2 Why Sanitation Needs to be a Public Process

Sanitation is of public interest (**Box 15**) and hence is a public process. In order to implement what needs to be provided is, for the governments, to identify the main requirements, the areas of responsibility, the risks associated, who is responsible for what, the different options to address needs, and the associated costs. Once this is performed, it is required to review, set up or adapt the legal and institutional framework, and to educate all the persons involved (from society to politicians, experts, regulators, private companies and functionaries,

besides children and women). Sanitation management (basic sanitation facilities management, wastewater collection, treatment and reintegration, by-product management, and risk control) requires the coordination of different public institutions, society, academia, private enterprises, and in some cases, even different countries. Therefore, the government is needed to set up the programs.

4.06.10.3 Why Private Participation can be Involved

Today, around the world, it is still mostly government agencies that construct and operate wastewater collection and treatment systems. However, private companies are contracted to conduct operations in many places, and all countries have significant commercial enterprises built around collecting excreta and septage and managing wastewater sludge and biosolids, mostly in cities. Theoretically, private companies, if well used by the government, could be useful to increase sanitation coverage if the level of society is raised and private companies are not used to increase the already-considerable differences existing between economic social classes. Nevertheless, private participation is not increasing in sanitation. After steadily increasing at a global level between 1990 and 1997, it began to decrease ([Lenghton *et al.*, 2005](#)). There are many reasons for this, one of which is that it is not easy to build up successful schemes combining private and public interests.

Box 15 How industrialized governments approached funding for sanitation (with information from [Lenghton L, Wright A, and Davis K \(eds.\) \(2005\) *Health, Dignity and Development: What Will It Take? Millennium Development Goals*. London: Earthscan.](#))

In general, in developed countries, public water infrastructure components have been highly subsidized by governments, reflecting an understanding that the public health benefits of sanitation generate substantial positive external gains that merit public investment. In Britain, for example, urban authorities borrowed more than £7.7 million for sewerage work during the period 1880–91. Eventually, the public provision of sanitation became an uncontroversial and indeed, an expected part of life. Similarly, for many municipalities in the United States, public financing of sanitation infrastructure was seen as the only option for ensuring investment adequate to protect public health. In the nineteenth century, Boston, for example, had lower-than-expected connection rates among households to the city's new water and sewer network; this prompted the city to cover the cost of service pipes for all unconnected households. In 1850, an influential state sanitary survey concluded that governments must accept responsibility for financing public sanitation infrastructure because, left to their own devices, a large proportion of Massachusetts residents would be unable or unwilling to take on personal responsibility to conduct their lives in accord with recommended sanitary principles. Until recently, grants of up to 70% or more were provided for innovative sanitation technologies in the United States.

Table 14 Type of service and technology more suitable for private and public participation

Type	Modality	Type of service	Technology needed
Private	Public or private sector provision	Sewerage plus wastewater treatment plants	Low or normal volume flush water closets; house connections; sewers, biological or physicochemical treatment centralized or decentralized operated.
	Self-provision	Septic tank systems	Septic tanks; soakaway pits or absorption trenches; water closets or pour-flush toilets
		Pour-flush toilets VIP latrines Nonventilated pit latrines	Squat slabs over pits or connected to offset pits
Public	Provision by public, private businesses or NGOs	Public latrines	Public water closets; public VIP latrines; public pour-flush toilets; public nonventilated latrines

Adapted from [Lenghton L, Wright A, and Davis K \(eds.\) \(2005\) *Health, Dignity and Development: What Will It Take? Millennium Development Goals*. London: Earthscan.](#)

One aspect to keep in mind concerning public and private participation is that for the sanitation field, these funding options combine better with certain type of sanitation systems, characterized in terms of their size and used technology (Table 14).

4.06.10.4 Differences between Low- and Middle-Income Countries

Low-income countries need to invest 10–30% of their GDP to fulfill their MDGs (Lenghton *et al.*, 2005). For some, these are figures difficult to reach even if the use of loans is considered. For them, external donors can play an important role. Middle-income countries have fewer needs and more economical capacity to meet their MDGs. For some, it is estimated that they could use up to 15% of their GDP, and hence it is considered that no external finance is needed (Lenghton *et al.*, 2005). Moreover, this situation, from the point of view of some authors, offers to inform the private sector of great opportunities to conduct a business and, as a result, in several middle-income countries private funding is being promoted. One possible risk, which needs to be considered by local government and known by society in general, is that through private participation and international loans, technology and sanitation schemes from other countries are promoted, which

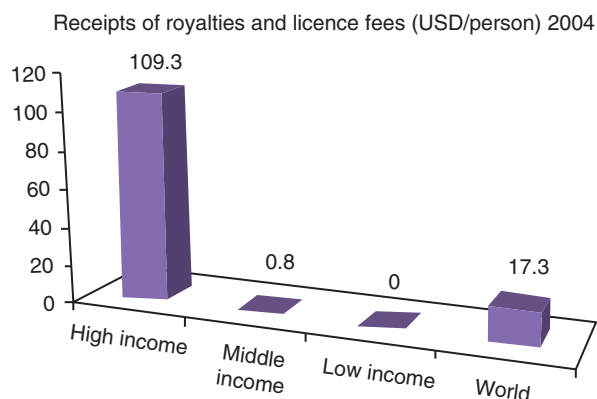


Figure 16 Receipts of royalties and license fees in countries with different income (with information from UNDP, 2006).

do not always effectively solve local problems in the cheapest and most efficient way. Another risk is the use of the money for additional purposes. To deal with this, it is important, on the one hand, for the government to be accountable and, on the other hand, for society to demand transparency.

In any case, it is certain that developing countries need to be creative to raise funds for sanitation. One option is to raise them as part of other projects in which sanitation can be a component; these include those considering goals for food security, health, land remediation, environmental problems control, and adaptation to climate change, for which several donors may be available. As an example, carbon credits could be used to fund projects to manage sludge and fecal sludge.

4.06.11 Science and Innovation: Need to Develop Individual Knowledge

In developed countries, a complex and complete system of public agencies, private companies, equipment vendors, consultants, scientists, engineers, operators, and supporting professional and educational organizations makes sanitation possible. Promoting this organizational and human capacity in developing countries is one of the challenges on the path to increasing adequate sanitation, wastewater reuse, and proper fecal sludge and wastewater sludge management.

Science and innovation are needed in developing countries to reduce their intense dependence on developed countries. Unfortunately, in many situations, technology originating in high-income countries is still preferred and implemented. However, this may not match the actual needs or promote local

Table 15 Information concerning the first three Prosab research phases (with information from Andreoli *et al.* (2008))

Area	Number of projects	Public resources (million USD)
Water	12	2509.00
Wastewater	30	3931.00
Sludge	16	1845.00
Solid waste	13	1548.00
Total	71	9833.00

Box 16 Research program for sanitation in Brazil (with information from Andreoli *et al.*, 2008, Garbossa LHP, Lupatini G, and Pegorini ES (2008) Brazil. In: LeBlanc RJ, Matthews P, and Richard RP (eds.) *Global Atlas of Excreta, Wastewater Sludge, and Biosolids Management: Moving Forward the Sustainable and Welcome Uses of a Global Resource: UNHSP*, pp. 131–146. Vienna: UN.).

The Brazilian Sanitation Research Programme (Prosab) is a public program that has received financial support for different projects since 1996. Its goal is to develop and optimize existing technologies for water supply, wastewater treatment, and solid residues management. For that, its objectives are

- to establish the state of the art of technology;
- to adapt or develop technology to provide sanitation services in local and regional conditions, and to meet the different needs of all population sectors, preserving and restoring the environment;
- to make technology and knowledge part of the public domain; and
- to support participatory processes, creating cooperative research networks to discuss subjects.

The total investment for the three phases listed is around US\$9 million distributed as shown in Table 15, in which investments made for salaries and scholarships are not considered. Both, research papers and technological innovation, were produced from this program.

economic development. In some other cases, developing countries are even used as laboratory testing grounds for new magic solutions. In low- and middle-income countries, examples can be found where a significant part of the investment made for wastewater treatment plants is used to pay for the intellectual property rights of the processes, as happens with many other activities. In Figure 16, it is shown that royalties received because of patents in developing countries are non-existent or low while those for developed countries are high; sanitation could be in the future another source of this dependency and inequity. On the top of this, some of these processes do not solve actual problems and, as a result, around the world, several places can be found where new solutions for providing sanitation to poor people have been installed in series unsuccessfully. This situation has two negative effects: first, it discourages donors from making further investments and, second, it makes local people wary of possible solutions. The only way to prudently overcome this is to promote the development of technology by people immersed in local problems. For this purpose, investment in education and local research is important (Box 16 and Table 15).

As presented here, the solution to sanitation problems can be combined with the solutions to other problems. The possibility therefore exists to develop new and individual technologies, to adapt the existing ones, and even to rediscover ancient local solutions. In parallel, the same can be done with policies to manage water.

4.06.12 Conclusions

At an international level, there is current mobilization to support and improve sanitation conditions in developing countries. This mobilization is being expressed in terms of donors, private participation, and international aid agencies support. From this chapter, it is concluded that there are many reasons explaining why providing sanitation in developing countries is different to the solutions implemented in developed ones; therefore, care must be taken to not to use the aid to implement projects, which may prove not successful. For this reason, it is important to promote that each country defines first its needs and works defining programs. As the challenges to provide sanitation are many and very complex (policy definition, technologies to be used, education and awareness programs implementation, development of adequate institutional capacity, finding new financing options, etc.) it is important for developing countries to share among them their knowledge and experiences in the framework of the so-called South–South cooperation.

Sanitation is an important pillar to develop wealthy societies (in terms of health and economic capacity) and, for this reason, governments should promote investments in this field that are to be properly and responsibly managed. The only way to assure this is to promote, allow, or to demand a participatory approach.

Finally, the water situation in developing countries has some bright sides. The first consists in the fact that the wide divisions observed in developed countries within the water sector (water supply and wastewater experts) does not exist or is not so pronounced. This allows easier understanding and

promotes the integrated management of the problem. The second has to do with the high degree of solidarity existing among the population, which may play an important role in speeding up a sanitation program proven successful and contributing to raising the quality of life.

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