Global Potable Water: Current Status, Critical Problems, and Future Perspectives

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Abstract Providing access to potable water and sanitation has become a human right through various designations in international treaties and declarations. Many countries and international organizations have established water quality guidelines for potable water supplies, thereby defining standards for treatment processes to meet. Unfortunately, potable water for all is a goal that has not yet been fully realized. Water-related diseases remain the number one cause of death for children under five worldwide; these problems are particularly evident in rural areas of developing countries. In addition, emerging contaminants and disinfection by-products have been linked to chronic health problems for people in the developed and developing world. This chapter provides an overview of critical problems relating to the provisioning of global potable water. First, current health impacts of water-related illnesses as well as natural and human influences that will alter our current water supply in the coming decades are reviewed. The technical limitations to water treatment in both developed and emerging economies are then discussed. Additionally, a brief look at the social and political factors influencing potable water access such as government capacity, competing interests, and the influence of food choices on water availability will be discussed. Finally, some current innovative approaches and suggested strategies for water management in the future are presented.

Keywords Potable water access • Anthropogenic impacts • Water and health • Technical limitations • Societal challenges • Emerging issues

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T. Younos and C.A. Grady (eds.), *Potable Water*, The Handbook of Environmental Chemistry 30, DOI 10.1007/978-3-319-06563-2_2,

1 Introduction

Access to drinking water is a critical global issue. What constitutes water access? The currently accepted definition comes from the United Nations as outlined in 2000 [1]. This UN definition focuses on three distinct measurable characteristics of drinking water sources: (1) the quantity of water, (2) the safeness or quality of water, and (3) the distance for collecting water. The recommended quantity of safe water is 20 L per person, per day [1].

The second and third components of the UN definition of water access are progressively harder to measure. The UN definition articulates that safe water "does not contain biological or chemical agents directly detrimental to human health" [1]. In practice, this definition applies to treated surface water and untreated water from improved water sources such as protected springs, bore-holes, and sanitary wells. Water is often referred to as the "universal solvent" because of the wide range of constituents that can be dissolved or suspended in it. This allows for a broad spectrum of contaminants, both biological and chemical, to be present in water supplies. The UN definition of "improved sources," which targets surface contamination, leaves much to be desired because water quality can be impacted by natural contaminants such as fluoride and arsenic [2].

The third and final pillar of the access to water is distance. As defined by the United Nations, a convenient distance for an urban population is less than 200 m from a place of residence. In rural areas, the third component is defined by a distance that allows people to not spend a disproportionate amount of time each day collecting water [1]. This too can be a difficult measure since a short distance may still constitute a large portion of time if many people are sharing the same water source [2].

Although the definition of water access may not encompass everything necessary to provide water to all people, it is a good starting point to define and measure water access. An aim of this chapter is to give the reader an overview of different limitations and setbacks with providing water access to people worldwide. After reading this chapter, the reader should have an understanding of the critical challenges facing water provisioning for citizens in both developed and emerging countries.

2 Anthropogenic Impacts on Drinking Water Sources

Agricultural production, industrial activities, and urbanization influence the status of water access. Climate change is an emerging factor which relates to multiple access issues. A contaminant's origin, its properties, and how it may affect human health provide a clear understanding of the limitations for provisioning safe water. From health perspective, acute and chronic diseases caused by contaminated water influence the approaches needed to meet global potable water demand.

Natural water sources are commonly used to transport and "dispose" of wastes from domestic and industrial activities. Many of these waste products include components that are known to cause disease in human [3]. Domestic sewage has been a source of water pollution since the advent of communal settlements. Since the industrial revolution, additional pollutant burdens have also been introduced from agricultural runoff, industrial and mining operations, and urbanization [3]. All pollution sources present both technical and social limitations to access safe water worldwide.

2.1 Agricultural Impacts

Plant macronutrients (especially nitrogen and phosphorus) that are applied to agricultural lands through the application of synthetic and natural fertilizers have influenced the widespread occurrences of nutrient-enriched waters. Nutrient abundance in natural waters has become one of the most critical global water quality problems, particularly since the agricultural revolution of the 1960s and 1970s [3–5]. Excessive nutrient input to surface waters contributes to eutrophication, hypoxia, and ultimately marine organism deaths [6, 7]. Nitrate, which originates largely from agricultural productions systems, is the most abundant chemical contaminant found in groundwater worldwide [3, 8]. Moreover, agricultural uses of pesticides, herbicides, and pharmaceuticals (e.g., antibiotics) have resulted in this global distribution of these compounds in drinking water sources and watershed soil [9, 10]. More details will be discussed in Chap. 7.

In addition to nutrient influxes caused by fertilizer application to agricultural land, modern agricultural practices can also alter the salinity of groundwater and mobilization of salts [11]. Overpumping groundwater in coastal areas has been linked to seawater intrusion, which results in increased groundwater salinity that tends to be difficult to remediate [12, 13]. Salinization is often an outcome of long-term changes in natural water flows caused by irrigated agriculture [14]. Salinization presents another difficult problem, a negative feedback loop that reduces agricultural production due to increased soil salinity [15]. Agricultural practices can also promote soil erosion, thereby leading to increases in sediment concentration in receiving waters. In addition to increases in turbidity that are caused by the introduction of colloidal particles, sediment inputs can function as carriers of many of the pollutants described above, thereby further contributing to degradation of surface water quality [16].

2.2 Industrial and Mining Impacts

Industrial processes such as pharmaceutical production, petroleum refining, paper manufacturing, textiles fabrication, and various mining operations can negatively affect water quality. Wastewater generated from industrial operations often contains nutrients, sediments, heavy metals, a variety of other toxic chemicals, and microbial contaminants. There are many examples of correlations between industrial processes and degrading water quality. For example, in Malawi, water downstream of industrial practices was shown to be potentially harmful for human consumption [17]. Moreover, industrial water usage could foreclose public usage because of limited access to freshwater, as well deterioration of water quality. In China, the water-intensive industrial sectors cause abundant water withdrawals and generate large amounts of wastewater at the same time, which potentially contaminate drinking water sources. This issue exacerbates both ecological sustainability and economic growth [18]. Additionally, there are new and emerging questions about the impact of energy production on water quality worldwide. Traditional power plant processes such as coal-fired power plants increase surface water temperatures, which can affect ecosystem health [19]. New concerns about wastewater used in hydraulic fracturing and high intensity oil extractions such as tar sand extraction include various types of contaminants such as methane, ammonia, sulfate, chloride, and other pollutants [20, 21].

Mining activities also can introduce water quality problems. Mining can contribute heavy metals, salts, mercury, and many other contaminants to groundwater and surface water [3, 22]. Contaminants are transferred to water through mining operations, disposal of tailings, and runoff in and out of mine sites [22].

2.3 Urbanization Impacts

People have been migrating from the rural, agriculture-based areas to urban, industry-based cities for decades. Between 1990 and 2010 urban areas grew from 2.3 billion people to 3.5 billion people [23]. Urbanization has also been associated with increases in impervious surfaces, which in turn results in increased runoff and associated pollutants introduction to receiving waters [24, 25]. For example, in Shanghai, a 50-year case study demonstrated an extensive relationship between water quality and urbanization, particularly in and around industrial complexes in urban areas [26]. Increased impervious surfaces can cause increased transport of stormwater runoff-associated contaminants into surface waters. These contaminants include heavy metals, oils, and rubber residues, among others. In addition, improperly treated human wastes from urban and suburban areas cause significant water quality problems [3]. Increased migration of rural residents to urban areas in recent decades, largely attributable to the pursuit of employment, has caused significant sanitation and water quality problems. Population growth will only continue to exacerbate the issues of water quality management in urban areas.

3 Water and Health

Worldwide, millions of people, especially children, die from acute water-related diseases each year. In addition to short-term diseases, drinking contaminated water can also cause a variety of chronic diseases such as cancer. Acute and chronic diseases caused by unsafe water influence the access to potable water worldwide and new approaches are needed to meet global potable water demand.

3.1 Acute Diseases

In developing countries, acute water-related diseases remain the number one cause of mortality. For children between the ages of 1 and 5, diarrhea and malaria, which are both related to water, account for approximately 1.3 million deaths annually [27]. While tremendous gains have been made in providing access to safe water throughout developing countries, there are still roughly 800 million people who do not have access to improved water and 2.5 billion people are without access to proper sanitation [23].

Acute water-related diseases can take many forms and transmit illnesses to people through several mechanisms. The classification system of water-related diseases, shown in Table 1, includes diseases that are directly transmitted through drinking contaminated water (waterborne), through lack of water for proper hygiene (water washed), through dermal uptake of contaminated water (water based), and through insects that consume water in one or more stages of their life cycle (insect vector).

Pathogens that lead to diarrheal diseases and malaria remain the largest threats to human health worldwide [27, 28]. Within the broad category of waterborne diseases, the most common pathogens include viruses, bacteria, and protozoa. It is estimated that diarrheal diseases kill between 2 and 5 million people annually [29]. Even if the United Nations Millennium Development Goals are achieved across the globe, water-related deaths have been estimated to total somewhere between 34 and 76 million deaths between the years 2000 and 2020 [30]. In addition to mortality, water-related diseases increase financial and social burdens on families, who are affected since illnesses increase the cost of health care, reduce ability to earn income, and cause children to miss critical periods of schooling, among other things [30–33]. While important strides have been made in providing access to improved water in an attempt to mitigate the impacts of water-related diseases, there are still many limitations to access safe water throughout the world. Limitations to access include both technical limitations and social and political factors which will be discussed throughout this chapter.

Table 1 Common classification of acute water-related diseases [28]

Classification	Examples	Causes
Waterborne	Cholera Hepatitis Typhoid	Drinking contaminated water
Water washed	Scabies Trachoma	Lack of water for proper hygiene
Water based	Schistosomiasis Guinea worm Threadworm	Swimming or walking in contaminated water (through skin)
Water-related insect vector	Malaria Dengue fever Yellow fever	Bite by infected insects that breed near water

3.2 Chronic Diseases

While acute water-related diseases pose immediate health threat, some contaminants in drinking water have been linked to chronic diseases. Many of these contaminants occur naturally in rock formations and soils, are soluble in water, and are detected in both surface and groundwater sources. Table 2 provides a summary of some of the most common contaminants that are linked to chronic diseases in humans.

It is difficult to estimate the number of people affected by chronic water-related diseases across the globe. Most of these diseases can also be caused by other types of exposure and can also be underreported, especially in developing countries. Correlation between water contamination and chronic diseases can be deduced from health studies of exposed populations (Table 2); however global averages are not available. Many of contaminants that may be present in water are tasteless, odorless, and cannot be detected without performing field sampling and precise laboratory analysis. Additionally, as discussed in the preceding chapter, many chronic disease contaminants are unregulated. For example, Arsenic is a contaminant that has an enforceable compliance standard in the United States, while nitrate has a suggested health goal that is not enforceable [52, 53].

4 Technical Limitations

Limitations to water access can be grouped according to technical, social, and political factors. There are technical limitations in both developing and developed countries. Limitation characteristics are somehow different in emerging and developed countries. In emerging countries the technical limitations are observed in various design phases of water or wastewater infrastructure intervention strategies.

Table 2 Contaminants in drinking water linked to chronic diseases in humans

Contaminant	Natural occurrence	Human-induced occurrence	Chronic diseases	Water and health studies
Arsenic	Rocks and soils	Animal production, legacy farm fields	Cancer (including bladder, kidney, skin, and lung), peripheral vascular disease	[34–37]
Heavy metals	Rocks and soils	Household plumbing, mining, construction, industrial wastes	Various cancers, brain damage, nervous system damage	[38, 39]
Fluoride	Rocks and soils	Drinking water treatment	Dental fluorosis, skeletal fluorosis	[40–42]
Radionuclides	Radioactive elements (e.g., uranium and radium), rock	Mining, nuclear plant failure	Cancer (including stomach and bone)	[43–45]
Nitrate and nitrite	Nitrogen compounds in soil	Animal waste, fertilizers, landfills	Methemoglobinemia, cancer (including bladder and ovarian), thyroid disruptions	[46, 47]
Pesticides, herbicides, and chemical pollutants	–	Industrial wastes, leaking tanks, household wastes, agricultural activities	Parkinson's disease, various cancers	[40, 48, 49]
Disinfection by-products	–	Water disinfection processes	Cancer (including bladder, liver, kidney); skin rashes	[40, 50]
Pharmaceuticals	–	Agriculture activities, industrial processes, household wastes	Various cancers,	[49, 51]

In developed countries critical technical issues are often related to aging infrastructure and water availability.

4.1 Emerging Countries

Constraints to water access include barriers to the design phase, implementation issues, monitoring and evaluation, as well as operation and maintenance. Technical constraints can include limitations that directly relate to the engineering aspects, the technical capacity of people implementing and running these water services, and costs associated with water provisioning.

Table 3 Technical constraints to effective water provisioning in developing countries

Design process phase	Constraint examples
Design	Difficult sites and terrain
	Complicated site layout
	Conventional system overreliance
Implementation	Investment capital
	Institutional capacity
	Community participation
Monitoring and evaluation	Regulations, guidelines, standards
	Technical capacity
	Decentralization
Operation and maintenance	Finance, ability to pay
	Post-construction support
	Community participation

Table 3 shows a variety of constraints to water access in emerging countries. This list is by no means comprehensive; however it provides an overview of common technical problems.

4.1.1 Design Phase Limitations

Design phase limitations include limitations that impact the planning stage of water and sanitation intervention strategies. These problems include having to design water and wastewater interventions on rough terrain and complicated site layouts. In addition, engineers and urban planners often design on traditional centralized systems even if those designs are not well suited for the situation.

Both urban and rural human populations living in poverty tend to live on undesirable pieces of land. Many of the poorest countries in the world are chronically dry, and the poorest people are often restricted to marginal lands [54]. This continues the cycle of poor people being trapped in a feedback loop between poverty and environmental degradation. In urban environments, the more undesirable the land, the less expensive it is. Slums, shantytowns, and favelas are often found on difficult terrain such as steep country sides and floodplains [55]. Although land values in these areas tend to be low, the cost of bringing services to them, such as water and sanitation, is generally higher than in other areas [56]. Additionally, even if water access can be established to these marginal lands, these areas are often most susceptible to landslides and floods, thereby causing disruption in services [56].

In addition to marginal and difficult site conditions, many cities, towns, and villages in emerging and developing countries have been developed without using appropriate and standard urban planning techniques. This lack of planning often leads to sites being developed haphazardly [56]. This presents challenges for the design phase of water and sanitation provisioning services, because engineers or government institutions often have no record of what structures are in place, how the traffic flows, who manages shared resources, etc.

Finally, engineers and planners often rely on designing and implementing conventional water and sanitation service-delivery systems, even though these systems may not fit with the complexities of informal settlements and unplanned neighborhoods [56]. This limitation stems from traditional curricula of engineering schools as well as a lack of social and community engagement in traditional engineering design [56]. For some communities in developing countries, distributed models for delivery of potable water and sanitation services may represent a more appropriate approach than the conventional centralized systems that are common in developed countries [56].

4.1.2 Implementation Phase Constraints

The largest and most obvious constraint for providing access to water is financial. Capital investment for project implementation is not meeting the needs of current development efforts [57–59]. Additionally, the recent global financial crisis increased the number of people living in poverty and decreased the public and private financial support to the water and sanitation sector [59].

A second barrier to the implementation of water and sanitation projects in developing and emerging countries revolves around institutional capacity. First, large-scale projects require many aspects to come together. These include tasks such as land acquisition, displacement of people, and business contracts that require considerable institutional capacity of governments, which is not always possible [58]. Additionally, corruption in the water, energy, and transportation sectors is well documented in both developed and developing countries [58]. Community participation in implementation of water and sanitation projects is also important and often becomes a limitation or downfall of projects in developing countries.

4.1.3 Monitoring and Evaluation Limitations

For the purpose of this chapter, monitoring and evaluation refer to drinking water quality, while operation and maintenance have been separated to address limitations associated with overall function of water and sanitation systems. Monitoring and evaluating of water quality in developing and emerging countries are currently insufficient due to lack of resources, lack of capacity and expertise, time requirements, and management of institutions in charge of regulations and standards [3]. These limitations tend to be associated with lack of standards, regulations and guidelines, lack of technical capacity, and the decentralized nature of water and sanitation throughout these countries. Wide variations of drinking water standards and regulations are evident [60], which complicates assessments of the status of global access to safe water. Another challenge relating to standards and regulations is that groundwater use is often not regulated or monitored properly. Global information on the quality of groundwater is very limited due to regulation variation, time, and cost of monitoring [3]. Having and maintaining the appropriate disinfection residual also remain a challenge in many developing countries [61]. This can occur due to both human and mechanical failures during the treatment process [62].

The technical capacity and expertise of professionals in developing and emerging countries should be strengthened to improve understanding of water quality throughout the world [3]. According to the World Health Organization, the authorities responsible for drinking water supply monitoring have roles that encompass not only water quality, but also public health of people with and without access, information management, and reporting of waterborne diseases [61]. Many public health ministries may not have the capacity to cover all of these tasks, leaving some to fall to other agencies or organizations. This can often lead to inadequate monitoring and reporting [61].

Currently, monitoring and evaluation of drinking water focus on centralized conventional water distribution systems, even though many people in the developing world obtain water access through decentralized community systems [61]. This presents monitoring challenges relating to the time, capacity, and resources needed to monitor rural decentralized systems. There is a need to develop different tools to support monitoring of small community supplies compared to large conventional piped systems [61].

4.1.4 Operation and Maintenance Limitations

While monitoring and evaluation deal directly with overseeing the technical quality of the water service, operation and maintenance can refer to a more broad sense of system functionality. Overall, the percentage of water and wastewater treatment projects that fail to be sustained for long-term use ranges from 20 % to 75 %; many recent assessments have indicated that half of all water projects in developing countries fail within 5 years. As early as 1981, the United States Agency for International Development (USAID) recorded that 35–50 % of systems in preindustrial countries became “inoperable” before the end of 5 years due to the failure in resources required for maintenance of improved water and sanitation systems [62]. Regionally, the World Bank estimated that more than 33 % of all existing infrastructure in rural communities throughout South Asia, including water and wastewater, are dysfunctional [63]. A survey of approximately 700 boreholes constructed in the 1980s throughout Kenya showed 43 % did not have normal water flow by the year 2000 [64].

It is difficult to maintain these water systems when water tariffs cannot be collected, water prices are not set to adequately fund maintenance, or governments do not have the resources to subsidize access [56, 59, 62]. The long-term maintenance of water infrastructure reduces the cost-effectiveness of these interventions, especially when compared to other intervention strategies such as hygiene education [65]. Additionally, many projects funded by international development agencies or nonprofit organizations have no mechanisms for post-construction support after projects are completed and grants are fully utilized. Post-construction support and community participation are critical to sustained operation of water and sanitation interventions in developing countries [66–68]. Operation and maintenance limitations are often linked to poor community participation, especially among decentralized rural water and sanitation programs that are common in many developing countries. In centralized water systems throughout emerging and developing countries, inadequate financial and human capacity can lead to large volumes of unaccounted water due to system leaks in the water conveyance system [69]. Other operational limitations include inadequate pressure, leaks, corrosion, and intermittent water supply [62].

Throughout this section, many technical limitations to water provisioning in emerging and developing countries were discussed. While each of these can be detrimental in singularity, these factors are often compounded and linked. Additionally, one system perturbation can cause negative feedback loops to form, which can lead to additional negative consequences. Many of the limitations derived from emerging and developing country systems can be attributed to the lack of uniformity in water provisioning. Countries with large rural populations often implement decentralized water systems. These tend to be economical to build and are often based on technologies that are simple to maintain, but may suffer from inadequate monitoring. There are also many countries that lack adequate capacity within the central governing body to implement and monitor water and sanitation systems. Obviously, financial resources related to capital and tariff pricing and collection can also have important impacts on more than one phase of this process.

4.2 Developed Countries

Limitations and constraints to water provisioning in developed countries can take many forms and encompass more than one aspect of the design phase. The limitations discussed here, while not all encompassing, give a general overview of constraints that fall into three categories: factors due to age, water extraction factors, and water treatment factors (Fig. 1).

4.2.1 Aging Infrastructure

One of the most commonly cited constraints to effective water provisioning in developed countries is the "aging infrastructure" problem. Some components in water and sanitation conveyance systems in the United States and Europe are more than 100 years old [70, 71]. Aging infrastructure presents many technical limitations for effective water provisioning.

First, degradation of infrastructure system integrity leads to system losses and water leaks. The water lost in the conveyance process is often referred to as "non-

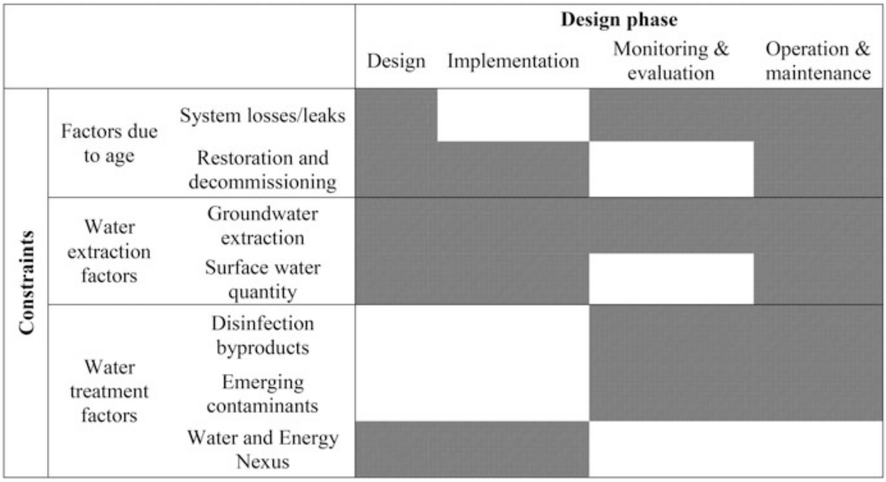

Fig. 1 Technical constraints to effective water provisioning in developed countries

revenue water" because it leaves the system prior to the water meter, which is generally used to define cost paid by the user. For the United States, non-revenue water ranges from 10 % to 30 % of total water, while in England this value has recently been estimated to be 25 % [71, 72]. In addition to leaks in pipes, system losses can be caused by water main breaks or other failures due to aging infrastructure. In the United States, there are approximately 240,000 water main pipe breaks each year [71].

Constraints noted above present challenges to the design phase. First, this presents a question of the effectiveness of current design strategies. When a system is leaking or breaks, should the section of that system be replaced or should an alternative design be considered? Additionally, from a monitoring and evaluation standpoint, leaks in a system indicate the potential for introduction of contaminants. Often in developed and developing countries, the monitoring and evaluation of potable water quality occur at the point of treatment or the centralized water treatment plant. If there are leaks in the conveyance system after this treatment point, the water quality is not effectively monitored afterwards. Water quality is also affected by the corrosion of pipes [73]. Microbes can grow on corroded surfaces and iron oxides can become increasingly adsorbed, both of which can happen after the point of monitoring and evaluation [74]. Additionally, in reference to the operation and maintenance or broad sense of system functionality, the location of leaks can be difficult to pinpoint.

In addition to constraints for drinking water monitoring and evaluation constraints, there are difficulties with wastewater treatment in developed countries. The sewer networks in many urban areas of the United States, particularly the Midwest and Northeast, involve the use of combined sewers. By necessity, these systems must include combined sewer overflows (CSOs), which protect downstream operations from hydraulic overloading during runoff events. With increasing populations and changes in rainfall patterns, wastewater overflows from CSOs have result in discharge of 11–38 billion liters of untreated wastewater to streams and rivers in the United States each year [71]. After this untreated wastewater enters the river system, downstream cities and towns then withdraw the water for municipal drinking water. The hydrologic cycle creates a system of impact where upstream parties contribute to the water quality of those downstream.

In addition to leaks and losses in the conveyance systems of water infrastructure, the rehabilitation and/or decommissioning of large infrastructure projects remains a significant challenge in most developed countries. The aging infrastructure, including but not limited to water-related infrastructure, in the United States will require over $1.6 trillion dollars to bring up to acceptable standards and functionality [74]. The U.S. Environmental Protection Agency (EPA) estimates that the United States will have a funding deficit of $533 billion dollars for water and wastewater infrastructure operation and maintenance costs between 2000 and 2019 [71]. These high costs introduce design and management questions. For example, is it preferable to rehabilitate an old system or replace it?

To date over 600 dams of the nearly 79,000 in the United States have been decommissioned or removed for safety and economic reasons [75]. The design and implementation phases for dam or levee decommissioning are complicated due to ecosystem connections, such as the value of artificial structures and change of water flow and fish habitat [75]. For example, the Three Gorges Dam in China, which was built for flood control, electricity generation, and navigation, has huge impacts on economy, ecosystem, geophysical processes (e.g., nutrients transportation and sedimentation), and water quality [75–77].

4.2.2 Water Availability Limitations

Water availability is becoming increasingly critical in some areas due to population growth and increased water demand. Technical constraints to water access in developed countries include challenges associated with groundwater extraction and water treatment limitations due to degradation of surface water sources.

Groundwater use worldwide has increased in recent decades due to expanding crop irrigation, population increase, high water demand in larger cities, and increased water demand in arid and semiarid areas [3, 78]. Over-withdrawal of groundwater can cause increased soil salinity, water stress and vegetation changes, and other impacts [3, 79, 80]. The technical constraints to groundwater withdrawal and use relate to all phases of the design process. These constraints stem from a lack of information about the state and status of groundwater aquifers worldwide [3, 79, 81]. There is inadequate information on the quantity of water in aquifers, particularly fossil aquifers deep below the earth's surface. This lack of information can affect the use of groundwater. Additionally, monitoring and evaluation of groundwater can be difficult and costly due to the fact that we have a poor understanding of many of the locations, quantity, and functions in natural systems of groundwater resources [82]. Often, groundwater recharge rates and extraction estimates are based on models relating to rainfall and not on specific well or groundwater monitoring [79, 83]. Since aquifers do not necessarily follow political boundaries, monitoring and evaluation as well as operation and maintenance of aquifers are often difficult to pinpoint [82]. For example, if one municipality designs a groundwater extraction system based on knowledge of local water quantity, this system can influence the quantity and quality of water available to other users of this same aquifer.

4.2.3 Water Treatment Limitations

In developed countries there are several technical constraints to water treatment requirements that will continue to present challenges in coming decades. Three of these challenges include disinfection by-products, emerging contaminants, and the water/energy nexus.

The term disinfection by-products (DBPs) refers to chemical compounds that form as a result of disinfection processes. Examination of DBP formation originated with the discovery of chloroform formation following application of chlorine [82]. Since chlorine is inexpensive and efficient for inactivation of many types of bacteria and viruses, it is often applied in treatment processes for drinking water and wastewater. However, chlorine is known to react with natural organic materials (NOMs) and organic pollutants to form a wide range of disinfection by-products [43, 83, 84]. Beyond chloroform and the other trihalomethanes, DBPs identified to date that are common to halogenated waters include haloacetic acids, chloramines, halonitriles, N-nitrosamines, and other compounds [85]. These DBPs have been linked to a wide range of acute and chronic health risks including cancer, skin infections, respiratory irritations, and birth defects. Not all DBPs in drinking water are regulated in the United States and European Union [86]. Moreover, new DBPs are still being discovered, in part because of improvements in instrumentation and methods for analysis of water quality. For some of these DBPs, their associated human health implications remain undefined [87, 88].

Emerging contaminants generally refer to the synthetic organic chemicals and pathogens that are not commonly monitored in the environment but have been recently detected in the environment. The true fate of these contaminants and the health risks associated with them are largely unknown, but are being examined [89–92]. Among the challenges that emerging contaminants present are monitoring and evaluation of operation and maintenance processes. From a monitoring and evaluation standpoint, there are a few regulations relating to the water and wastewater treatment industry for these emerging contaminants [93]. The practices of industrial and manufacturing breakthroughs have surpassed the regulatory practices, particularly in the most recent decades [93]. The challenges during the operation and maintenance of existing systems include the cost of retrofitting treatment plants to filter and treat these new contaminants. Additionally, many of these contaminants are present at low concentrations, which can make them difficult to analyze and remove [93]. This threat on the global potable water is further developed in a later chapter of this book.

The water and energy nexus is often described when discussing limitations to water treatment because the water treatment process in centralized water distribution systems requires a large amount of energy. More generally, the water/energy nexus refers to the feedback loops between power generation and water treatment and provisioning [93, 94]. Many of the treatment processes capable of combating concerns such as disinfection by-products and emerging contaminants require more energy consumption than treatment processes currently in place. In addition, with increasing populations and increasing demand for electricity, water use is needed in more power generation plants. The feedback loops between water and energy will be a concern for both developed and developing countries in the decades to come.

5 Global Challenges

Focusing on the technical constraints to water and sanitation provisioning in developed and emerging countries, this chapter has touched on a variety of different issues, including the ones that will be developed in more detail later in this book. While these topics provide a framework to conceptualize important issues, it is critical to discuss global societal challenges that impact global potable water access. As with all of the topics discussed thus far, this section provides an overview of important societal issues. Three central issues that encompass a variety of societal questions include competing interests, virtual water, and water as a target for warfare.

5.1 Competing Interests

Potable water provisioning is a basic human right. This has been clearly articulated by international organizations such as the United Nations. However, access to food is also a human right. Providing food through agricultural production remains the single largest sector of water use worldwide. At present, about 70 % of the water withdrawn worldwide is used for agriculture [95]. With increasing population food demand, an increase in water demand associated with the agricultural sector is expected. In the coming decades, water managers will have to make difficult decisions on water provisioning for various sectors. Will water be given to municipal and domestic needs before agricultural needs? What about the impact of industrial water use? How does one weigh the benefits and drawbacks of water provisioning for competing sectors?

Due to the global nature of the economy, industrial practices have large impacts on livelihoods. Manufacturing provides goods sold all over the world, it provides jobs and income, and it processes food and other products critical to daily life. With recognition that water is used worldwide to meet various demands, i.e., industrial processes, economic development, agriculture production, and of course drinking water, one can see the immense challenges, ethically and technically, in balancing needs versus the finite amount of available water. In part, these challenges stem from inadequate pricing and valuation of water [96].

5.2 Virtual Water Use

Virtual water is a term that refers to the hidden water use and associated costs of goods and services. It quantifies the amount of water required to produce a commodity [97, 98]. The virtual water concept was developed by J. Allen who conceptualized the significant amounts of food products imported into the Middle East and North Africa despite the relatively low water availability in those regions [97]. Since the concept was coined, it has been used to calculate the import and export of water based on food crops worldwide.

More than just conceptualizing trade flows according to the water demand of commodities: virtual water presents a dialogue on societal implications of food consumption. In developed countries, the concept of virtual water has popularized the amount of water required to produce beef and poultry compared to vegetables. Additionally, it has presented questions about the consumption rates and disposal of commercial products such as cell phones and clothing. These questions relating to water footprint of commercial goods have implications concerning the competition between multiple sectors, the water/energy nexus, and pricing. Appropriate pricing of water is still a topic of debate [62, 99]. Societal values are a part of the pricing decisions for a resource that is a basic human right. As discussed previously, financial resources are desperately needed for capital and operational maintenance costs. However, if water is too expensive, it can be cost prohibitive, particularly for people living in poverty. Additionally, current food prices in many developed countries do not reflect the cost of water or other agricultural inputs, due to subsidies and import and export tariffs.

5.3 Conflicts

The importance of water as a basic human need makes water infrastructure and water resources a clear target for violence, intimidation, sabotage, and terrorism [100, 101]. While, to date, water has never caused a direct war between nations, there have been many historical water conflicts [100–102]. Using water infrastructure as a political or military target dates back to over 2,500 years [101–103]. Deliberate water contamination is the easiest way to distribute biological or chemical agents for the purpose of terrorism [104]. The potential impact of a large-scale attack could potentially be catastrophic [103].

One critical challenge for combatting this global problem is that there are major knowledge gaps with regard to the inspection methods for protection of water against biological or chemical agents [104]. Additionally, there is no standard set of policies or procedures for operation and maintenance of water infrastructure to administrate readiness, response to terrorist events, and recovery [105]. Vulnerability assessments, increased security measures, and improved quality control measures can help to prevent death and illness from biological or chemical terrorism [104].

6 Discussion and Future Implications

Throughout this chapter, an overview of critical problems relating to the provisioning of potable water worldwide has been developed. First reviewed review of current health impacts of water-related illnesses was presented, including acute and chronic ailments, as well as natural and human influences that have led to our current status of degraded water quality. The technical limitations to water treatment in both developed and emerging economies were discussed utilizing the phases of the design process as a framing mechanism. Additionally, a brief mention of societal factors that influence potable water access, such as competing interests, and the influence of food consumption on water availability have been discussed.

Shifting climates, increasing and decreasing rainfall, and changes in water cycle timing will affect water quality and water access in coming decades. Some areas may see increases in rainfall while others see decreases. Additionally, the seasonality of rainfall patterns may shift. A large portion of the world population is already experiencing various forms of water stress [106]. Areas that experience an increase in rainfall due to climate change will likely experience an increase in sedimentation and contaminant runoff [3]. Regions of the world that become drier may see an increase in concentration of contaminants [3, 107]. Increased variability could also influence the transport of microbial agents that cause acute water diseases which may create more water-related disease outbreaks [108, 109]. There are numerous publications in the refereed literature that develop models and predictions for how climatic changes will influence the hydrologic cycle and water access. These data can be used to help prepare for future water management strategies. Additionally, this chapter presented the human-centered point of view relating to global potable water. Water management and water provisioning for human consumption must account for water needed to sustain ecological systems. Water needs for nature are important to factor into decision-making strategies for water management worldwide.

Despite all of the seemingly overwhelming critical problems faced in developed and emerging countries alike, there has been tremendous progress on providing access to potable water made in recent decades. Millions of people in emerging countries now have access to improved water supplies not available 20, 10, or even 5 years ago. Target 7c of the UN's Millennium Development Goals, to reduce by half the number of people without sustainable access to safe drinking water, was met in 2010, 5 years before the goal deadline [23]. Between 1990 and 2010, over 2 billion people obtained access to improved drinking water sources [23]. In this same period, approximately 1.8 billion people gained access to improved sanitation.

Ongoing research continues to analyze risks associated with emerging contaminants and disinfection by-products. Governments and managers worldwide strive to update regulations and standards to keep water safe for all.

Public perceptions of wastewater reuse and water consumption habits have changed in some localities [110]. For example, in Singapore, government water managers have invested in not only the treatment of wastewater for reuse but also the marketing and acceptability of this NEWater as a viable potable bottled water source [110, 111]. This water reuse project is critical to the sustainability of Singapore's water systems since it is a small country with high population density and limited freshwater availability. Additionally, cities in the United States such as San Diego are currently employing educational outreach to combat perceptions and concerns for wastewater reuse.

Whatever the response will be to these critical problems, managers will need to develop diverse and resilient solutions for a diverse and variable time. One solution, pollution prevention of worldwide water resources, is often the cheapest and easiest way to protect the quality of potable water [3]. Strengthening the strategies to reduce harmful contaminants, both technically and socially, will foster progress in pollution prevention. Another necessary solution to increasing water access is to expand and improve water and wastewater treatment [1, 23, 30]. We can achieve this by investing in a variety of solutions including high tech, energy-intensive, centralized treatment mechanisms as well as low tech, small-scale, rapid-deployment point of use treatment systems. Increasing our understanding of contaminants will provide more insight into developing effective treatment systems. More importantly, the social values and cultural conditions of communities need to play a role in their water management strategies. Engineering technologies alone cannot solve current or future potable water problems.

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http://www.springer.com/978-3-319-06562-5

Potable Water
Emerging Global Problems and Solutions
Younos, T.; Grady, C.A. (Eds.)
2014, XVII, 233 p. 45 illus., 33 illus. in color., Hardcover
ISBN: 978-3-319-06562-5