# Sustainable Urban Water Management

**Chapter** · December 2017

DOI: 10.1007/978-3-319-65338-9_13



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# Chapter 13
# Sustainable Urban Water Management

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**Abstract** Sustainability in urban water management is of utmost importance. The distribution of water should depend not only on the availability of the valuable natural resources but also on its efficient use. Water quality plays an equally significant role since if different water uses are taken into account could provide a more sustainable water distribution. We establish that water quantity and quality should be jointly studied and managed in order to acquire a beneficial sustainable water environment for urban areas.

**Keywords** Water management • Water sustainability

## Introduction

> "Urbanization brings opportunities for more efficient water management and improved access to drinking water and sanitation. At the same time, problems are often magnified in cities, and are currently outpacing our ability to devise solutions."
> Ban Ki-moon, UN Secretary General, 2014

The exploding urban population growth creates unprecedented challenges, among which provision for water and sanitation for millions of people. Even though water supply networks are as ancient as human civilizations, water management is as urgent as ever, since water is not distributed evenly on Earth and among countries. Climate change is always an additional source of uncertainty in water quantity prediction and water supply planning. Therefore, sustainability in urban water management is prominent to arid or remote regions, as well as to big industrial cities. The distribution of water should depend not only on the availability of this valuable natural resource but also on its efficient use. On the other hand, water quality plays an equally significant role, as different water uses set different requirement standards, which, if taken into account, would provide a more sustainable distribution of water on Earth. As it will be developed in this

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A. Karakitsiou et al. (eds.), *City Networks*, Springer Optimization and Its Applications 128, DOI 10.1007/978-3-319-65338-9_13

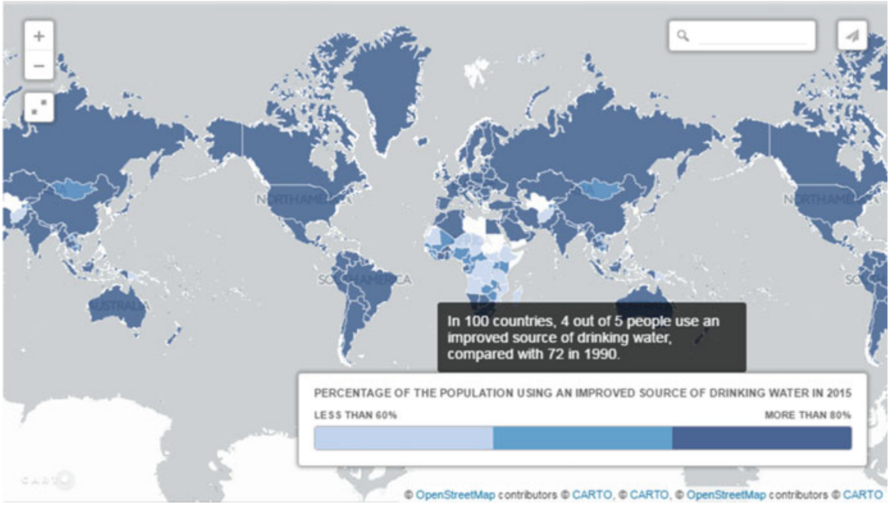


**Fig. 13.1** Percentage of population using an improved source of drinking water in 2015 [1]

chapter, water quantity and quality should be jointly studied and managed in order to acquire a beneficial sustainable water environment for urban areas. Coping with the growing needs of water and sanitation services within cities is one of the most crucial issues of this century.

Half of humanity now lives in cities, and by the middle of the twenty-first century, it is projected that it will approach 60%. Urban growth is more eminent in the developing world, where cities are augmented by an average of five million residents every month. Global water demand is expected to increase, as countries develop and populations grow. The growing population creates problems, such as water deficiency and deterioration of water quality, which at the same time invokes challenges to the scientific and engineering community to develop new methods to better manage the water resources. Sustainable, efficient, and equitable management of water in cities has never been as important as it is now.

Sustainability in cities cannot be met without ensuring reliable access to safe drinking water and sanitation. The latest published percentages of the population using an improved source of drinking water and improved sanitation facilities in 2015 are shown in Figs. 13.1 and 13.2 [1]. However, less people are gaining access to drinking water and sanitation needs than the corresponding global population growth, as Fig. 13.3 clearly shows, based on data collected for approximately two decades, between 1990 and 2008 [2].

In most developed countries, access to safe water and sanitation is taken for granted. However, in the middle of the nineteenth century, big cities were hit by infectious diseases, due to misfortunate neglect of sanitation measures and legislations. Child death rates were as high as they are now in much of sub-Saharan Africa (see Figs. 13.1 and 13.2). The significant progress that was acquired was

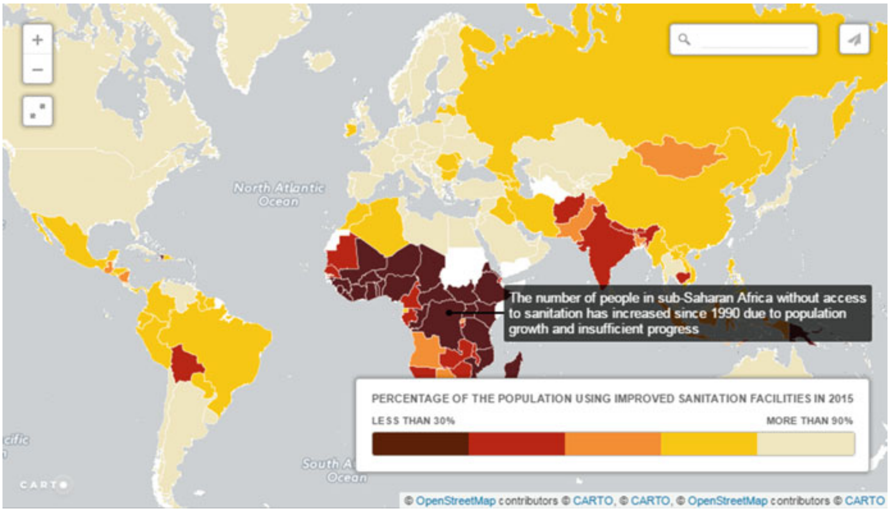


**Fig. 13.2** Percentage of population using improved sanitation facilities in 2015 [1]

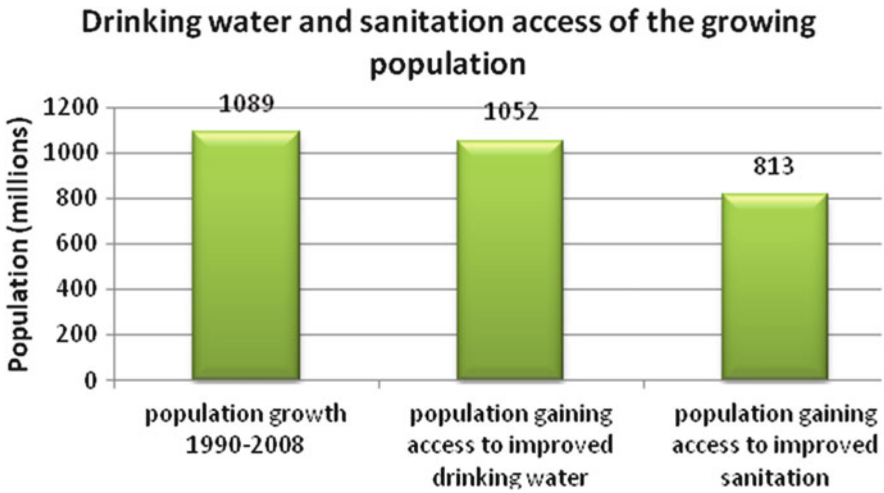


**Fig. 13.3** Population gaining access to improved drinking water and sanitation vs population growth, 1990–2008, on a global scale

due to extensive reforms in water and sanitation. In fact, in a 2007 poll by the British Medical Journal, clean water and sanitation access was designated the most important medical advancement since 1840. On March 2015 Springer published a book on *Water Policy in Canada* which dedicated one chapter on health issues related to inefficient water management in developed countries, pinpointing two major waterborne disease outbreaks in the USA and Canada within a period of 11 years [3]. However, the developing countries are facing health-related problems

**Fig. 13.4** The water crisis leaves millions of people without safe water [5]

continuously due to poor water quality. According to the World Health Organization and UNICEF [4], nowadays:

- In low- and middle-income countries, 1/3 of all healthcare facilities lack a safe water source.
- Water-related diseases affect more than 1.5 billion people every year; one million of them die each year due to water, sanitation, and hygiene-related diseases.
- 160 million children suffer from chronic malnutrition, poor quality water, and lack of sanitation. Diarrhea is the third leading cause of children's death. Every 90 s a child dies from a water-related disease.

In Fig. 13.4, the world is divided into regions that show the populations that lack access to water in descending order [5]. The Southern hemisphere, with the only exception of Australia, has still a long road ahead to reach sustainability in terms of water supply. Moreover, these regions are facing more rapid population growth, water scarcity, higher temperatures, and economic deficiencies (poverty).

The populations that lack access to water worldwide, in descending order, are:

- 332 million people in Africa
- 155 million people in South, West, and Central Asia
- 131 million people in Southeast, East Asia, and Oceania (except Japan and Australia)
- 32 million people in Latin America and the Caribbean
- 13 million people in developed countries (USA, Canada, Europe, Russia, Australia)

These global aggregates also pinpoint large inequalities between nations and regions, rich and poor, between rural and urban populations, as well as disadvantaged groups and the general population. It is also documented that:

– More than 1.7 billion people live in river basins where water use exceeds natural recharge, leading to the dehydration of rivers, depletion of groundwater, and the degradation of ecosystems.
– It is projected that by 2025, two thirds of the world's population could be living in water-stressed countries, if water consumption continues in the same ratio.

The water crisis is the number one global risk, based on impact to society (as a measure of devastation), as announced by the World Economic Forum in January 2015 [5, 6]. The outcome document adopted at Rio + 20 "The Future We Want" [7] states that "Water is at the core of sustainable development, as it is closely linked to a number of key global challenges." Water is vital for reducing the global burden of diseases and toward improving health, welfare, and productivity of populations. It is also central to the production and preservation of a whole of benefits and services for people. Water is also at the heart of adaptation to climate change, serving as the crucial link between the climate system, human society, and the environment.

The Millennium Development Goals (MDGs), agreed in 2000, set the goal to decrease the percentage of people without sustainable access to safe drinking water and basic sanitation to half, between 1990 and 2015. According to UNDESA [8]:

– From 1990 to 2015, 2.1 billion people progressively gained access to a latrine, flush toilet, or other improved sanitation facilities, helping to comprise a total of 68% of the global population.
– Nevertheless, 2.4 billion people (1 out of 3) still lack access to a toilet [5, 9].
– In 2015, however, 663 million people (1 out of 10) lack access to safe water and still withdraw water from unimproved sources [4, 5].

The United Nations declared the years 2005–2015 as the "Water for Life" decade [8]. Its goal was to promote efforts to fulfill international commitments on the globe by 2015. They tried to establish further cooperation between governments and other stakeholders, between nations and diverse communities, and between economic interests and the needs of ecosystems and the poor, in order to achieve the water goals of the Millennium Declaration, the Johannesburg Plan of Implementation of the World Summit for Sustainable Development and Agenda 21. In July 2010, the General Assembly adopted a resolution, which "recognized the right to safe and clean drinking water and sanitation as a human right that is essential for the full enjoyment of life and all human rights [10]." In September 2015, the General Assembly finally agreed on a water goal to "ensure the availability and sustainable management of water and sanitation for all." This reflects that water and sanitation has become a key priority for UN member states. Water should no longer be considered a "free resource", but rather a valuable resource for life.

The MDG target for sanitation was a pressing challenge. To reach the requirements of the right to access to safe drinking water requires real improvements for several billions of people. There are many smart ideas to be implemented by individuals and governments to resolve world's water crises, by securing and/or transforming water use.

Building a sustainable water supply system consists of a viable infrastructure for the collection, transfer, treatment, storage, and distribution of water for public and private use, in residential, commercial, industrial, and irrigational areas. Public use refers, but is not limited, to schools, hospitals, and other public buildings, but also firefighting, gardening, and street cleaning. Of all municipal needs, provision of potable water is undoubtedly the most important. Citizens depend on water for drinking, cooking, washing, and other domestic everyday needs. However, urban water supply systems must also cover quantitatively all other public, commercial, and industrial activities.

Public or private water supply companies worldwide set as their primary goal to provide to their consumers best quality water, for both urban and non-urban use. Back in the 1990s in the USA, however, it was raised as an issue whether that approach was the designated one. The possibility of running two parallel pipes of different quality water, to different destinations, was under serious consideration. Two decades later, small steps are made toward this direction, as it is very hard to apply it to big developed cities. It's rather appropriate to design new cities or extensions to old ones with a more sophisticated water supply system.

In 2004 the term water footprint (WF) was introduced by Prof. Arjen Y. Hoekstra and Dr. Ashok K. Chapagain at UNESCO-IHE [11], to assess how much water is used per person. Since then numerous publications focused on quantifying and mapping national WF, as a measurement of water use, under-use, or overuse [12–14]. It can also serve as an indicator of a nation's socioeconomic development. WF's increase indicates allegedly an escalation in living standards, as it is closely related to water consumed by an individual for his/her personal needs. Water footprint of an individual, community, or business is defined as "the total volume of freshwater that is used to produce the goods and services consumed by the individual or community or produced by the business." This is due to the fact that people use water for personal needs (drinking, cooking, and washing), but even more for producing things (such as food, paper, cotton clothes, etc.) [15]. The water footprint (WF) is an indicator of water use that looks at both direct and indirect water use of a consumer or producer [16]. Or else, the WF of national consumption is estimated as the sum of the direct WF of consumers and the indirect WF components of agricultural and industrial water use:

$$\text{WFcons} = \text{WFcons, dir} + \text{WFcons, ind (agricultural)} + \text{WFcons, ind (industrial)}$$

The water footprint of national consumption for countries (both developing and developed) with a population larger than five million, for the decade 1996–2005, distributed to agricultural, industrial, and domestic use [17], illustrates a wide range of 500–3500 $m^3$/yr/cap, which depicts the disparity in water use among nations. The extreme values can possibly be related to insufficient and/or unreliable collected data on consumption and water productivity in those (mainly developing) countries. The world average consumption is 1385 $m^3$/yr./cap. Water consumption for agricultural use is leading the global WF, by 92%, whereas that for industrial products and domestic use account only for 4.7% and 3.8%, respectively. This

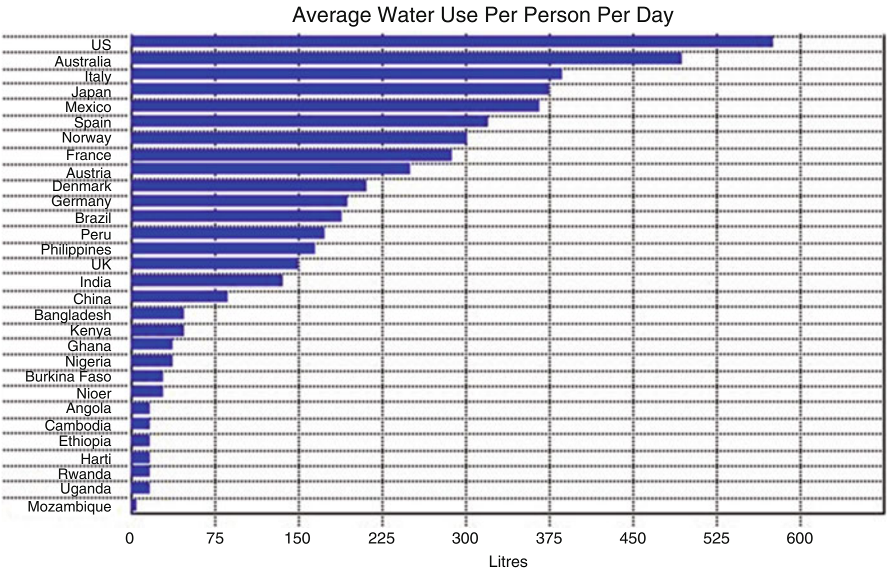


**Fig. 13.5** Average daily water consumption per person for various countries [18]

ranking of countries also shows that industrialized countries have WFs per capita in the range of 1250–2850 $m^3$/y. The UK, with a WF of 1258 $m^3$/y, is at the low end of this range, whereas the USA, with a footprint of 2842 $m^3$/y, is at the high end. Surprisingly enough Greece is close to the high end, with approximately 2300 $m^3$/yr./cap, next to Canada and Australia.

In accordance with the aforementioned WF, the average daily water consumption per person, for different countries of the world, is given in the following more comprehensive chart [18]. Similarly, it is denoted that a person in the USA is consuming more than 550 L/d, whereas in the UK a citizen is consuming approximately 150 L/d (Fig. 13.5).

Conventional methods of estimating national water use take into account only water withdrawals. By introducing WF, as a measure of humans' appropriation of freshwater resources, in terms of domestic, agricultural, and industrial use, provokes countries in developing well-informed national policies, by extending these statistics to including data on rainwater use and volumes of water use for waste assimilation and by adding data on water use in other countries for producing imported products, as well as data on water use within the country for making export products [19]. Therefore WF can be distinguished into three components [17]: blue, green, and gray [19]. The blue WF refers to the consumption of blue water resources (surface and groundwater), whereby consumption refers to the volume of water that evaporates or is incorporated into a product. The blue WF is thus often smaller than the water withdrawal, because generally part of a water withdrawal returns to the ground or surface water. The green WF is the volume of green water (rainwater)

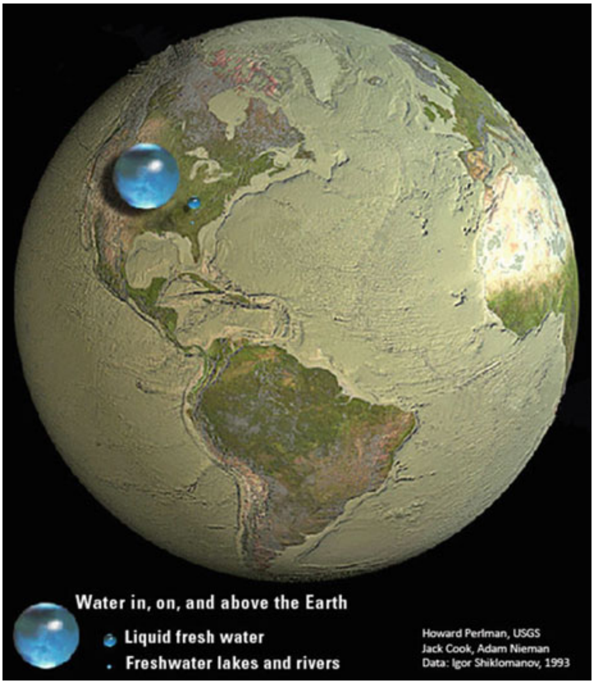


**Fig. 13.6** Graphical representation of freshwater in rivers and lakes, with respect to the total liquid freshwater and the entire water in, on, and above the Earth [20]

consumed, which is particularly relevant to crop production. The gray WF is an indicator of the degree of freshwater pollution and is defined as the volume of freshwater that is required to assimilate the load of pollutants based on existing ambient water quality standards.

In addition to all that, there are countries that depend upon freshwater resources on other countries. Highly water-scarce countries that have a large external water dependency are in descending order, Malta, Kuwait, Jordan, Israel, the United Arab Emirates, Yemen, Mauritius, Lebanon, and Cyprus, with dependencies varying from 92–71%.

In order to eliminate the big discrepancies between nations in terms of the water use and provide an optimal water resources management, we need to incorporate all of the above valuable conclusions into an inquiry on sustainable water management, which involves (Fig. 13.6):

- Sustainable use of groundwater
- Optimal use of surface water
- Efficient use of stormwater/rainwater
- Desalinated sea water use, where available

Water is present in abundant quantities in our planet. However, as the above figure shows very brilliantly, liquid freshwater is a tiny proportion of the total available water on Earth. In the bibliography, it is well portrayed that most of Earth's water (estimated 1.4 billion km$^3$) is in the oceans or frozen in polar ice caps and glaciers. Less than 3% is freshwater and less than 1% of it is liquid freshwater, since of the total freshwater, more than 68% is sheltered in ice and glaciers. Another 30% of freshwater is confined in the ground. Fresh surface water sources, such as rivers and lakes, that are the main sources of water supply globally, only constitute about 1/150th of 1% of total water (about 93,100 $km^3$) [21]. Freshwater, containing less than 3 g/L of salts, has to satisfy all human needs. Unfortunately, it is not always available, as it is not uniformly distributed over the Earth. In many cases good quality water is deteriorated due to urban development, industrial growth, and environmental pollution. Ocean water, on the other hand, contains about 35 g/L of dissolved minerals or salts, making it unfit not only for drinking but also for most industrial or agricultural uses. It remains to be investigated whether desalinated water can satisfy all human needs. In addition to these natural resources of the water cycle that can be withdrawn, treated, and delivered to cities, there are alternative methods that should be investigated and applied in order to relieve arid or overpopulated areas. These alternative water resources include:

- Reuse of grey water
- Reuse of treated wastewater

In an effort to illustrate graphically a sustainable water network that can utilize all accessible sources and all available technology, Fig. 13.7 is created to establish a distribution network of different quality water to different end users. This optimization, of course, requires eloquent management and a robust economy, to satisfy water uses at all levels. This interrelated series of water and energy transfer is the suggested management for a sustainable city network.

## Surface and Groundwater

Water was playing a significant role in the selection of the location for the earliest settled communities, and the evolution of public water supply systems is tied directly to the urban development. In the exploitation of water resources beyond their natural condition in rivers, lakes, and springs, the digging of shallow wells was probably the earliest innovation. Wells provided at the same time the necessary storage area and protection from environmental factors, as in the ancient underground storage tanks of Athens (Fig. 13.8a). The need to channel water supplies from distant sources was an outcome of the growth of urban communities as in Athens, Pisistratio aqueduct 600bC, and the Roman aqueducts of Nikolopis, first or second century aC, or Kavala, 1530aC (Fig 13.8b, c, d, respectively).

Surface water and groundwater are both valuable sources for urban water supply needs. Groundwater is less susceptible to bacterial pollution than surface water, because the soil and rocks, through which groundwater flows, filter most of the bacteria. The chemical and biological nature of groundwater is acceptable for most uses. Groundwater may contain dissolved minerals, as it dissolves them from the rocks with which it comes in contact, and gases, that give it the tangy

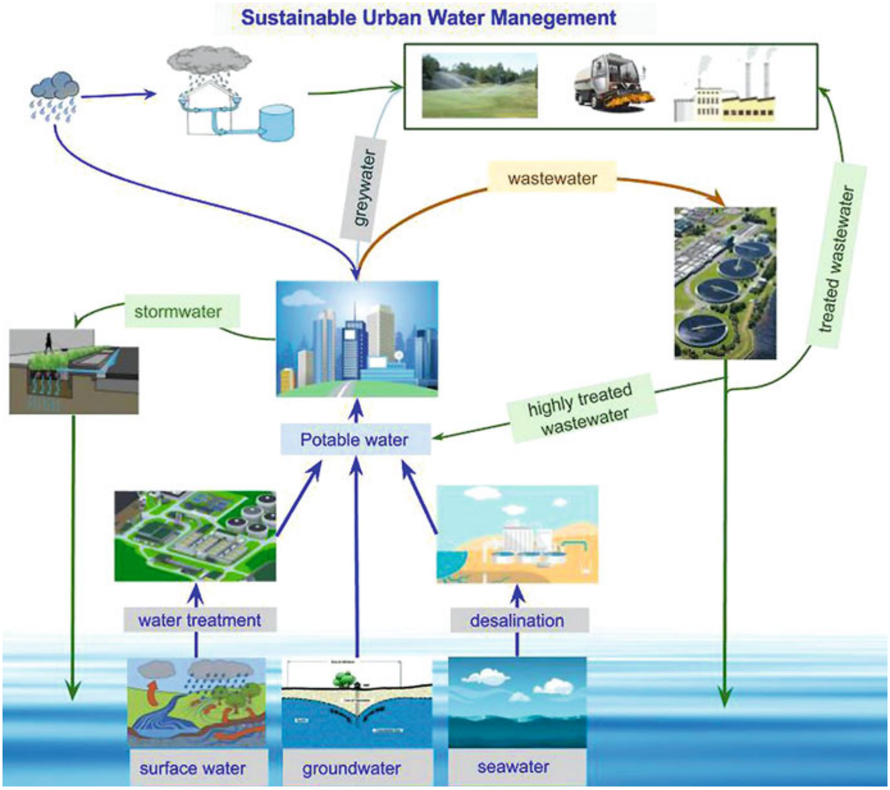


**Fig. 13.7** Proposed water management for sustainable city networks

taste enjoyed by many people. Without these minerals and gases, the water would taste flat. Many unseen dissolved mineral and organic constituents are present in various concentrations, such as sodium, calcium, magnesium, potassium, chloride, bicarbonate, and sulfate. Most are harmless or even beneficial; though occurring infrequently, others are harmful, and a few may be highly toxic. The quality of groundwater, in particularly shallow grounds, is changing as a result of human activities. Bacteria occasionally find their way into groundwater, sometimes in dangerously high concentrations.

The value of an aquifer as a source of groundwater is a function of the porosity of the geologic stratum, or layer, of which it is formed. Water is withdrawn from an aquifer by pumping it out of a well or infiltration gallery. An infiltration gallery typically includes several horizontal perforated pipes radiating outward from the bottom of a large-diameter vertical shaft. Wells are constructed in several ways, depending on the depth and nature of the aquifer (Fig. 13.9). Wells used for public water supplies, usually more than 30 m deep and 10–30 cm in diameter, must penetrate large aquifers that can provide dependable yields of good quality water.

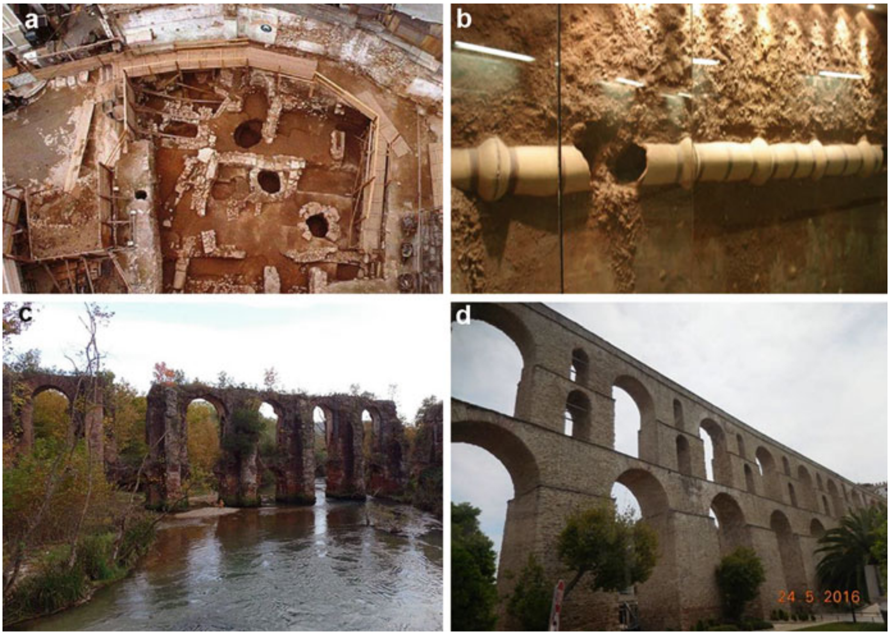


**Fig. 13.8** Hydraulic works from ancient Greece: (**a**) Athens (www.tovima.gr/culture/article/), (**b**) Athens (personal archives), (**c**) Preveza (apeirosgaia.wordpress.com), (**d**) Kavala (personal archives)

They are drilled using impact or rotary techniques and are usually lined with a metal pipe or casing to prevent contamination. The annular space around the outside of the upper portion of the casing is filled with cement grout, and a special sanitary seal is installed at the top to provide further protection. At the bottom of the casing, a slotted screen is attached to strain silt and sand out of the groundwater. A submersible pump driven by an electric motor can be used to raise the water to the surface. Sometimes a deep well may penetrate a confined artesian aquifer, in which case natural hydrostatic pressure can raise the water to the surface.

## Rainwater and Stormwater Management

The volume of water available for municipal supply depends mostly on the amount of rainfall. It also depends on the size of the watershed, the slope of the ground, the type of soil and vegetation, and the type of land use. Figure 13.10 shows global average annual precipitation, in millimeters and inches, where dark blue represents high and light green low precipitation, in areas that can be considered “deserts” [22].

Centuries ago, people in arid and semiarid regions used to collect rainwater for their daily needs or for irrigating their crops during extended dry periods.


Fig. 13.9 Public water fountains and wells in Greece

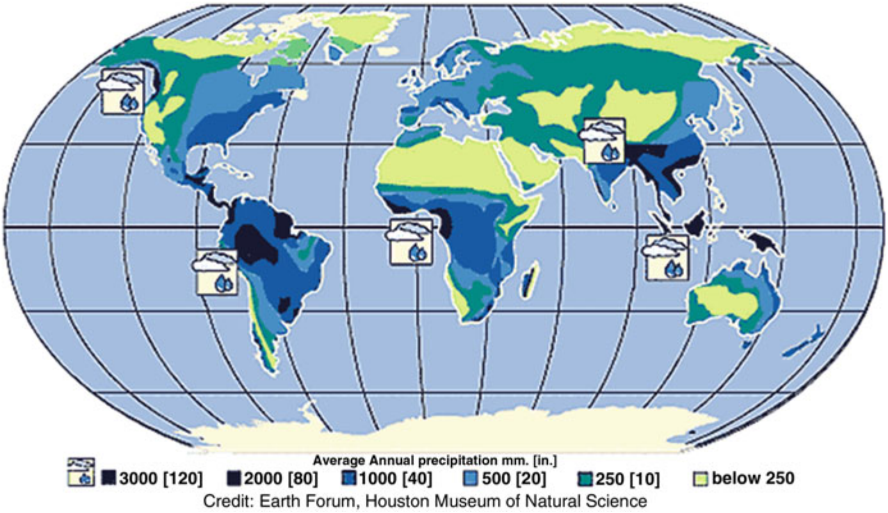


Fig. 13.10 World average annual precipitation, in millimeters and inches [22]

An excellent example is the Persian qanats [23]. Throughout the arid regions of Iran, agricultural and permanent settlements are supported by the ancient qanat system of tapping alluvial aquifers at the heads of valleys and conducting the water along underground tunnels by gravity, often over many kilometers. The traditional communal management system still in place (Fig. 13.11) allows equitable and sustainable water sharing and distribution. The qanats provide exceptional testimony to cultural traditions and civilizations in desert areas with an arid climate. Therefore, rainwater harvesting is not a new technique. It can serve however as an alternative source of water, for urban use, in modern times.

Another exquisite example of rainwater harvesting from the ninth century is Chand Baori, in India [24]. It has 3500 narrow steps arranged in perfect symmetry, which descend 20 m to the bottom of the well (Fig. 13.12a). There are similar

**Fig. 13.11** Persian qanats [23]

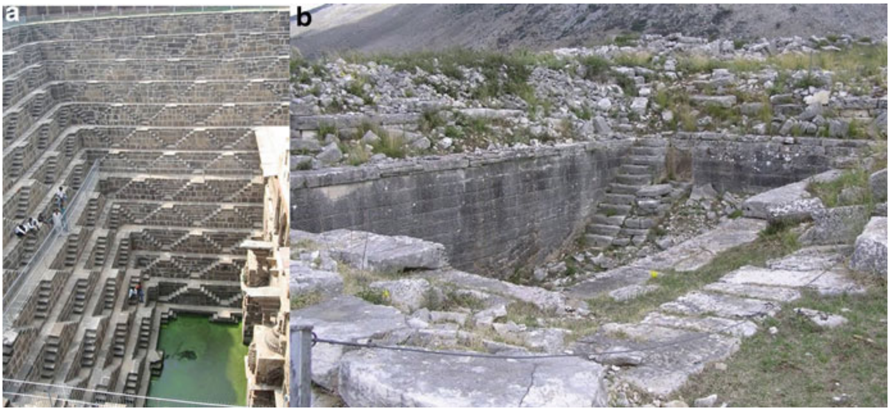


**Fig. 13.12** (**a**) Chand Baori, India. (**b**) Rainwater harvesting tank in ancient city of Orraon, Epirus, Greece (https://ellinondiktyo.blogspot.gr/2016/)

constructions in Greece from the fourth century BC (Fig. 13.12b). Many well-known examples in the Aegean islands exist, where people traditionally harvested rain runoff from building roofs and paved areas and stored it in underground cisterns for domestic use or irrigation (Fig. 13.13).

Although in most cases this practice is not in use anymore, artificial lagoons have been constructed recently for rainwater harvesting in many Greek islands [21], such as the artificial lagoon in Astypalea (Fig. 13.14a), constructed in 1998 with a volume of 875,000 $m^3$, providing water to the island's water supply system and irrigation demands, or the rainwater harvesting tanks in Cyclades islands (Fig. 13.14b). More and more these islands are investing on rainwater harvesting, as it is the most independent and economic way of collecting and providing good quality water to their inhabitants and visitors. Sifnos has always been using this method.

Urban stormwater runoff is generated from rain and snowmelt events that flow over land or impervious surfaces, such as paved streets, parking lots, and building rooftops, and does not infiltrate the ground. Precipitation quality, runoff surfaces, and deposits determine stormwater quality, which in turn depends on special regional characteristics, such us human activity (e.g., industrial activity, residential

**Fig. 13.13** Cisterns and sternes in the Greek islands of Paxoi, Santorini, and Folegandros and from continental Souli (Epirus)

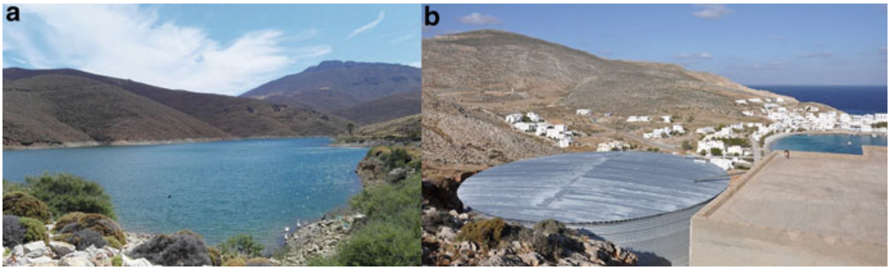


**Fig. 13.14** (**a**) Artificial lagoon in Astypalea, Greece. (Source: www.kathimerini.gr). (**b**) Rainwater harvesting tank in Cyclades Island, Greece (http://gr.coca-colahellenic.com/en/sustainability/csr-programmes/mission-water/)

density, traffic loads), meteorological characteristics (e.g., prevailing winds), and geomorphological characteristics (e.g., materials of geological formation, proximity to the sea) [25, 26]. Furthermore, constructed materials of runoff surface and deposits from birds or other animals, atmospheric deposits and characteristics of harvesting network affect the quality of collected stormwater. Common pollutants in stormwater are heavy metals like zinc (Zn), copper (Cu), and lead (Pb), nitrates and nitrites, phosphates, and suspended solids (SS), originated from construction materials, vehicle, and industrial emissions [26]. Polluted stormwater runoff is commonly transported through municipal separate storm sewer systems and combined sewer overflows, and then often discharged, untreated, into local water bodies.

Based on all the above, stormwater is adequate for non-potable uses, such as toilet flushing, vehicle washing, irrigation of gardens, or industrial use. Research results [25, 27] show that physicochemical parameters (such as temperature, pH, total nitrogen, total phosphorus, heavy metals) are within the limits that are set by international regulations, for potable water, whereas microbiological parameters (such as total coliforms, *E. coli*) are found to be of inferior quality than required for potable use. Conclusively, harvested stormwater is suitable for non-potable use and definitely not appropriate for direct potable use without a treatment.

Nowadays, modern cities face a challenge in the field of stormwater management, as the old outdated urban stormwater drainage networks lack the potential to respond to new emerged conditions. Rapid population growth and diminution of permeable surfaces as a result of urbanization, in combination with climate change, which causes extreme rainfall events and extended dry periods, impose an extreme pressure to current urban stormwater infrastructures. At the same time, urban communities have to deal with depletion and quality degradation of conventional sources of water, and the threat that extreme weather events and continuous urbanization set to city infrastructure and especially to water supply system.

It is obvious that antiquated sewerage installations and water supply systems are required to be modernized to meet future needs and uncertainties. Under these circumstances, opportunities have arisen for effective stormwater management in combination with utilization of alternative water resources, such as stormwater and rainwater reuse. An effective strategy to implement this is the decentralized stormwater collection, treatment, and storage for reusing purposes, in small-scale infrastructures [28]. Example of these practices are detention ponds, rain barrels and cisterns, permeable pavement, and stormwater management, using vegetation like stormwater planters and rain gardens or grassed swales and filter strips. The above techniques usually are referred in bibliography as best management practices (BMPs), which according to US EPA are structural, vegetative, or managerial practices used to mitigate runoff volumes and associated nonpoint source pollution [29]. Some examples of BMPs are shown in the following figures (Figs. 13.15, 13.16, 13.17, 13.18 and 13.19) and analyzed thereafter.

Stormwater planters and rain gardens are vegetated areas that collect and treat runoff from the impermeable surrounding area such as building roofs, streets, pavements, and parking lots. These vegetated structures slow down runoff during storms, prevent flooding, and protect receiving water bodies from pollution. Grassed swales and filter strips are linear rain gardens. Depending on the available space and the indented stormwater management plan, the proper vegetated structure is chosen. Rain gardens using plants and soil are capable of capturing water and pollutants including bacteria, phosphorus, nitrogen, heavy metal, oil, and grease. They should be drained after 48 h in order to manage larger quantities of rainwater; for this reason, a soil with adequate permeability should be chosen. The infiltrated water could replenish groundwater aquifer or be collected with a drain pipe and directed to sewerage pipes or tanks for reusing. Finally, rain gardens always have an overflow pipe connected with the sewerage or storm drain. Those vegetated areas are effective


**Fig. 13.15** Best management practices [28]

**Fig. 13.16** BMPs: Parkside neighborhood of Camden, NJ. (Photo courtesy of Caitrin Higgins, Rutgers University) Source: nemo.uconn.edu/raingardens/

only in sites where the groundwater aquifers are deep, and they must be constructed at safe distances from buildings, sewerage networks, and septic tanks [28, 30].

Permeable pavements and streets allow groundwater recharging, by permitting rainwater to infiltrate the ground and groundwater. They contribute in reducing flooding and ponding on pavements and streets during heavy rain events and the ice formation during cold winter days. Furthermore, as water infiltrates through permeable materials to the soil, pollutants are removed by natural filtration, and

**Fig. 13.17** BMPs: Grid system filled with grass (Source: http://www.plantmoreplants.com/press-photo/category/) & permeable pavements

**Fig. 13.18** BMPs: dry and wet detention ponds https://www.highpointnc.gov/731/Best-Management-Practices-BMP-Devices)

stormwater loads are reduced. Permeable pavements that can be used are soft paving such as grass and mulch, permeable concrete, concrete, or other material grid system filled with soil and grass or gravel. These constructions need regular maintenance to avoid clogging, especially in regions where runoff has high suspended solids concentration [28, 30].

Detention ponds are constructions which collect stormwater for a period of time, before being released into receiving water bodies. Detention of water in a tank results in sedimentation of pollutants and therefore in mitigation of receiving water quality degradation. There are two types of detention ponds, those that stay empty after slowly releasing water to a river, lake, or sea, until the next rain event, and those that are always full of water and during each rain event the new stormwater replaces the pond water.

A common practice in the area of rainwater harvesting and reusing are the buildings' roof harvesting systems. Rainwater flows to horizontal gutters and then to vertical ones in order to be collected to tanks. Rain barrels and cisterns serve that purpose. Rainwater collection tanks can be implemented at home or community

**Fig. 13.19** BMPs: Cistern at the Chicago Center for Green Technology (Source: Abby Hall, U.S. EPA; https://www.werf.org/liveablecommunities/toolbox/rainbarrel.htm)

base. Moreover in an integrated urban water management plan, a "pipeline grid" connecting regional reservoirs can be installed [31]. Determination of required tank size is achieved based on various local characteristics, for instance, rainfall height, available collection area, runoff coefficient of collection area, dry period length, and water demand. Optimal design of tank size is required, as large tanks may trigger construction difficulties and high cost; also long retention time of stormwater in a tank may cause quality degradation. On the contrary, a small tank may not be adequate during a long dry period. In [32] daily water balance method was used to dimensioning stormwater harvesting tanks. The appropriate volume of a tank to satisfy a predetermined percentage of daily residential water demand of up to 240 L/day is found to be 50 $m^3$ and a roof collection area up to 300 $m^2$. In the construction of such a system, a device for restraining large objects is required, in order to protect the system from clogging and to maintain better water quality in the tanks. Pumps send the stored water, through separate distribution network for designated uses. Usually, the system in favor of better quality of harvested stormwater is equipped with first-flush diversion procedure, to remove the first-flush, which is the first and most polluted part of the runoff, also a valve to empty the collected first-flush after each rain is needed [25].

Conclusively, rainwater and stormwater harvesting systems benefit the environment, the end users, and the community as a whole. If collected stormwater undergoes treatment, it can also contribute to the water supply system of unprivileged urban areas. Many applications of these systems can be found in international bibliography. In Beijing, China a covered rainwater storage pond has been constructed, which provides suburban farmers with good quality irrigation water for their greenhouses, resulting in improvement of crops' productivity and in lowering the cost of water supply and consequently decrease of their expenses. Also in Belo Horizonte, Brazil pilot projects were developed for harvesting rainwater for irrigation and cleaning of a school surrounding area, which also provide educational opportunities for students on water issues and for urban agriculture [33]. Singapore has managed to reduce the quantity of imported water from Malaysia, among other actions, through a comprehensive network of drains, canals, and rivers that collect rainwater and stormwater, taking advantage of its humid climatic conditions [34].

New technology trends are moving toward the collection of humidity in the air, in order to produce water in remote areas. Turbines working 24 h/7 days can create even potable water, by condensing pure water from the air, without using any power or chemicals. It can produce 27 L/d with or without air [35]. Less technological advanced methods are also used in poor countries, such as Peru, where nearly one million people in its capital lack access to good quality water; BBC World Service introduced Abel, the "fog catcher," who captures humidity, in the form of fog droplets, in nets. Water may not be drinkable, but can be used to irrigate their crops or boil water and cook soups.

## Seawater and Brackish Water Management

Although Earth is a planet where the water is the dominant element, the biggest part of it is saline: approximately 97% of global water is contained in the oceans, and a small portion of groundwater and surface water is also saline or brackish. As Fig. 13.20 shows, rising sea level, due to climate change, increases groundwater's salinity. Furthermore, part of groundwater runs in depths that are not technically feasible or economically efficient to be pumped. The remaining available water has to cover all the human needs, with or without treatment. But since the quality of conventional sources of water is degraded and their quantity is depleted, and since the cost for water treatment is substantial, desalination becomes an emerging option. In addition to all that, climate change and urbanization enhance urban water demand, leading to urban water deficiency and making desalination an even more attractive option [36].

Since saline water is not appropriate for direct use for human population needs, its purification was imperative. Desalination is the eminent procedure, which produces fresh water from saline water (seawater, brackish or wastewater) by removing dissolved salts from water. Water salinity based on dissolved salts, for saline water is in the order of 3–5% (30–50 g/L), whereas for fresh water less than 0.05%. Brackish water has more salinity than fresh water, but not as much as seawater. It may result from mixing of seawater with fresh water, as in estuaries, or it may occur in brackish fossil aquifers. Brackish water contains 0.5–30 grams of

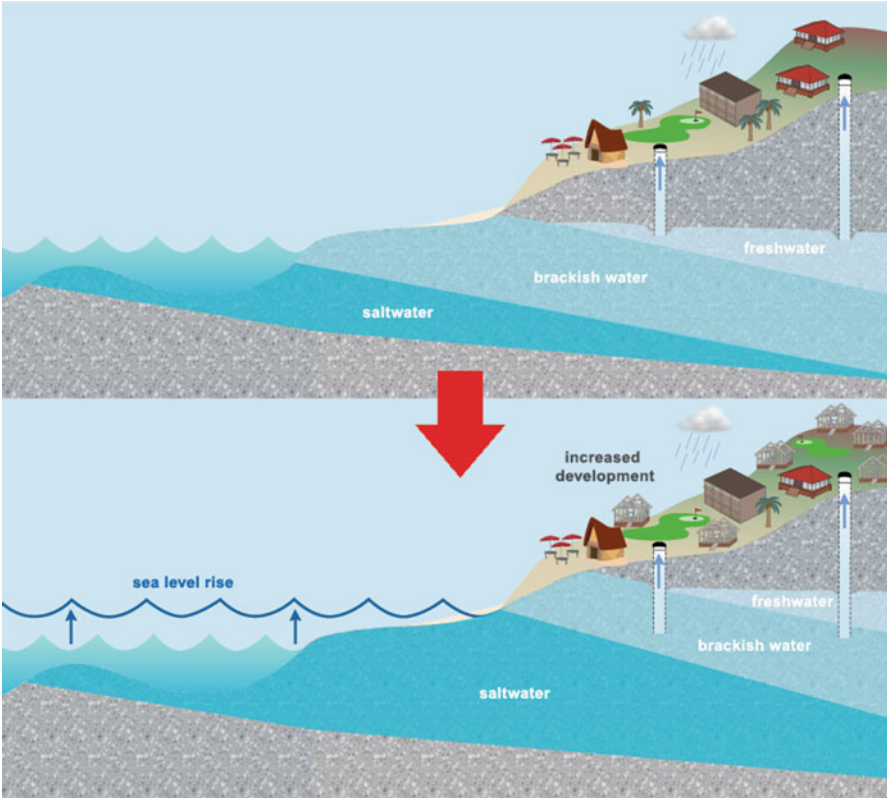


**Fig. 13.20** Saline and brackish water layers (source: http://www.teachoceanscience.net/)

salt per liter (more often expressed as 0.5–30 parts per thousand (‰) or 0.05–3%), which is a specific gravity of between 1.005–1.010.

The design of a desalination plant is based on several parameters: the purpose and usage of the product water (potable or non potable use), and the available intake water and product water quality characteristics. Moreover, the available technology and financial resources in conjunction with the location of the plant contribute to the planning. Desalination units are usually placed at coasts, which are selected for water pumping, rather than leisure and tourism, therefore the surrounding land is devalued (Fig. 13.21). These parameters define the efficiency, the energy consumption, and the total cost for installation, operation, and maintenance of a desalination infrastructure. Other parameters that affect the performance are the salinity and temperature of feedwater, the required freshwater recovery percentage, and the desired quality of product water, whereas the cost and energy consumption depend on the distance between the plant and the end users as well as the engaged technology [37].

**Fig. 13.21** Desalination unit in Israel (http://knowledge.wharton.upenn.edu/article/what-other-nations-can-learn-from-israels-solutions-to-the-scarce-water-challenge)

The quality of product water as well as the process result is related to the quality of input seawater or brackish water. It is worth mentioning that seawater is the receiver of domestic and industrial sewage, ship wastewater or runoff water [38]. Therefore, input water contains high percentage of total dissolved solids (chloride, sodium, sulfate, magnesium, and other ions). Furthermore, feedwater regularly also contains various microbial contaminants like pathogen bacteria, viruses, parasites, organic carbon, and chemicals such as boron, iodide, sodium, and potassium. Although saline water does not provide a friendly environment to pathogens, there are some kinds which can survive therein, like *Vibrio cholerae*. Also, some marine algae species produce toxins, potentially hazardous for humans [39].

The two major categories of desalination available technologies are membrane-based procedures and thermal-based procedures. A broadly used membrane-based desalination process is reverse osmosis (RO). With RO a large amount of total dissolved solids are removed from water by a pressurized flow of saline water through a RO membrane [40]. Some of the novel membrane technologies are thin-film nanotechnology (TFN) membranes and graphene-based membranes. Nanocomposite membranes boost water permeability while maintaining the same efficiency in salt removal and product water quality, as RO membrane. Frequent are the cases where RO membrane is coupled with another membrane technology for ameliorating installation efficiency in terms of energy consumption, recovery percentage, and quality of desalinated water. The most renowned thermal-based procedures are multistage flash (MSF), multi-effect distillation (MED), and vapor compression distillation (VCD). All these methods use evaporation and phase change in order to remove salt from water and usually need enough energy to achieve this [37].

Monitoring and pretreatment of feedwater is recommended in many cases for both protecting membranes and obtaining superior quality of product water.

Common pretreatment procedures are sedimentation, filtration (e.g., microfiltration and nanofiltration) for removing suspended solids, and some kind of disinfection, usually chlorination of saline water, for removing microbial contaminants before entering the desalination processes [39]. Chemicals that are used during pretreatment and desalination procedures, as well as for membrane cleaning, may probably be present at product water. Moreover, materials of plant structures and transportation pipes can release harmful chemicals in water which pass through or stay in touch with those materials [39]. Hence, selection of the right materials, the wise use of chemicals, the discharge of wastewater, and the flushing and discharge of wastewater after membrane cleaning is of great importance. An appropriate treatment, if needed, before the product water reaches the end user, can be applied along with the utilization of appropriate protection measures in order the product water to be of the desired quality for potable or other uses.

Posttreatment may engage blending desalinated water with partially treated seawater or untreated groundwater, adding minerals (e.g., treatment with limestone) or disinfection procedures (chlorinate, ultraviolet light, etc.) and/or adding more membranes to reduce risk of microbial infection of product water. Furthermore, during storage and distribution of product water before reaching the end user, there is high risk of growing pathogens like *Legionella*, especially when hydraulic conditions, temperature, and used materials are favorable, and when a significant amount of biodegradable organic matter and nutrients exists. To avoid these phenomena, materials that prevent biofilm development should be chosen, and a necessary quantity of residual disinfectant should be sustained in the output water [39]. Saline and desalinated water have heavy corrosion influence on metal and concrete infrastructure material. As a result treatment processes for balancing pH of water and addition of chemicals for protection construction materials are also necessary [38]. Parameters that affect the aesthetic quality of desalinated water are turbidity, taste, odor, and total dissolved solids. These parameters normally don't pose the consumers' health at risk, but they can cause nuisance and negativity against desalination [38]. Thus, taking measures, like posttreatment, is crucial to gain social acceptance for desalination.

The flowchart (Fig. 13.22) describes clearly the simple desalination procedure with RO, including pretreatment and posttreatment, as well as the connection to Sydney's water supply system. Desalination is becoming more and more a popular alternative solution for producing water for several domestic, agricultural, and industrial uses, even for potable use. More than 300 million people, in more than 150 countries depend on desalinated water to satisfy a portion of their daily needs or, in some extremely arid areas, their total everyday needs. There are 18,426 desalination installations around the globe, and they produce about 86.8 million cubic meters freshwater per day, according to International Desalination Association data for 2015. Leader countries in desalination are Spain, Australia, the United Arab Emirates, and the USA (Fig. 13.23). According to MIT's Journal Technology Review [41], Spain built Europe's first desalination plant nearly 50 years ago and is the largest user of desalination technology in the Western world. Spanish companies lead the market, operating in regions including India, the Middle East,

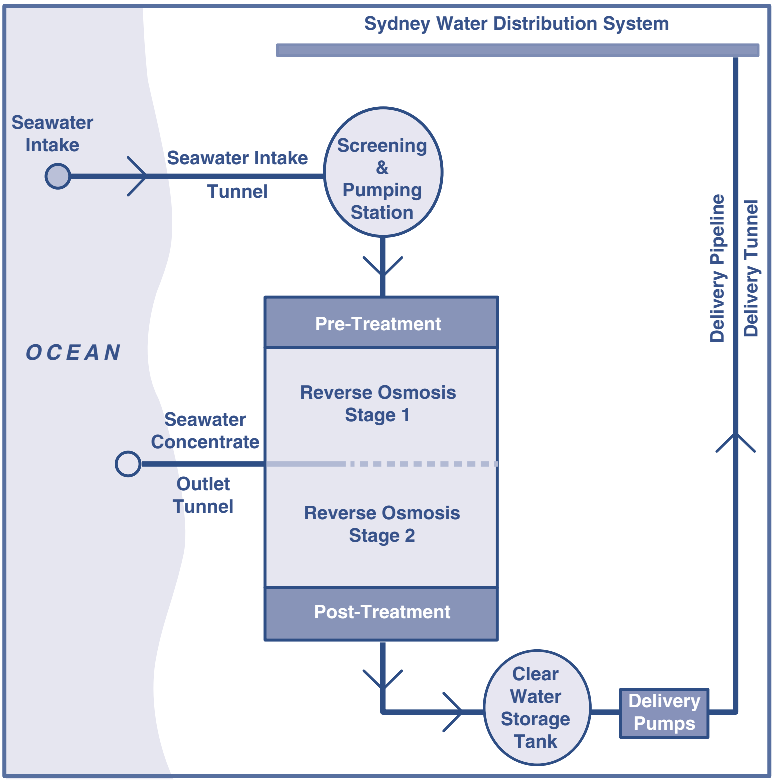


**Fig. 13.22** The process of desalination through reverse osmosis at Sydney Water (http://www.awa.asn.au/AWA_MBRR/Publications/Fact_Sheets/Desalination_Fact_Sheet.aspx)

and North America. Spanish innovation contributes to advancing desalination to bring sustainable clean water to millions. On the other end, in Perth, Australia, 47% of total regional water supply comes from desalination, 46% from groundwater, and only 7% from surface water, mainly dams. One of Australia's seawater desalination plants is providing critically needed drinking water supplies for cities during floods (Fig. 13.23b) [42].

Traditionally, desalination is an expensive procedure mainly due to the engaged technology, the operational cost, and the energy consumption [37]. The major energy consumption results from achieving the appropriate pressure and for the needed pretreatment and posttreatment of the water. However, in the last years energy demand is reduced due to lower pressure requirements [40]. In the direction of reducing energy consumption, recent desalination technologies are directed toward the combination of thermal-based procedures with membrane technologies, such as membrane distillation. When brackish water is used, which is characterized by lower salinity, less energy is needed. Also, the larger the installation, the lower the cost per cubic meter of produced freshwater is [27]. Finally, when the facilities

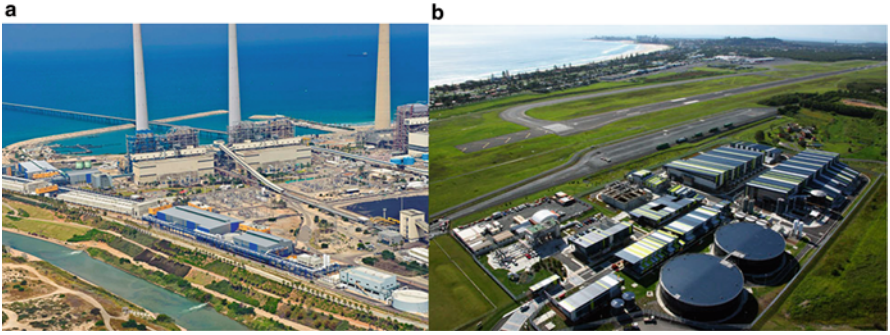

**Fig. 13.23** World's largest desalination units in (**a**) Ras Al-Khair, Saudi Arabia (https://www.betterworldsolutions.eu/the-largest-desalination-plants-in-the-world/) and (**b**) Gold Coast, Tugun, Queensland, Australia (water-technology.net)

**Fig. 13.24** Hydriada, a floating desalination unit in Irakleia, Cyclades, Greece, powered by wind and solar energy

incorporate renewable or alternative sources of energy, such as solar and geothermal energy or waste heat, the cost and environmental impacts are reduced [40]. Such an example is "Hydriada," a small renewable energy operated desalination unit in Cyclades islands of Greece, which was introduced in 2007 to relieve a small island from water inadequacy (Fig. 13.24).

Even though desalination is a broadly accepted alternative for urban water supply, it has some negative environmental impacts. Desalination facilities contribute to the increase of greenhouse gas emissions, due to high energy consumption, and saline density, due to the rejection of residual salt back to the sea, but also to high level noise pollution, due to the continuously working pumps. To reduce noise volume desalination plants should be equipped with the appropriate technology and be placed at a location where the surrounding environment impact is as less as possible, such as airports [36]. On the other hand, discharges of desalination plants are very saline (approximately 50% more salt for the same water volume) in higher than normal temperatures, contain chemicals and metals, which, when discharged into the sea without any treatment, can have negative effect on the marine environment. They cause contamination in seawater, and thus the new intake water for desalination processes is polluted with entailed consequences, such as increased need for energy and chemicals additives. Also marine fauna and flora are affected because of contaminants, rising of normal seawater temperature, changes in oxygen level, and turbidity. The aforementioned changes in the marine environment can cause algae blooms or marine organism deaths. Moreover, degradation of marine environment may disturb recreation activities and cause loss of aesthetic value of urban seafront areas, because of odors and turbidity, even pose health risks to humans after contact with polluted seawater. Another concern is the possibility of leakages of pipes or storage tanks of desalination by-products or saline water, which can severely pollute soil, groundwater, and even freshwater distribution networks if they exist in proximity, with toxic constituents and solids, or induce aquifers salinization. According to an effect analysis of the operation of the desalination units in Cyprus [36], the energy use, the $CO_2$ emission, and the economic cost score the highest, in a scale 1–5, whereas the land use, the brine and marine environment, the aquifers, and the noise play a less significant role.

In the recent years, important advancements in desalination technology are made in the energy demand, such as the use of wind and solar energy, where available, solar thermal energy for the desalination process, and at the same time generation of electricity (STEP-EW), which is applied in Cyprus, multiple effect distillation method (MED), which requires low electrical energy, self-covered through heat source (sun), and operates without any use of chemicals. With respect to the diminution of the saline production, the latter is not environmentally sound, but reprocess of the saline water by vaporization, crystallization, and drying, which is applied in Tinos island by the National Technical University of Athens, results to an average percentage of 65% pure water and 35% pure salt [36].

In conclusion, new technological applications of desalination that reduce energy consumption in combination with implementation of environmental risk assessment and appropriate mitigation measures, make desalination a technically feasible, environmentally and economically efficient alternative source of water, in the light of upcoming water scarcity, especially in vulnerable urban areas.

## Wastewater and Greywater Management

Urban wastewater in developed countries, where sanitation systems exist, is directed in wastewater treatment plants (WWTPs) and then after being treated, it is released in the environment. From an innovative point of view, this water can comprise a precious source of water for several uses and contribute with satisfaction to intensified human needs, due to population growth, urbanization, and climate change, without overexploiting water resources. More importantly, wastewater is a reliable alternative water resource, since it is not seasonal, like stormwater and rainwater.

Treated wastewater can be reused for residential, agricultural, industrial, even potable uses, and for environmental purposes such as wetlands' restoration and groundwater recharging. Domestic consumers may use recycled water for toilet flushing, indoor and outdoor washing, garden irrigation, and in extreme cases for human consumption. In commercial and industrial domain, reclaimed water is used for cooling tower, boiler feeding, and washing. Public urban uses of treated wastewater are fire protection, irrigation of parks, fields and school yards, roads, and parking lot washing.

Leading countries in the domain of wastewater reuse are Singapore where 30% of treated wastewater is reclaimed, followed by Saudi Arabia where 16% is reclaimed, Australia where 8% is reused, and the USA where 7–8% of treated wastewater is reused [43].

Urban wastewater can be of diverse origins, with different composition and as a result requiring different treatment in order to be disposed or be recycled and reused for various uses. Those types are feces, urine, or yellow water, flush water, blackwater, greywater, and stormwater. As blackwater is considered the sum of feces, urine, and flush water and as greywater the water produced from kitchens, dishwashers, sinks, bathtubs, showers, laundry tubes, and washing machines [33]. Greywater constitutes 50–80% of the total wastewater of a household [44].

Reclaimed wastewater can be used for indirect potable reuse (IPR) and direct potable reuse (DPR). In case of using treated wastewater for surface or groundwater enrichment, planned IPR is implemented. For example, in Orange County, California, USA, reclaimed water is returned to the aquifer which supplies drinkable water, and in Singapore, where reclaimed water is blended in the city's reservoir. On the other hand, DPR refers to the introduction of purified water, derived from municipal wastewater, after extensive treatment and monitoring to assure that strict water quality requirements are met at all times, directly into a municipal water supply system. Such an application comes from Big Spring, Texas, USA, where reclaimed water is provided in a raw surface water conveyance for potable reuse [43].

In developing countries, untreated wastewater is regularly used, posing at serious risk human health. Raw wastewater use is intentionally and unofficially practiced, from low-income farmers for agricultural irrigation. For these farmers, wastewater is the only source to water their crops and earn their living. In Middle East and North Africa, wastewater, which may sometimes be untreated, is used for agricultural purposes [43].

In developed countries wastewater treatment is a common practice and, in most cases, enforced by law. However, as Fig. 13.25 clearly shows, not all European countries have established a connection of households with biological treatment plants, according to the newest (2013) recorded data [45]. Wastewater treatment is performed in wastewater treatment plants (WWTPs) and is the procedure

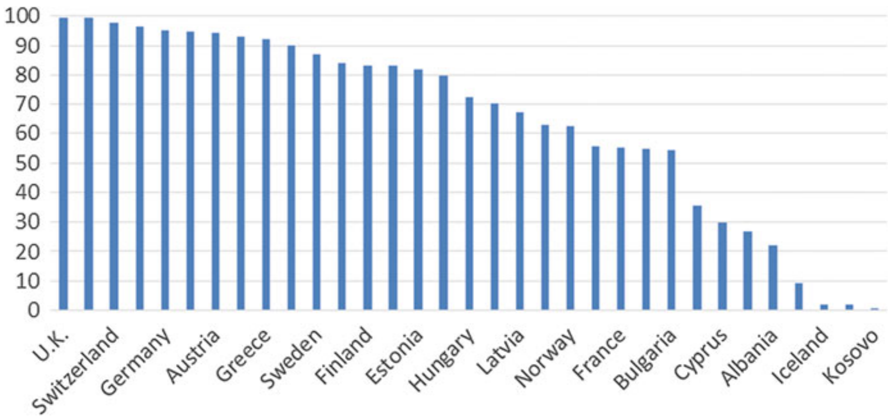


**Fig. 13.25** Share of the population connected to secondary urban wastewater treatment in 2013

that mainly removes suspended solids, organic matter, and nutrients. For reusing wastewater, additional treatment is required to remove pathogens and chemical contaminants, which is performed in water reclamation plants (WRPs) and therefore is called reclamation treatment. There is a large number of available reclamation technologies, which can be categorized as intensive or conventional, and extensive or non-conventional technologies [44, 46]. Intensive technologies are physical-chemical systems (coagulation—flocculation, sand filters), membrane technologies (ultrafiltration, reverse osmosis), rotating biological contactors, and disinfection technologies (ultraviolet radiation, chlorine dioxide, ozone). These technologies engage artificial processes and require large amounts of energy. On the other hand, extensive technologies rely on natural processes and therefore require less energy, and low but considerable operation and maintenance, and more space than the conventional methods. Extensive technologies utilize waste stabilization ponds (maturation ponds, stabilization reservoir), constructed wetlands, and infiltration-percolation systems. Usually, a combination of reclamation technologies is used in order to attain the desired water quality. The criteria, based on which the reclamation technology is selected, are wastewater's quantity and quality, the water quality standards for its final use, as well as economical and environmental aspects of the project [44].

In the direction of protecting human health, environment, soil, and plants, many countries such as Australia, Canada, China, Japan; many US states such as California and Texas; European countries like Spain, Cyprus, and France; and organizations like World Health Organization (WHO) and US Environmental Protection Agency (USEPA) have adopted guidelines for the reused water quality standards. These guidelines refer to reused water designated uses, required treatment directed to specific end-uses, water quality limits for certain parameters, and guidelines for which parameters need to be monitored and in what frequency, measures for the onsite construction and maintenance in order to avoid cross connection with other water supply systems and unwanted human contact, environmental monitoring of the effect of reclamation project and communications strategies to achieve stakeholders, and public acceptance [44]. Parameters that are commonly used for reclaimed water quality evaluation are pH, $BOD_5$, total suspended solids (TSS), turbidity, *E. coli*, thermotolerant coliforms, and chlorine residual [47]. Thresholds for these parameters are strict, and a higher level of treatment is required when reuse involves unrestricted public exposure, with higher probability of human contact or inhalation of aerosols, such as toilet flushing, laundry, and garden irrigation. On the contrary, restricted reuse of reclaimed water means that public exposure to the reclaimed water is controlled and lower treatment may be sufficient [43]. Furthermore, guidelines comprise directions for the installation, planning, and maintenance of the wastewater recycling systems, such as keeping safe distances from other pipes, using different colors, and marking for reclaimed water apparatus like pipes, valve boxes, pumps, and outlets to distinguish potable pipes network from wastewater pipes network [47]. The American Public Work Association (APWA) in 2003 proposed purple color for reclaimed water pipes [43].

As mentioned above, greywater, which comes from kitchens, dishwashers, sinks, bathtubs, showers, laundry tubes, and washing machines [33] has lower nutrient and pathogenic loads than wastewater and as a result needs less if any treatment for being reused. Simple treatment like sand/gravel filters or constructed wetlands are sufficient for achieving high water quality. Greywater from kitchen sinks, dishwashers, and washing machines are usually more contaminated than those from showers and bathtubs, because they usually contain solids and organic substances. Therefore, regularly, the reuse of less polluted part of greywater is chosen, excluding kitchen greywater which contain fats, grease, oil, food particles and has higher amount of organic pollutants and laundry greywater that may contain fecal substances [48].

However, greywater is characterized by variability in quality and no constant flow [47], depending on living standards, the chemicals used for cleaning and personal care, pharmaceuticals products, water supply system, and water availability. Greywater volumes range between 60 and 120 L/person/day although it can be reduced to 20–30 L/person/day for low-income countries with basic water supply system and low water availability. However, it is considered adequate to cover water demand for non-potable usages [48].

Greywater collection and treatment can be implemented in decentralized systems, located in individual or multistory dwellings (Fig. 13.26) or in a centralized system collecting and treating greywater from an entire region. Centralized systems involve lower investment and maintenance cost for the households, but require the installation of larger storage infrastructure and distribution network. A case study was studied and presented for the Port Authority of Thessaloniki, Greece, which proposed the collection and treatment of greywater from 14 multistory buildings in the vicinity of the Port, to eliminate the cost of cleaning demands of the ships and the port facilities, but would not cover the potable water needs (Fig. 13.27) [49].

The cost and the characteristics of the system that is adopted for greywater reuses depend on several parameters such as the end-uses, existing pipes, available space, and pumping requirements. For instance, for subsurface restricted irrigation, greywater can be diverted and used after coarse filtration, without additional

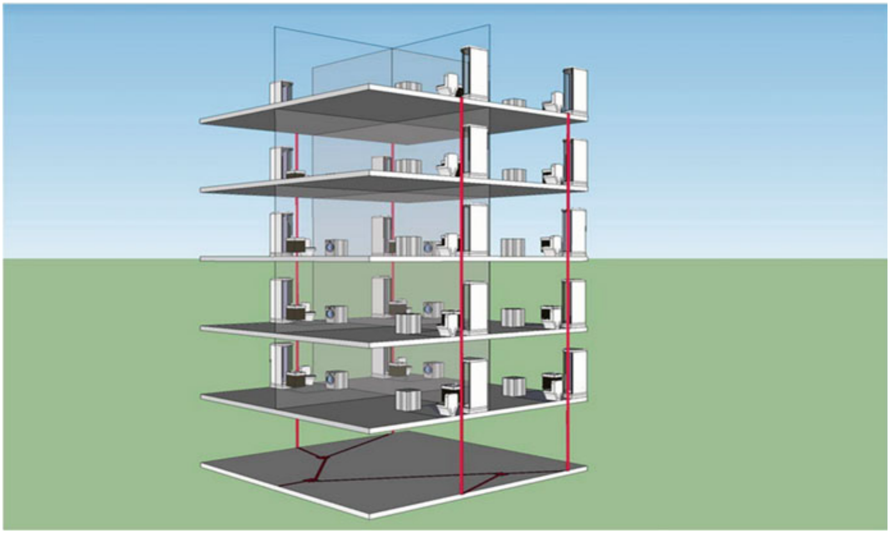

Fig. 13.26 Greywater collection in decentralized system, in multistory dwellings [49]


Fig. 13.27 Proposed greywater collection and treatment for the Port of Thessaloniki [49]

treatment, with only a few hours storage requirement, resulting in lower cost and simpler infrastructures. On the other hand, for garden irrigation and indoor uses, like toilet flushing and laundry, collection and storage is required as well as advanced treatment such as fine filtration, biological treatment, and disinfection, and thereby the cost is risen and more complex infrastructure is needed. Furthermore, the cost is higher as, in most cases, a diversion network is required and when a pumping system is needed if gravity pipes are not applicable due to the location of the irrigated area. Greywater from washing machines or showers can be collected into a barrel and used for plant irrigation with a simple hose or with a more sophisticated irrigation system.

One case study in the field of wastewater reclamation is in Arizona, USA, at the city of Sierra Vista, the Environmental Operations Park, where the reclaimed wastewater is treated in constructed wetlands and recharged into the local aquifer, which was overpumped in the previous years. In San Diego, California, USA, a wastewater reclamation program has been implemented since mid-1980, which nowadays includes advanced treatment facilities and produces water that is sent to San Vicente Reservoir and then is treated and distributed as potable water. In Australia, wastewater of a 29-story office tower is captured and recycled for reusing, in order to cover non-potable demand for cooling tower makeup and toilet flushing. Furthermore, since building's wastewater is insufficient, supplemented water from city sewer is used. This practice achieves the reduction of building's freshwater demands by 90%. Singapore utilizes NEWater project that produces high quality of reclaimed wastewater, which is used in industry, for air-conditioning and cooling in commercial and institutional complexes. Furthermore treated wastewater in Singapore is used for indirect potable reuse (IPR) by blending NEWater with raw reservoir water, following the conventional treatment that is required for raw reservoir water to produce potable water for the city. Finally, at Costa Brava, Spain, in Tossa de Mar, a small town that receives large number of tourists in the summer, reclaimed wastewater is used for non-potable uses, such as street cleaning and public irrigation [43].

However, wastewater reclamation may have certain drawbacks, such as altering land uses by changing ecosystem characteristics and water balance of an area, or by allowing development of residential, commercial, industrial, or recreational uses where it was not possible before due to water scarcity. It is also possible that it can shift the prevalent hydrologic regime of an area, by modifying wet and dry weather stream flows. Finally, surface and groundwater quality may be affected by discharging reclaimed wastewater to them [43].

Water is a finite and irreplaceable resource that is fundamental to human well-being. The water footprint is a measure of humanity's appropriation of freshwater in volumes of water consumed. Building a sustainable urban water system, in view of climate change and water pollution and scarcity, is a challenge. It depends upon the available water resources, i.e., precipitation (rainwater and snowmelt), humidity, enriched groundwater aquifers, and sensitive surface water (rivers and lakes). When these resources are not available or abundant, alternatives must be found and followed, such as water reclamation by means of treated greywater or wastewater, or desalination in coastal areas. Water is renewable if only well managed. It can pose a serious challenge to sustainable development, but, managed efficiently and equitably, can play a key enabling role in strengthening the resilience of social, economic, and environmental systems in the light of rapid and unpredictable changes. Water is a critical asset for socioeconomic development and the viability of ecosystems. Governments and leading businesses need to take first local action to improve their water use and have implicitly a global impact. Our goal is to ensure that freshwater is shared fairly to sustain thriving communities and nature's diversity.

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