Chapter 2

Wastewater production, treatment and reuse in MENA:
Untapped opportunities?

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Key messages

- Water reuse has great potential to help overcome some of the challenges posed by the increasing pressure on already stressed water resources.
- Wastewater is the only source of water that increases as population and water use grow. Currently, the MENA region[1] produces around 21.5 billion cubic meters (BCM) of nutrient-rich municipal wastewater per year.
- Many MENA countries are substantially improving their wastewater treatment rate, however, about 40% of produced domestic wastewater and a substantial portion of industrial wastewater in the region are still left untreated. This poses serious risks to human health and ecosystems and reduces the amount of fresh water that is safe to use.
- The region has doubled the number of projects for direct water reuse every decade since 1990, and indirect water reuse is frequent. Nevertheless, up to 54% of the municipal wastewater that is produced is still not put to good use. It is either being discharged into the sea or evaporated (on land or along rivers).
- This wasted wastewater, if recovered, can increase the energy, nutrients and water availability and enhance the region's ability to adapt to changes in climate and enhance food security. The lost wastewater, if fully recovered, could additionally irrigate and fertilize more than 1.4 million hectares (ha). The carbon embedded in the generated wastewater, if recovered in the form of methane, would have a caloric value to provide electricity to 8 million households.
- The region needs to overcome the factors that limit the materialization of the regional full water reuse potential, including: cultural barriers and distrust; institutional fragmentation; inadequate regulatory frameworks; and the lack of appropriate tariffs, economic incentives and financial models, which undermines cost recovery and the sustainability of reuse projects.
- The region also needs standardized data collection and reporting efforts across the formal and informal reuse sectors to provide more reliable and updated information, which is essential to develop proper diagnosis and effective policies for the safe and productive use of these resources.

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[1] This book has compiled data from 19 Arab countries of the MENA region (namely, Algeria, Bahrain, Egypt, Iraq, Jordan, Kuwait, Lebanon, Libya, Mauritania, Morocco, Oman, Palestine, Qatar, Saudi Arabia, Sudan, Syria, Tunisia, the United Arab Emirates and Yemen). Throughout this book the terms 'MENA region' and/or 'the Region' refer only to those 19 countries."

2.1. Introduction

The Middle East and North Africa (MENA) is the most water-stressed region in the world. Freshwater withdrawals exceed renewable water resources in almost all countries in the region. The gap between the supply and demand is widening every year. Currently, the average per capita renewable water resources availability (551 m^3/year) is 10 times less than the worldwide average (FAO 2020).

Since 2000, the region has witnessed a series of conflicts and droughts. This has led to a considerable displacement of people and has potential for long-term impacts on the already stressed land and water resources (Taheripour et al. 2020). Pathogens heavily affect many rivers in the region (UNEP 2016). The occurrence of emerging pollutants in water is also a growing concern (Haddaoui and Mateo-Sagasta 2021; Ouda et al. 2021). Pollution reduces even further the amount of water that is safe to use. Water scarcity and pollution are impacting various sectors of the economy (Fragaszy et al. 2022a; Fragaszy et al. 2022b).

These pressures on the water resources and infrastructure may become structural and be aggravated by population growth, changes in our consumption patterns and climate change. Population and urbanization have grown and will continue to grow. The de facto population of the region has increased from 272.2 million inhabitants in 2000 to 418.3 million estimated for 2020 (UN 2019). Urban agglomerations like 'Greater Cairo,' Riyadh and Dubai now host 25.5, 8.6 and 4.5 million people, respectively, and are forecast to grow at an annual rate of 1.5–2% by 2030 (CAPMAS 2022; GASTAT 2019; GD 2021). Changes in calorie intake and diets have also increased the demand for a greater diversity of foods, including meat and dairy products, which have large water footprints. This has increased water demand for irrigation and food production (Mateo-Sagasta et al. 2018). Forecasts suggest that these drivers will continue to widen the water supply and demand gap in the next decades.

On top of all this, precipitation in the region is forecast to decrease, with more frequent and intense droughts, while evapotranspiration will increase (Zittis 2018; Babaousmail et al. 2022). Water scarcity is forecast to reduce GDP by 6–14% yearly by 2050 (World Bank 2018). Furthermore, increased water scarcity could reduce labor demand by up to 12% and lead to significant land-use changes, including loss of beneficial hydrological services (Taheripour et al. 2020).

Agriculture is the largest user of water in MENA and is particularly susceptible to water availability, accessibility and quality. The sector is expected to produce more food to ensure food security. This will require substantial and additional amounts of water.

Taheripour et al. (2020) conclude that "unless new and transformative policies for sustainable, efficient and cooperative water management are promoted, water scarcity will negatively impact the region's economic prospects and undermine its human and natural capital." Governments in MENA are responding to this water crisis by urgently seeking interventions to increase water security by optimizing water management, narrowing the supply-demand gap and preventing water quality degradation. Such interventions typically include increases in water use efficiency and productivity, reductions in unproductive water loses in water networks and increases of the water budget by using non-conventional sources of water, such as municipal effluents.

Municipal effluents are mostly (99%) made of water. The 1% that remains is made of different compounds including valuable resources such as nitrogen and phosphorus. These resources can be recovered and used as fertilizers for agriculture, organic carbon that can be used as an ameliorator of soils or energy in the form of methane. Nevertheless, these effluents also have pathogens and chemicals that can pose risks to human health and the environment. If these hazards are removed or controlled, the resources embedded in wastewater can be recovered and used with benefits for all.

Rather than losing wastewater that has been discharged to the sea or evaporated on land or along rivers, we can recover it and bring new water back to the water budget. Additionally, agriculture can benefit from a constant flow of water all year round, thus making agricultural systems more resilient to droughts. Nutrients such as phosphorus and nitrogen can be reused as fertilizers with increased yields.

Cities can increase their food security if water reuse favors the development of productive green belts around urban areas. Cities can also use agriculture as a tertiary treatment where crop uptake nutrients that otherwise could pollute receiving waters. The environment will also benefit from reduced pollution and the conservation of fresh water for environmental purposes.

Water reuse has great potential to help overcome some of the challenges posed by the increasing pressure on already stressed water resources (WWAP 2017). MENA cities and towns produce millions of cubic meters of wastewater every year. The fate of this wastewater is very different depending on the local context: wastewater can be collected or not, treated or not and finally used directly or indirectly or evaporate or be disposed in the sea with no beneficial use (Box 2.1; Box 2.2; Figure 2.1).

BOX 2.1 A note on definitions (adapted from Mateo-Sagasta 2015)

Wastewater can be defined as “used water discharged from homes, businesses, industry, cities and agriculture” (Asano et al. 2007). According to this definition, there are as many types of wastewater as water uses (e.g., urban wastewater, industrial wastewater or agricultural wastewater). When wastewater is collected in a municipal piped system it is called ‘sewage.’

The term ‘wastewater’ as used in this book is basically synonymous with **municipal wastewater**, which is usually a combination of one or more of the following: **domestic wastewater** consisting of blackwater (from toilets) and greywater (from kitchens and bathing); water from commercial establishments and institutions, including hospitals; industrial effluent within the city or town, where present; and stormwater and other urban runoff. Municipal wastewater does not include industrial wastewater (including wastewater from the mining, manufacturing or energy sectors) or agricultural wastewater generated and collected outside human settlements.

Wastewater can be collected or not, treated or not, and finally used directly or discharged to a water body and be either reused indirectly downstream or lost when it is discharged to the sea or evaporates with no beneficial use.

Wastewater collection

Wastewater can be collected and treated on-site (e.g., in septic tanks) or off-site (e.g., in piped sewerage systems connected to a treatment plant). The design and size of a septic system can vary widely; typically, within the tank there is sedimentation and primary treatment of wastewater and the partially treated effluent percolates to the soil through a constructed soak pit. It is also frequent in middle- and low-income countries that such tanks are not properly designed and maintained and the effluent drains directly into open canals. Sewerage systems collect wastewater from households but also from other commercial activities and industries within cites as indicated above.

Types of wastewater treatment

Before being treated, sewage usually goes through *pre-treatment* to remove grit, grease and gross solids that could hinder subsequent treatment stages.

Later, *primary treatment* aims to settle and remove suspended solids, both organic and inorganic. The most common primary treatments are primary settlers, septic and imhoff tanks.

In *secondary treatment* soluble biodegradable organics are degraded and removed by bacteria and protozoa through (aerobic or anaerobic) biological processes. Typical secondary treatments include aerated lagoons, activated sludge, trickling filters, oxidation ditches and other extensive processes such as constructed wetlands.

Tertiary treatment aims at effluent polishing before being discharged or reused and can consist of the removal of nutrients (mainly nitrogen and phosphorous), toxic compounds, residual suspended matter or microorganisms (disinfection with chlorine, ozone, ultraviolet radiation or others). Nevertheless, this third stage/level is rarely employed in low-income countries. The tertiary treatment process can include membrane filtration (micro-, nano-, ultra- and reverse osmosis), infiltration/percolation, activated carbon and disinfection (chlorination, ozone or UV).

Finally, *water reclamation* refers to the treatment of wastewater to make it suitable for beneficial use with no or minimal risk.

BOX 2.2 Types and examples of uses of reclaimed water (adapted from Mateo-Sagasta 2015)

Agricultural and forestry irrigation: irrigation of crops, forests, agroforestry or commercial nurseries.

Landscape irrigation: reuse for parks, schoolyards, freeway medians, golf course, cemeteries, greenbelts or residential.

Industrial uses: cooling water, boiler feed, process water or heavy construction.

Groundwater recharge: groundwater replenishment for saltwater intrusion control or subsidence control.

Recreational uses: leisure activities like fishing, boating, bathing or snowmaking.

Environmental uses: lakes and ponds, marsh enhancement, stream-flow augmentation and fisheries.

Potable reuse: Planned augmentation of a drinking water supply with reclaimed water. It can be indirect potable reuse (e.g., through groundwater recharge or by blending in water supply reservoirs with a subsequent drinking water treatment) or direct potable reuse (e.g., pipe-to-pipe water supply).

Non-potable urban uses: All other urban uses that do not involve potable reuse or landscape irrigation, such as fire protection, air conditioning or toilet flushing.

The direct use of wastewater implies that treated or untreated wastewater is used for different purposes (such as crop production, aquaculture, forestry, industry, gardens or golf courses) with no prior dilution. When it is used indirectly, the wastewater is first discharged into a water body where it undergoes dilution prior to use downstream.

Reuse can be planned or unplanned. Planned water reuse refers to the deliberate and controlled use of raw or treated wastewater, for example, for irrigation. Most indirect use occurs without planning. Aquifer recharge might be an exception.

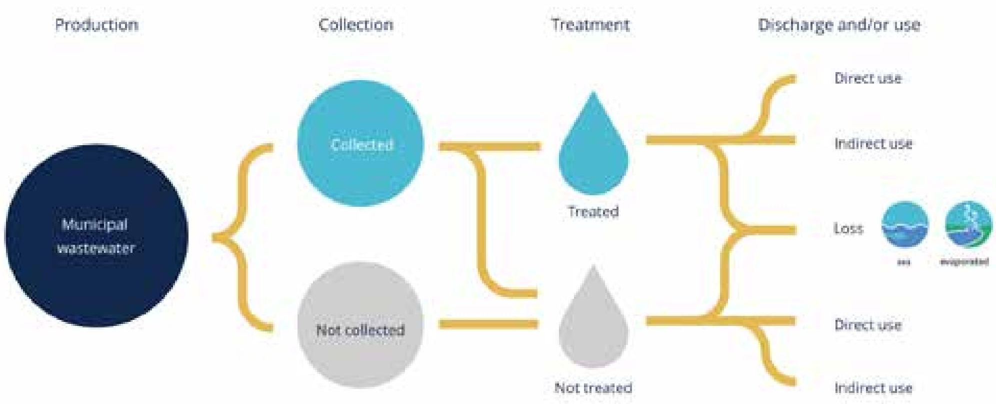

FIGURE 2.1 Wastewater fate flows (adapted from Mateo-Sagasta and Salian 2012).

Improving the treatment of wastewater, increasing the direct use of treated wastewater and making the indirect use of polluted water safer are key to addressing the MENA water crisis.

This chapter offers a systematic and synthesized review of municipal wastewater generation, composition and fate in MENA countries based on the best available data from hundreds of sources. The chapter also provides definitions and key figures to better understand the subsequent chapters of this book. The chapter also looks at the dimension of valuable resources embedded in wastewater streams and the extent to which these resources are so far being recovered for beneficial uses. Where data are weak or scarce, the causes of such data gaps are discussed.

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2.2. Production, composition and treatment of municipal wastewater

2.2.1. Production of wastewater

Wastewater is a resource that can be mined, and as such, it is important to understand how it is geographically distributed in the MENA region. Municipal wastewater is generated where population concentrates, which is typically along the coasts and large rivers. Municipal wastewater production does not only depend on population density but also on the per capita wastewater production, which mainly depends on the per capita municipal water use, which, in turn, is more related to the income per capita than to actual renewable water resources abundance.

High-income countries such as Bahrain or Kuwait, which are water scarce but have access to seawater and can afford water desalination at a large scale, typically have much higher per capita wastewater generation than countries such as Yemen, Mauritania or Sudan or than water-scarce middle-income countries where desalination is limited, such as Jordan, Morocco or Tunisia (Figure 2.2).

Within countries, rural areas use less water per capita than urban areas and this also has an effect on the per capita wastewater generation.

Figure 2.2 illustrates how municipal wastewater generation per capita is calculated as the total municipal wastewater generated in 2015 as per AWC (2019) divided by the population per country in 2015 as per UNSTAT. Saudi Arabia (KSA) and Kuwait are exceptions and municipal wastewater data was drawn from GASTAT (2020) and CSB (2020), respectively, since the data from AWC (2019) was unrealistically low.

Domestic wastewater generation per capita in Figure 2.2 is calculated as the total domestic wastewater generated in 2020 as per WHO (2021) divided by the population per country in 2020 as per UNSTAT. Saudi Arabia and Qatar are exceptions and municipal wastewater data was drawn from GASTAT (2020) and PSA (2019) respectively as the data from WHO (2021) was unrealistically high for Saudi Arabia and low for Qatar.

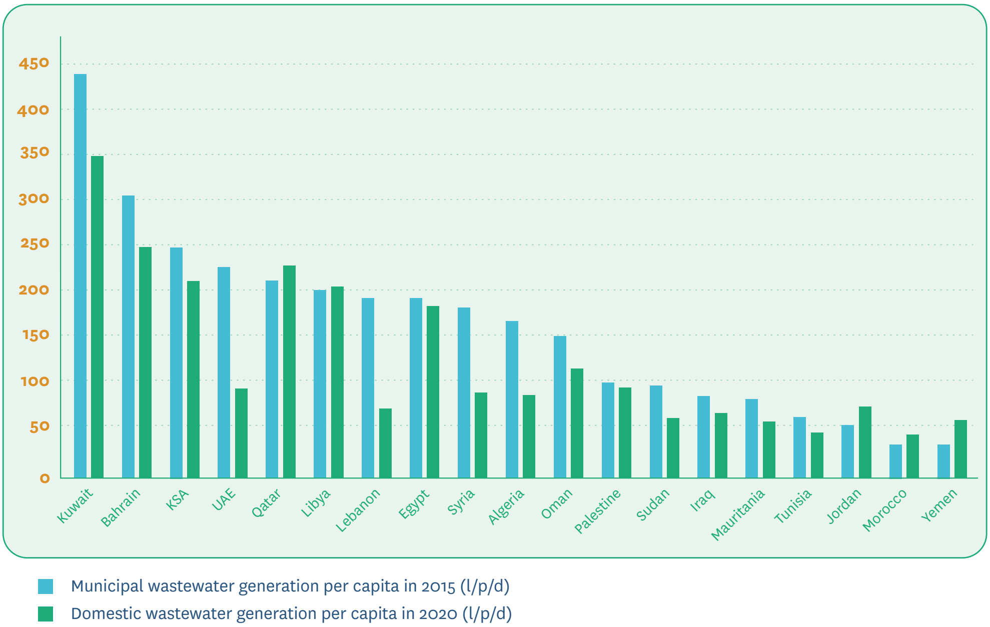


FIGURE 2.2 Per capita municipal and domestics wastewater generation in MENA countries.

By definition (see Box 2.1) figures for municipal wastewater should be larger than domestic wastewater, but this is not always the case in the data shown in Figure 2.2. This may be due to the different years compared (2020 for domestic and 2015 for municipal) or because of deeper methodological inconsistencies between sources. Both WHO (2021) and AWC (2019) collect data from country primary sources, which tend to use different methodologies and define terms differently. This may also be because in some MENA countries, there are very few industries, especially those that use lots of water, such as the textile industry.

Figure 2.3 shows the spatial distribution of the municipal wastewater generation in MENA resulting from combining per capita wastewater generation and population density based on Jones et al. (2021) and Velpuri et al. (forthcoming).

Jones et al. (2021) provided a spatially explicit distribution of global wastewater for 2015 at a special resolution of 5 arcmin (~10 km). This approach has been refined for the MENA region by developing and using the SEWAGE-Track model (Velpuri et al. forthcoming), which uses data from the nominal year 2015, has a resolution of 1 km, and differentiates and incorporates data on per capita wastewater production in rural and urban areas.

With these data and tools, we can precisely identify the location of where wastewater is generated (Figure 2.3). Cities are obviously hotspots of wastewater generation and produce 72% of the municipal wastewater in the region (the other 28% is generated in rural areas) (Velpuri et al. forthcoming). Nevertheless, water-demanding agricultural lands and tree plantations (the main users for reclaimed water in the region) are not always close to cities and sometimes are upstream of wastewater generation sites.

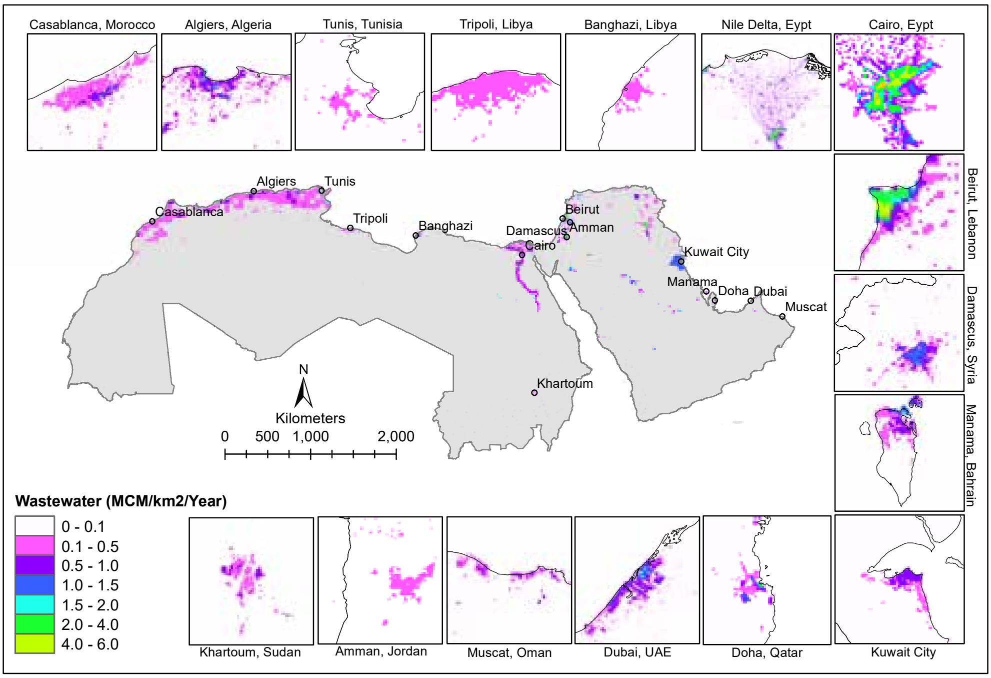


FIGURE 2.3 Wastewater generated in MENA.
NOTES: The map in the central region shows the distribution of wastewater generated by Jones et al. 2021. The insights for urban agglomerations in the periphery of the map show the wastewater generated by the SEWAGE-Track model (Velpuri et al. 2022).

This poses economic challenges for reuse since pumping wastewater back and beyond a given distance or height is not always economically feasible. In smaller towns and villages, which are closer to the WWTPs or surrounded by agricultural land, the challenge is typically that wastewater is collected on-site in septic tanks with limited treatment capacity. Effluents from septic tanks either percolate to groundwater or are discharged to open canals (if septic tanks are sealed) with very low treatment and poor removal of pathogens, which limits the potential for safe reuse.

When considering the trends, wastewater is the only source of water that increases as population and water use grow (Figure 2.4). This is particularly apparent in countries such as Egypt, which is the most populated country in MENA and experiencing booming growth of its urban areas, especially in and around Cairo. This trend is going to continue in the coming decades and the wastewater sector needs to adapt to cope with this increasing production of wastewater. An increasing body of evidence suggests that the economic costs (including environmental and health costs) of discharging wastewater into the environment untreated are higher than the costs of managing it properly (Hernandez-Sancho et al. 2015). From a resource mining perspective, the growth of wastewater production and treatment of waste-water as an economic asset (Drechsel et al. 2015) offer opportunities to increase economic and social benefits in a circular economy.

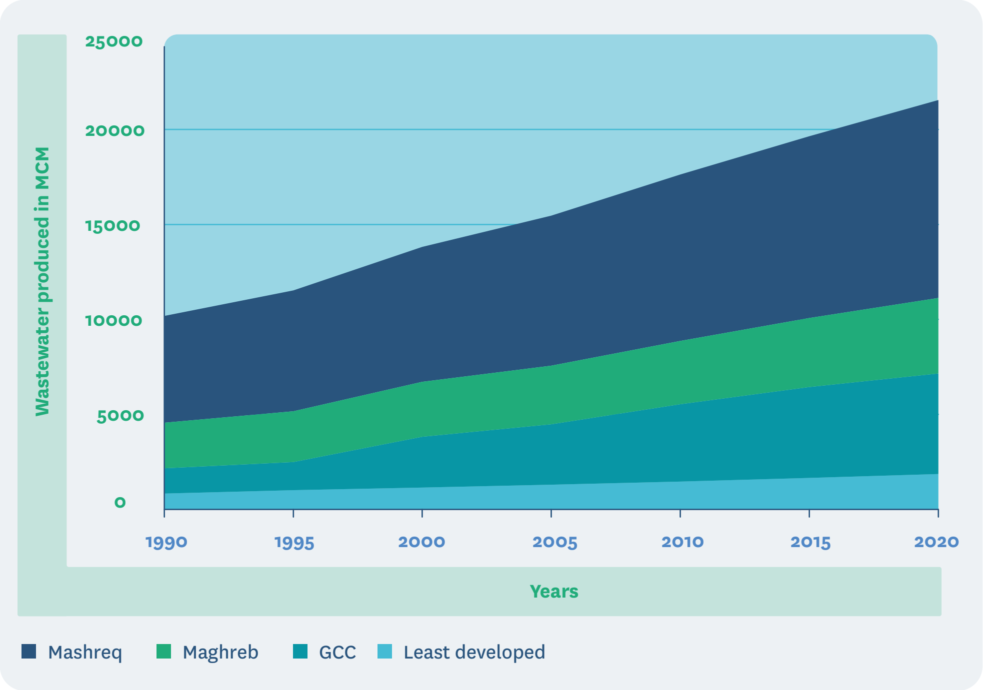


FIGURE 2.4 Trends in municipal wastewater generation in selected MENA countries.
NOTES: Mashreq includes Iraq, Jordan, Lebanon, Palestine, Syria and Egypt; Maghreb includes Algeria, Libya, Mauritania, Morocco and Tunisia; GCC includes Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and United Arab Emirates); Least developed countries include Sudan and Yemen.

The composition of raw municipal wastewater and the resources embedded, or the hazards contained in it, vary in different countries and in different cities within countries.

Water in municipal wastewater comes from households, from rainwater that drains cities and from industries and commercial activities. Most of the nutrients in wastewater come from human excreta. The excretion of nutrients per capita is highly dependent on diets (e.g., protein consumption), which differ depending on the country, wealth status and culture. Most of the nutrients are in urine. In wastewater, phosphorus does not come only from human excreta but also from detergents used in laundry and dishwashing (Mateo-Sagasta 2015).

As a result of these material flows, municipal wastewater concentrates valuable resources but also hazards such as pathogens or dangerous chemicals (Table 2.1; Box 2.3). Pathogens tend to come in excreta. Chemical hazards enter wastewater via discharges from economic activities connected to sewers, but also via household cleaning or pharmaceuticals excreted by people. The concentration of these resources and hazards depends very much on people's consumption patterns, diets, household and municipal water use and rainfall entering sewage systems (dilution). Table 2.1 shows the weighted average composition of raw wastewater in MENA countries based on influent data from 166 wastewater treatment plants (WWTPs). The averages have been weighted with the influent volumes of wastewater to the treatment plants

TABLE 2.1 Weighted average composition of influent wastewater in municipal wastewater treatment plants in MENA countries.

Country	TSS	BOD	COD	T-N	T-P	FC	EC	TDS	No. of WWTPs from which data has been collected
	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(CFU/ 100 mL)	(dS/m)	(mg/L)	
Algeria	357	330	660	23.2	10.0	1.84E+08	2.4	1,642	20
Bahrain	179	219	410	NA	NA	NA	NA	NA	1
Egypt	243	209	391	40.2	6.4	1.43E+09	1.1	654	13
Iraq	230	214	395	NA	NA	NA	1.9	1,379	5
Jordan	628	624	1245	100.0	10.5	2.87E+07	1.4	978	22
Kuwait	250	234	431	31.5	21.8	3.41E+07	1.0	645	4
Lebanon	412	291	618	63.1	12.0	1.13E+06	1.3	962	15
Libya	216	298	431	NA	2.8	NA	2.8	1,664	5
Mauritania	658	535	1811	NA	NA	NA	2.1	1,506	1
Morocco	475	1354	907	82.7	11.3	7.83E+08	2.7	1,869	9
Oman	420	245	920	87.7	12.0	1.45E+08	1.7	944	7
Palestine	781	471	951	66.6	10.2	2.22E+06	2.9	2,268	10
Qatar	150	178	418	35.0	5.0	5.01E+06	2.0	1,329	2
KSA	321	213	413	25.6	13.2	2.54E+06	2.3	1,488	10
Sudan	447	411	1076	NA	NA	NA	1.2	709	3
Syria	539	355	542	46.8	2.5	3.90E+07	2.3	1,701	3
Tunisia	419	372	899	92.9	12.6	7.93E+06	3.2	2,477	23
UAE	277	258	589	NA	6.2	NA	3.8	2,108	8
Yemen	444	743	1307	NA	15.0	2.93E+06	2.6	1,899	5
MENA	296	285	523	55.2	13.2	7.15E+08	2.5	1,490	166

TSS: Total dissolved solids, BOD: biological oxygen demand, COD: chemical oxygen demand, T-N: total nitrogen, T-P: total phosphorus, FC: fecal coliforms, EC: electric conductivity, TDS: total dissolved solids.
Sources: See complete list of sources by country at http://bit.ly/3hsRkDL

so that the composition of the influent wastewater in large treatment plants has a larger influence on the national averages. Data shows that wastewater tends to be stronger (i.e., with higher concentrations) in counties with less municipal water use per capita, such as Jordan or Mauritania.

The composition of municipal wastewater offers valuable information on both the risks and opportunities of water reuse. WWTPs designers will consider the wastewater composition and concentration when selecting technology or resource recovery processes. For example, for strong wastewater in warm climates, WWTP designers may choose anaerobic systems that tend to yield less sewage sludge and maximize energy recovery through biogas generation.

BOX 2.3 Emerging pollutants (EPs) in raw and treated wastewater in MENA (from Haddaoui and Mateo-Sagasta 2021)

Emerging pollutants are of increasing concern. Raw municipal wastewater in the MENA region has been reported to concentrate pesticides like endosulfan or DDT, pharmaceuticals such as acetaminophen, ibuprofen, paracetamol, naproxen, diclofenac or carbamazepine, and dozens of other emerging pollutants. The limited actual treatment of these wastes and wastewater in many MENA countries results in a large portion of these EPs making their way to water bodies, in turn increasing the risk of exposure downstream. Even in the cases where wastewater is collected and treated, the removal efficiency for EP in existing WWTPs is at best limited.

The data on EP removal effectiveness in treatment plants of the MENA countries suggest that secondary treatment is ineffective in the reduction of most EPs (e.g., pharmaceuticals compounds like carbamazepine, erythromycin and sulfamethoxazole). Tertiary treatment improves the elimination of many EPs, but this improvement is inadequate for some pollutants (e.g., tetracycline, ciprofloxacin and amoxicillin).

The extent of the wastewater treatment coverage and the types of wastewater and drinking water treatment technologies in most MENA countries are far from sufficient to effectively address the environmental and health risks posed by the EPs. Given the limited financial capacities of the middle- and low-income countries, and the limited effectiveness of the removal of EPs by the tertiary treatments, it is not practical nor affordable to promote wastewater treatment as the only way to address waterborne EPs. Instead, we recommend prioritizing a more cost-effective combination of solutions that includes a change in consumption and production patterns to prevent pollution from EPs at the source, wastewater treatment expansion to the extent required for conventional pollutants including pathogens, adoption of good irrigation practices and universal coverage of drinking water treatment.

Anaerobic treatment may not work optimally with weaker wastewater. High concentration influent (like wastewater in Jordan, Mauritania, Sudan or Yemen) correlates with lower energy consumption and lower costs per kilogram of pollutant removed, and with a higher nutrient recovery potential in wastewater treatment plants, which are critical factors that influence the selection of technologies. But high concentration influent also correlates with a higher greenhouse gas emission potential when removing pollutants (Zhang et al. 2020).

2.2.2. Treatment of wastewater

The potential for safe water reuse depends on multiple factors beyond the location and concentration of wastewater. One key factor that determines the safe reuse is the level of treatment. Countries are increasingly aware of the impacts and economic costs of untreated wastewater and are investing in improved wastewater collection and treatment. Nevertheless, the growth in investments and infrastructure is not keeping pace with municipal wastewater generation growth in many MENA countries. As a result, the total amount of wastewater that is discharged untreated to the environment keeps increasing in these countries. For example, in Egypt the municipal wastewater treatment capacity has grown from 3.1 BCM in 2000 to 5.3 BCM in 2020. The amount of municipal wastewater generated has grown from 4.8 to 7.2 BCM in the same period, which means that the amount of untreated wastewater has grown from 1.7 to 1.9 BCM despite growth in treatment capacity (GWI 2021, MHUUC 2022). Substantial amounts of wastewater do not reach treatment plants and many existing facilities are overloaded and produce effluents below the expected quality. There are some exceptions to this trend particularly in some Gulf countries, where capacity of treatment plants has increased more than the actual wastewater production.

The World Health Organization and UN-Habitat are the custodians of indicator 6.3.1 of the United Nations Sustainable Development Goals (SDGs), which tracks the proportion of wastewater flows from households, services and industrial premises that are treated in compliance with national or local standards. The household component includes both sewage and fecal sludge, treated on-site and off-site, and is monitored as part of the sanitary chain with direct links to indicator 6.2.1 on access to sustainably managed sanitation services. Data on 6.3.1 are commonly collected by national line ministries and institutions (e.g., for water, sanitation, environment, health, public services, planning, housing, infrastructure or production), utilities and on-site service providers as well as the national statistical office (household surveys and registers of economic activities).

The most recent data for 2020 in MENA countries in the framework of SDGs monitoring shows that about 60% of the domestic wastewater that is generated is safely treated. This includes household wastewater transferred through sewers to a WWTP (‘treated sewage’), released into an on-site treatment system (‘treated in-situ’) and released into an on-site system (e.g., septic tanks) for which fecal sludge is emptied and transported to a treatment plant (‘treated from on-site’).

The situation nevertheless varies greatly between countries (see Figure 2.5). Income per capita is a good predictor for the level of treatment. High-income countries such as Bahrain, Qatar, United Arab Emirates and Saudi Arabia treat most of the domestic wastewater generated. Lower middle-income countries such as Yemen, Sudan, Mauritania, Morocco and Egypt are having more challenges. Higher middle-income countries such as Jordan stand out and perform better than expected from their income, which reflects the relative high priority that wastewater and sanitation has in these countries’ agenda despite limited budgets. The effect that conflict, social unrest or economic crisis has on wastewater treatment in countries such as Yemen, Lebanon, Libya, Iraq, Palestine and Syria is unclear but very likely is heavily limiting the treatment potential (Faour and Fayad 2014; Qadri et al. 2017; Zolnikov 2013).

Table 2.2 shows the weighted average composition of treated municipal wastewater in 19 MENA countries based on data from 211 WWTPs. The averages have been weighted with the volumes of the wastewater treated in treatment plants so that the composition of the effluent wastewater in large treatment plants has a larger influence on the national averages. Vari-

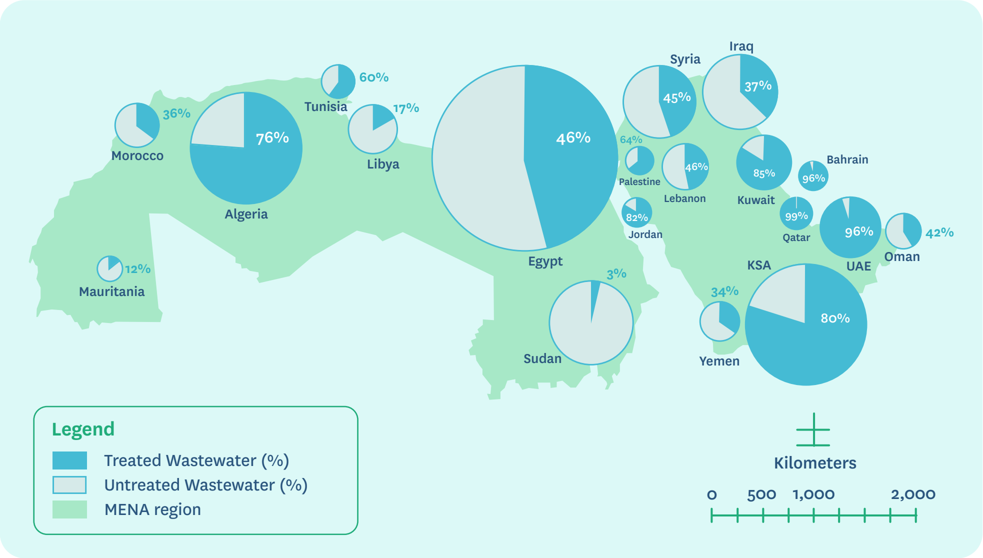


FIGURE 2.5 Proportion of domestic wastewater safely treated in 2020 as per WHO (2021).

ability within and between countries is mostly dependent on the quality of influent wastewater and the type and level of treatment.

On average, WWTPs in the region remove between 85 and 90% of the total suspended solids (TSS) and biological and chemical oxygen demand (BOD, COD). About 50% of the nitrogen and phosphorus is removed. The removal of fecal coliforms is on average in the order of 3-log, with larger removals in GCC countries, Jordan and others where large portions of the treated wastewater are disinfected. Removal of dissolved solids and salinity is nevertheless limited and averages only 12% in the region. In many instances, salinity removal is actually negative, which means that the salinity in the effluent is higher than in the influent. That is no surprise as only reverse osmosis and nano-filtration (which are rarely implemented in MENA to treat wastewater) remove salts and in other types of treatments that are commonly used in the region, water losses due to evaporation during treatment increase the concentrations of salts (Obotey Ezugbe and Rathilal 2020).

When treated wastewater is discharged to the environment, the removal of nitrogen and phosphorus helps prevent eutrophication of surface water or pollution of groundwater with nitrates. When the effluent is used in irrigation, nutrient removal will limit productivity if the concentration of nutrients in the irrigation waters is lower than the demand from crops (Chojnacka et al. 2020).

Salinity limits the potential of treated effluent to be reused. High concentrations of salts in irrigation make it difficult for plants to absorb water and cause reductions in crop yields. Farmers in the northern part of the Jordan Valley are concerned about the governmental plans to change the irrigation source to diluted reclaimed water from the Al Samra treatment plant, which has higher salinity levels than the water currently used (Tawfik et al. in review).

The most common indicator to monitor the salinity of water is electrical conductivity (EC). Salts in irrigation water can begin to accumulate in the soil, preventing plants from absorbing water and impacting the productivity of many crops and fruit trees. Crops such as onions, carrots or lettuce (Shannon and Grieve 1999) or fruit trees like citrus (Ruiz et al 1997; Levy and Syvertsen 2010) are particularly sensitive to salinity. Other crops such as asparagus or fruit trees such as dates, pistachio or pomegranate are more tolerant. Irrigation with brackish water will require the adoption of on-farm practices to mitigate agronomics risks such as changing to salt-tolerant crops, using additional water as leaching fractious and ensuring proper drainage.

TABLE 2.2 Weighted average composition of influent wastewater in municipal wastewater treatment plants in MENA countries.

Country	TSS	BOD	COD	T-N	T-P	FC	EC	TDS	No of WWTPs
	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(CFU/100 mL)	(dS/m)	(mg/L)	
Algeria	26	27	66	8.5	5.1	6.28E+05	1.9	1,238	22
Bahrain	9	2	32	NA	NA	2.21E+03	4.9	3,574	1
Egypt	49	48	112	25.6	11.1	2.68E+06	1.1	628	27
Iraq	78	53	99	NA	NA	NA	2.1	1,545	9
Jordan	28	19	112	29.6		2.17E+01	2.3	1,025	25
Kuwait	6	3	21	5.1	11.3	1.89E+02	1.1	757	4
Lebanon	49	37	109	16.0	15.1	8.54E+05	1.2	796	17
Libya	10	17	44	NA	0.7	3.00E+02	3.2	1,972	5
Mauritania	NA	NA	257	NA	NA	1.90E+04	1.9	1,176	1
Morocco	25	18	51	23.4	4.3	5.45E+05	2.1	1,385	8
Oman	28	3	34	8.0	2.6	1.00E+01	1.6	915	11
Palestine	95	72	232	8.9	3.2	9.68E+04	2.3	1,656	10
Qatar	2	2	13	5.9	0.8	0.00E+00	2.1	3,410	3
KSA	25	30	66	13.7	4.8	2.12E+02	1.9	1,263	17
Sudan	111	59	223	NA	NA	2.40E+03	1.7	1,097	3
Syria	165	83	140	29.0	1.4	NA	2.2	1,606	3
Tunisia	54	37	137	27.3	11.7	6.19E+04	4.4	3,005	27
UAE	5	4	36	10.1	6.3	2.00E+00	3.2	1,697	10
Yemen	194	84	285	NA	6.7	3.87E+06	3.1	2,223	8
MENA	38	32	84	21.5	8.3	8.04E+05	2.2	1,337	211

TSS: Total dissolved solids, BOD: biological oxygen demand, COD: chemical oxygen demand, T-N: total nitrogen, T-P: total phosphorus, FC: fecal coliforms, EC: electric conductivity, TDS: total dissolved solids.
Sources: See complete list of sources by country at http://bit.ly/3hsRkDL

2.3. Actual water reuse

It is challenging to describe the present quantities of water reuse in MENA due to the lack of reliable and sufficient data from national statistics. Much of the available information does not use uniform terms and units when describing water reuse, making it difficult to compare data between countries or establish regional inventories. The most recent and comprehensive attempts to compile data on municipal wastewater generation, treatment and reuse include the *Third State of the Water Report for the Arab Region* (AWC 2019) with data from 2015 or AQUASTAT with data from many of the MENA countries but with almost no recent data. The reported data on water reuse by these sources has major data gaps for recent years and at times includes data on indirect water reuse (i.e., treated wastewater discharged to rivers or drainage canal where it is diluted and reused indirectly downstream).

The ReWater MENA project, a regional project led by IWMI and funded by the Swedish International Development Cooperation Agency (SIDA), has established the largest inventory of projects to our knowledge for direct water reuse in the region so far. These are projects where reclaimed water is used directly for different purposes including the irrigation of agriculture and planted forests, landscaping (including golf courses), industrial processes, environmental uses and others. The inventory has collected data for more than 400 projects that are still operational and includes data on the startup year of the reuse projects, volumes treated and reused, and type of use made of the reclaimed water.

The region has been proactively investing in water reuse in recent decades. According to the ReWater MENA database, the number of water reuse projects has doubled every decade since the 1990s. In the 19 countries that were analyzed, the number of reuse projects has specifically grown from 40 in 1990, reusing a total quantity of 0.421 BCM, to 97 projects in 2000 (and 0.655 BCM directly reused), 200 in 2010 (with 1.249 BCM) and finally 409 in 2020 (with 2.275 BCM). In the last decade, the growth in the number of direct water use projects has been particularly high in countries like Saudi Arabia, United Arab Emirates, Qatar, Oman, Egypt, Algeria and Morocco.

The dominant uses of reclaimed water are for forestry, agriculture and landscaping, including irrigation of parks and gardens (See Box 2.2. for definitions). As shown in Figure 2.6, different countries have invested differently in various typologies of water reuse. Forestry and agriculture are the dominant users of reclaimed water, for example, in Egypt, Tunisia and Jordan, while landscaping is the preferred option in countries like Morocco, United Arab Emirates, Oman and other GCC countries. The pattern in other areas is not so clear, with a more mixed project portfolio. These patterns are a consequence of different factors, including perceptions about reuse, the quality of the effluents, and the different policies and legislation that have been shaped across the region as further discussed in subsequent chapters of this book.

The presence of water reuse projects for other purposes such as industrial use, non-potable urban use, aquifer recharge or environmental restoration are scattered and much less frequent. Examples include Al Shabab Power project and Jazan IGCC project in Egypt and

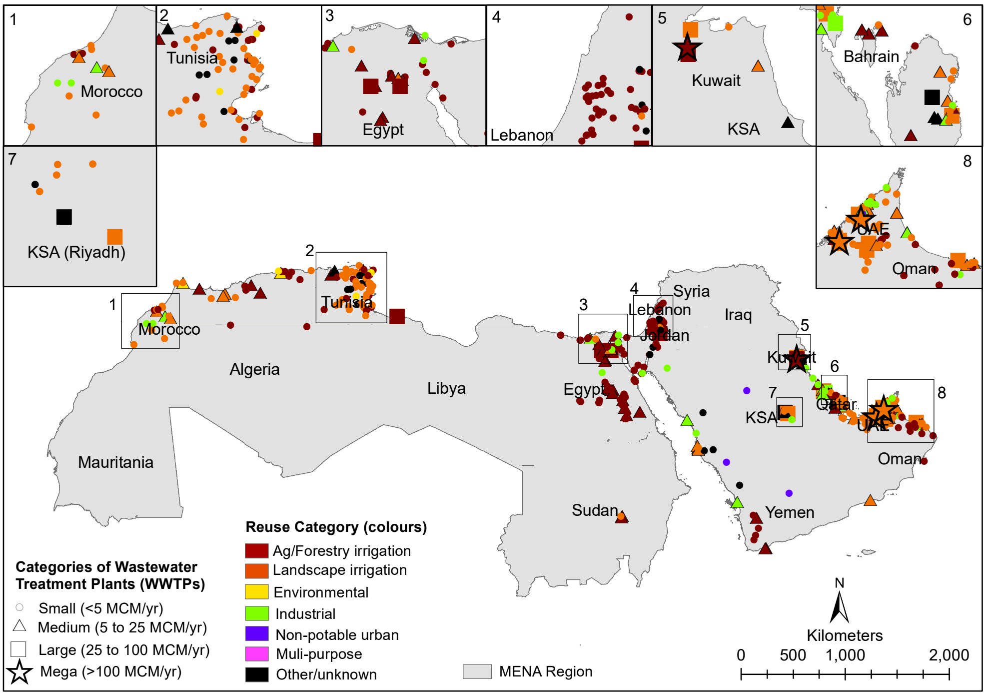


FIGURE 2.6 Location and distribution of operational water reuse projects in MENA as of 2020 (N=409). *NOTES*: The shape/size of each point indicates the capacity of the WWTPs classified as small (N = 312); medium (N = 76), large (N = 20) and mega (N = 1) and the color indicates the reuse category.

Saudi Arabia for industrial purposes (GWI 2021) and Emicool project and West Bay project in UAE and Qatar for non-potable urban use (GWI 2021). In Section 2 of this book, we have characterized in detail several key water resource projects from Morocco, Tunisia, Jordan, the West Bank and United Arab Emirates.

Despite the rapid growth of water reuse projects across the region, the amount of municipal wastewater that is treated and directly reused for beneficial purposes is still very limited in MENA and averages only around 10% of the total wastewater generated in the 19 countries that were analyzed (Table 2.3). The main exceptions are in the GCC with Qatar, UAE, Kuwait, Oman or Bahrain leading the ranking.

Jordan is a case in point. Most of the effluent from the Al Samra treatment plant, which serves Amman and surrounding areas, is fully reused in the Jordan Valley after traveling along the Al Zarqa wadi and being stored in the King Talal dam. This reclaimed water undergoes minimal dilution with other sources of water so it is considered in the literature and by the authorities as indirect water reuse and is not part of the national statistics on direct water reuse presented in Table 2.3. If, because of the negligible degree of dilution, this reclaimed water was considered as directly reused, then Jordan would be considered to reuse directly 70% of the generated wastewater, becoming one the leaders in direct water reuse in the whole region.

TABLE 2.3 Wastewater production, treatment and reuse in 19 countries within MENA in 2020 (or latest available year).

Country	Total municipal wastewater generated**	Municipal wastewater that is treated and directly reused	Directly reused from municipal wastewater	Projects where municipal wastewater is treated and directly reused	Methodological notes and sources to calculate municipal wastewater that is treated and directly reused
	(BCM)	(BCM)	(%)	(N)	
Algeria	2.649	0.100	3.8	22	Data up to 2015 from AbuZeid et al. 2019 with no additional projects found up to 2020
Bahrain	0.186	0.045	24	4	Data up to 2015 from AbuZeid et al. 2019 updated to 2020 with individual project data from GWI 2021
Egypt	7.196	0.341	4.7	77	Aggregation of individual project data up to 2020 from MHUUC 2022; GWI 2021
Iraq	1.232	NA	NA	NA	NA
Jordan	0.187	0.071	37.9	25	Aggregation of individual project data up to 2020 from Ibrahim et al. 2019; Kassab et al. 2020, GWI 2021
Kuwait	0.666	0.271	40.7	6	Aggregation of individual project data up to 2020 from Aleisa and Alshayji 2019; GWI 2021
Lebanon	0.481	0.002	0.4	4	Data up to 2015 from AbuZeid et al. 2019 with no recent projects up to 2020
Libya	0.514	0.040	7.8	1	Aggregation of individual project data from Kamizoulis et al. 2003
Mauritania	0.138	NA	NA	NA	NA
Morocco	0.415	0.076	18.3	22	Data up to 2015 from AbuZeid et al. 2019 updated to 2020 with individual project data from Nahli et al. 2016; Bensaad et al. 2017; Haji et al. 2021; GWI 2021
Oman	0.275	0.079	28.6	30	Data up to 2015 from AbuZeid et al. 2019 updated to 2020 with individual project data from Suaad et al. 2017; GWI 2021
Palestine	0.180	0.007	3.7	24	Aggregation of individual project data up to 2020 from PWA 2021; GWI 2021
Qatar	0.225	0.165	73.6	17	Data up to 2015 from AbuZeid et al. 2019 updated to 2020 with individual project data from PSA 2021; GWI 2021
Saudi Arabia	3.144	0.431*	13.7	40	Aggregation of individual project data up to 2020 from Al-Jasser 2011; Chowdhury and Al-Zahrani 2012, 2015; Alkhudhiri et al. 2019; GWI 2021
Sudan	1.533	0.029	1.9	3	Aggregation of individual project data from Maki 2010
Syria	1.147	NA	NA	NA	NA

Country	Total municipal wastewater generated**	Municipal wastewater that is treated and directly reused	Directly reused from municipal wastewater	Projects where municipal wastewater is treated and directly reused	Methodological notes and sources to calculate municipal wastewater that is treated and directly reused
	(BCM)	(BCM)	(%)	(N)	
Tunisia	0.254	0.034	13.4	63	Aggregation of individual project data up to 2020 from DGGREE 2021; ONAS 2021
UAE	0.801	0.549	68.6	64	Aggregation of individual project data up to 2020 from Dawoud et al. 2012; EAD 2021; GWI 2021
Yemen	0.326	0.036*	11.1	7	Aggregation of individual project data up to 2020 from Al-Gheethi et al. 2014; Rageh 2014; Rageh et al. 2017
MENA	21.549	2.275	10.5	409	

NOTES: *may include some indirect reuse or blending. **Estimated as the produced municipal wastewater in 2015 from Abu Zeid et al. (2019) plus the generated municipal wastewater in the period 2015–2020, the latter is calculated based on per capita wastewater in 2015 and the population growth in the period 2015–2020.

The potential to increase direct water reuse and free up freshwater for other high added value purposes remains large in most other countries. In the next section, we review such potential.

2.4. Potential for resource recovery and reuse

The 19 countries in the region that were analyzed produce around 21.5 BCM of municipal wastewater every year. This wastewater contains valuable resources, mainly water, nutrients (nitrogen, phosphorus, potassium, etc.) and organic carbon. All of these can be recovered for different uses. Water is the most important and abundant asset in wastewater and can be used as a substitute for freshwater if appropriately treated. Nutrients are valuable in agriculture and aquaculture. Organic carbon can be used as a soil conditioner or to generate energy. Based on the actual composition of municipal wastewater in the region (Table 2.1), we can estimate the amounts of nitrogen and phosphorus potentially contained in municipal wastewater and the amount of methane potentially generated from wastewater (Table 2.4).

The potential energy value from carbon in wastewater could be estimated based on the biogas production in relation to chemical oxygen demand (COD), which is about 0.5 liters (L) of biogas per gram (g) COD removed, corresponding to a methane production of approximately 0.35 L CH_4 per gram (g) of COD removed at 20°C. In practice, the amount of methane recovered per gram of COD removed will be less as some of the COD may be used as source of reducing equivalents for microbial growth; also not all COD may be biodegradable.

With the conservative assumption that 70% of the COD in wastewater can be actually transformed into methane (De Mes et al 2003) and considering that the caloric value of methane is 34.9 MJ/m^3 CH_4, the 21.5 BCM of municipal wastewater estimated to be produced in the region could potentially produce 2.650 BCM CH_4 with a global caloric value of 92.5 10^9

TABLE 2.4 Resources embedded in municipal wastewater in MENA countries.

Country	Water	T-N	T-P	CH4 potential***
	(BCM)	(Tm**)	(Tm)	(BCM)
Algeria	2.649	61,371	26,400	0.428
Bahrain*	0.186	10,268	2,459	0.019
Egypt	7.196	289,150	46,097	0.689
Iraq*	1.232	50,555	2,931	0.117
Jordan	0.187	18,718	1,970	0.057
Kuwait	0.666	20,959	14,554	0.070
Lebanon	0.481	30,313	5,786	0.073
Libya*	0.514	28,359	1,429	0.054
Mauritania*	0.138	7,610	1,823	0.061
Morocco	0.415	34,348	4,711	0.092
Oman	0.275	24,147	3,302	0.062
Palestine	0.180	12,003	1,842	0.042
Qatar	0.225	7,860	1,123	0.023
KSA	3.144	80,548	41,580	0.318
Sudan*	1.533	84,595	20,264	0.196
Syria*	1.147	29,671	7,107	0.071
Tunisia	0.254	23,558	3,207	0.056
UAE*	0.801	44,193	4,933	0.116
Yemen	0.326	18,014	4,896	0.104
MENA	21.549	876,240	196,414	2.650

NOTES: *countries where the average regional wastewater composition has been used for one or more parameters. ** Tm=Terameter ***Assuming 0.35 L CH_4 per g of COD removed at 20°C and that 70% COD is transformed into CH_4. Source: authors' calculations.

megajoules (MJ), which, if fully recovered, would be enough to provide electricity for about 8 million households, considering an average electricity consumption of 3,350 kilowatt hours (kWh)/household (World Energy Council 2016; Qadir et al. 2020).

Almost 9,000 tons (t) of nitrogen and 200,000 t of phosphorus are potentially embedded in the 21.5 BCM of wastewater generated in MENA (Table 2.4). Because part of the wastewater is treated, some of these resources are removed. Also, irrespective of treatment, part of the wastewater is discharged to water bodies and reused indirectly in agriculture, forestry and other productive water users and nutrient sinks, which means that part of this water and these nutrients are already recycled, although not in a planned or efficient manner.

There is nevertheless a good portion of the (treated or untreated) wastewater that is discharged into the environment that evaporates or ends up in the sea with no productive use. Some nutrients end up in non-productive sinks, such as weeds or algal blooms. Recent estimates from Velpuri et al. (forthcoming) suggest that the wastewater evaporated or lost in the sea can be as high as 54% of the total wastewater produced in MENA, while the rest is reused directly or indirectly (see a detailed analysis for Egypt in Box 2.5). There is still potential to recover these wasted resources (evaporated or lost in the sea) and to make a more efficient use of the wastewater that is currently reused indirectly.

BOX 2.4 The paradox of direct and indirect water reuse and health risks

Direct water reuse differs from indirect water reuse because, in the former, (treatment of untreated) wastewater is first discharged into a water body where it undergoes dilution prior to use downstream. Indirect water reuse is typically considered safer, so it is normally not regulated or controlled. Nevertheless, indirect reuse can be unintentional, and users downstream do not know the sources or quality of the water they are using. Farmers, for example, could irrigate vegetables to be eaten raw with diluted untreated wastewater, with obvious health risks.

On the other hand, direct reuse is often strongly regulated and sometimes prohibited for food crops (see Chapter 5), even when the quality of treated wastewater may have pathogenic concentrations orders of magnitude lower than the 'freshwater' (or better diluted wastewater) that is used to irrigate in many settings across MENA (Abi Saab et al. 2022). Paradoxically, at times, reclaimed water from an advanced treatment plant is discharged, diluted and wasted into a heavily polluted water body because direct reuse is not allowed.

The degree of dilution of (treated or untreated) wastewater in water bodies is not a good indicator of the safety of reuse. First, because we would need a dilution of five orders of magnitude (i.e., diluting 1 L of wastewater into 100,000 L of clean water) to get a reduction of *E. coli* of 10+EXP5, needed to get the 1,000 colony-forming unit (CFU)/100 mL required for unrestricted irrigation. Second, because a strong wastewater (i.e., with relatively high concentration of pollutants such as a COD of around 1,000 milligrams/liter (mg/L)) that undergoes only little dilution in a drain, canal or creek can have more concentration of pollutants than a weak wastewater (i.e., with relatively low concentration of pollutants such as a COD of around 250 mg/L) that is reused directly.

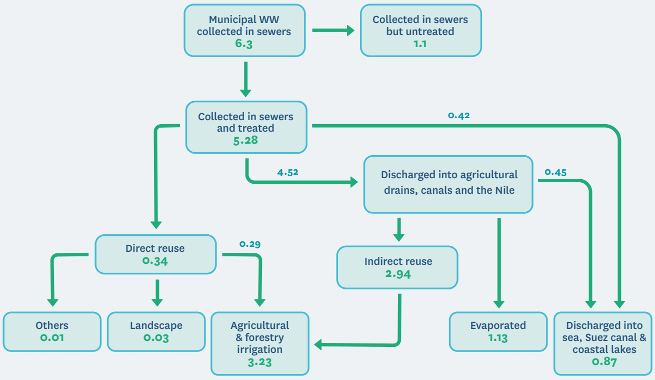
Indeed, all pollutants generated in urban settlements undergo some degree of dilution. Water used to flush toilets dilutes excreta and urine. Water used in kitchens dilutes organic matter from food waste and cleaning products. And water used in showers or house cleaning dilutes soaps and detergents. Pollutants are not only diluted within household premises, but also outside premises, with rainwater and urban runoff. In areas where precipitation and water use are high, dilution will be also high resulting in weak wastewater, with relatively low concentration of pollutants. This weak wastewater could then have a similar, or even lower, pollution concentration than the water in a canal or drain that receives a stronger wastewater even when this is diluted to an extent in this canal or drain.

BOX 2.5 Wastewater fate in Egypt

Egypt is the most populous country in the MENA region with around 106 million inhabitants (UN 2019). The wastewater sector is operated by the government through the Holding Company for Water and Wastewater (HCWW) and its subsidiaries in all provinces of Egypt. The Government of Egypt has paid a great deal of attention to the wastewater sector recently in order to better utilize the source of water that could contribute to mitigating the impacts of the water crises in Egypt (Orabi 2017).

HCWW operates more than 500 WWTPs. According to the Ministry of Housing, Utilities and Urban Communities (MHUUC), the amount of treated wastewater (TWW) was about 5.28 BCM in 2020 (MHUUC 2022, GWI 2021). Because the proportion of sewered wastewater safely treated at treatment plants is reported by WHO (2021) to be 84% in 2020, we estimate the volume of wastewater collected in sewers to be approximately 6.3 BCM. On the other hand, an additional amount of wastewater is collected in on-site systems like septic tanks.

Once treated, reclaimed water can be used directly and indirectly (after dilution), or it can be lost when it evaporates or ends up in the sea with no productive use. In Egypt, 0.29 BCM of reclaimed water are directly used for agroforestry irrigation, 0.03 BCM for green areas' irrigation and 0.01 BCM for non-potable urban uses (MHUUC 2022; GWI 2021). The remaining 4.94 BCM is discharged into agricultural drains, canals and the Nile (4.52 BCM), or coastal lakes, the Suez canal and the sea (0.87 BCM). A relatively small portion of treated effluents is evaporated before reaching any water body or reuse. Assuming a loss through evaporation in running waters of 25%, and that 10% of the wastewater discharged into the surface wasters is dumped in the sea unproductively (Simpson et al. 1991, Zhu et al. 2022), we estimate that 2.94 BCM are reused indirectly after dilution in surface waters. Therefore, the total balance is as follows:



Fate of municipal wastewater in Egypt 2020 *(Units: billion cubic meters)*

According to the Egyptian code for wastewater reuse (no. 501/2015), edible crops cannot be irrigated by treated wastewater directly, regardless of the treatment level (Ahmed et al. 2022). However, as mentioned in Box 2.4, treated wastewater is sometimes better than water in canals and drains used for irrigation, which collects pollution from uncontrolled point and non-point sources. This is something to be considered by policy.

If all wastewater that is lost was recovered, the region can unlock new opportunities whilst enhancing the region's ability to adapt to changes in climate and enhance food security. The 11.6 BCM of municipal wastewater estimated to be lost, if fully recovered, could additionally irrigate and fertilize about 1.4 million ha with a relatively high application rate of 8,000 m^3/ha/year (Steduto 2012). If no wastewater was lost and 70% of the COD was recovered in the form of methane, the energy produced could provide electricity to around 4 million households, or to all wastewater treatment plants in the region and an additional surplus for hundreds of thousands of households.

As the population grows, so does the demand for fertilizer. Nutrient recovery from wastewater, sludge and other wastes (such as food waste) can regionally and locally help to meet this demand and is particularly interesting in and around cities, close to where these wastes are produced, and where intensive agriculture is expanding to feed the increasingly hungry cities. Moreover, for an essential nutrient like phosphorous, its recovery from waste is decreasingly an option but is a necessity as it is a non-renewable resource obtained from mining of finite deposits in a few countries (Mihelcic et al. 2011).

However, structural and financial shortcomings in the wastewater sector, combined with challenges of governance and inadequate regulatory frameworks for reuse management, impede the fulfillment of this potential. Poor administrative capacities in the planning, implementation and management of existing WWTPs and future reuse systems further hinder the water reuse potential. The mandates of state authorities are frequently fragmented and often conflicting. In countries under economic, financial and political crisis, such as Lebanon, these barriers have become more entrenched and tend to attenuate the technical potential (Eid-Sabbagh et al. 2022). There are nevertheless ways to address part of these constraints as shown in Section 2 and in the regional success stories in Section 3.

2.5. Conclusion

Wastewater treatment and reuse for beneficial purposes offers the means to combat water scarcity and pollution at the same time. Nevertheless, the spread of managed wastewater reuse is uneven across the MENA region despite it being one of the most arid and water-scarce regions in the world. Some countries, such as the Gulf countries, Jordan and others, promote wastewater treatment and reuse as an integral component of their water management strategy; however, many other countries make very limited use of wastewater. Regional statistics indicate the considerable potential to increase treatment and reuse of wastewater in the MENA region.

The region needs overcome the factors that limit the fulfillment of the regional water reuse potential. These limiting factors are: cultural barriers and distrust; institutional fragmentation; inadequate regulatory frameworks; and the lack of appropriate tariffs, economic incentives and financial models, which undermines cost recovery and the sustainability of reuse projects.

The region also needs to increase efforts to collect and report standardized data across the formal and informal reuse sectors to provide more reliable and updated information, which is essential to develop proper diagnosis and effective policies for the safe and productive use of these resources.

Although water reuse in the region is currently limited, there are noteworthy water reuse success stories at different scales in and beyond the region. Subsequent chapters of this book analyze the economic, policy and social challenges to uncap the water reuse potential and suggest practical ways to address them.

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