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## CHAPTER 5

c0025

# Water reuse: A resource for Mediterranean agriculture

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### s0010 5.1 Introduction

p0075 The Mediterranean region is particularly vulnerable to the adverse consequences of multiple and mutually reinforcing structural changes that include global warming, biodiversity loss, soil erosion, and population growth. Many of these changes contribute to water scarcity, one the most pressing challenges the region is facing in the very near term. The southern and western shores of the Mediterranean, the Middle East, and North Africa (MENA) are already the most water-stressed regions in the world. But the European shore is not spared, as Greece, Cyprus, Macedonia, and Spain also top the list of the world's most water-stressed countries.<sup>a</sup> In many places, absolute water scarcity is compounded by a marked degradation in water quality due to pollution and salinization. The heightened competition over an increasingly scarce resource raises fears of social unrest and uncontrolled population flows.

p0080 If all economic sectors consume ever larger quantities of water, irrigated agriculture is still by far the largest user. Between 80% and 90% of all available water is consumed by irrigation in the southern shore, although that ratio is halved at the other end of the spectrum, in the case of France. Therefore, the widening gap between water supply and demand is primarily a challenge for food production, especially as all governments appear anxious to prioritize other uses (i.e., domestic and industrial) should a water shortage erupt.

p0085 To what extent, then, can water reuse be part of a broader policy mix aiming at providing food production with a larger and more reliable supply of water when the resource is limited and irregular? And, in addition to its strictly quantitative potential, under what hydrological, agronomic, institutional conditions can water be reused safely and at reasonable cost? Before giving an overall assessment, we should emphasize that the term

np0015 <sup>a</sup> For a regular updating of this list, and bearing in mind the shortcomings related to national averaging, see: <https://www.wri.org/applications/aqueduct/country-rankings/?indicator=bws>.

“water reuse” can be applied to a wide variety of situations. To begin with, the extent to which reused water is treated can vary considerably. Today, it has been calculated that a total of 36 million hectares worldwide (some 12% of all irrigated land) receive some urban wastewater; however, only around 15% of this water is deemed adequately treated [1]. When it is not, those who use wastewater typically disregard specific practices that might protect them or their consumers from health risks. Second, irrespective of whether it is adequately treated or not, wastewater can either be tapped at the point of rejection (direct reuse) or withdrawn a little farther away, mixed to varying degrees with surface or groundwater (indirect reuse). The latter is by far the most common, although it is not adequately captured by national statistics that define “reuse” only as direct reuse (Box 5.1). Finally, some projects are formally planned and regulated by state authorities while other types of uses occur informally, although in the latter case state officials may still exercise some measure of informal control. Again, and by definition, unplanned uses are not well captured by national statistics that focus on planned reuse. Thus, although examples of unplanned water reuse are common on the Southern shore of the Mediterranean, total wastewater reuse is only few volume of all officially quantified reclaimed wastewater.

p0090 Against this complex background, it should be noted that, over the past few decades, the development of more efficient treatment systems for domestic and industrial wastewater has made water reuse increasingly safe for human health, and an increasingly viable option in economic terms. Many projects now have an attractive cost-benefit ratio compared to the construction of dams that would provide a comparable volume of water.

b0010 **BOX 5.1 Main stages and types of wastewater treatment processes [2].**

- Before treatment, sewage usually goes through pretreatment to remove grit, grease, and gross solids that could hinder subsequent treatment stages.
- Next, *primary treatment* aims to settle and remove both organic and inorganic suspended solids. The most common primary treatments are primary settlers and septic tanks.
- During *secondary treatment*, soluble biodegradable organics are degraded and removed by bacteria and protozoa through (aerobic or anaerobic) biological processes. This process may include the removal of nutrients (mainly nitrogen and phosphorous). Typical secondary treatments include aerated lagoons, activated sludge, trickling filters, oxidation ditches, and other extensive processes such as constructed wetlands.
- *Tertiary treatment* aims at refining the effluent before it is discharged or reused and can include the removal of some nutrients and residual suspended matter by filtration, nutrients and residual suspended matter, or microorganisms (disinfection with chlorine, ozone, ultraviolet radiation, or others). Tertiary treatment can include membrane filtration (micro-, nano-, ultra- and reverse osmosis), infiltration/percolation, and activated carbon. This third stage/level seldom exists in low-income countries.

The potential for water reuse, and the fact that it could provide some good quality water in a reliable way throughout the year, is now widely recognized. However, water reuse can also be justified on grounds other than purely quantitative ones. At least three additional justifications are routinely given. First, wastewater supplies valuable additional nutrients (mainly nitrogen and phosphorus) to crops. Second, when officially organized, it can provide an additional source of revenue for water utilities. Third, it can be considered a supplementary treatment stage that improves the quality of water ultimately discharged into ecosystems. Given these rationales, it is important to take a careful look at how this resource is currently managed, to assess whether it can live up to its promises, and to think about possible ways to better harness it by combining legal reforms, policy incentives, technological improvements, and better management practices.

p0095 Despite the ancient and well-recognized use of wastewater around the Mediterranean, scientific knowledge is still in need of improvement, especially with respect to real practices on the ground. The aim of this chapter is to provide an overview of the current situation across the region, including the types of treatment processes, legal frameworks, policy orientations, irrigation practices, and agronomical performances. Some local cases are analyzed in greater detail. Finally, an integrated approach is recommended for future studies that includes environmental, economic, and equity considerations.

## s0015 **5.2 Water's second life for agriculture**

### s0020 **5.2.1 Definitions and qualities of water reuse**

p0100 Water reuse is probably as old as cities themselves. According to Angelakis et al. [3], domestic wastewater (sewage) has been used for irrigation by a number of civilizations since the beginning of the Bronze Age (around 3200–1100 BC), including cities in Egypt, Mesopotamia, and Crete. Later (around 1000 BC–AD 330), wastewater was used for irrigation and fertilization by both Greek and Roman civilizations, especially around major cities such as Athens and Rome. Throughout human history, the term “reuse” has referred to the use of raw or only partially treated wastewater for beneficial purposes, mostly in agriculture.

p0105 In recent decades, a fundamental change has taken place, as the diffusion of treatment plants has allowed treated water reuse to become an object of public policies. Many countries now consider water reuse as an important component of their overall water mix, mainly for the agricultural sector as irrigated area continues to expand [4, 5]. Countries like Jordan, where 87% of the safely treated wastewater is now reused directly or with little dilution, Israel, where treated wastewater accounted for 40% of all water used for irrigation in 2011, and to a lesser degree Tunisia, where about 25% of treated water is now reused, have become recognized leaders in this rapidly expanding field [6]. Israel, in particular, uses more than 300 Mm<sup>3</sup>/year of tertiary-treated effluents or secondary

chlorinated effluents in agricultural irrigation, mainly for industrial crops, cotton and fodder, citrus trees, cooked food, and unrestricted irrigation crops [7]. To put this volume into perspective, it represents about 40% of the total amount of treated water used in the whole European Union.

p0110 However, despite recent improvements, wastewater treatment is still far from being universal in the MENA region. For example, it is estimated that only 8% of the wastewater generated in Lebanon is treated. About 11% of the population benefits from safely managed wastewater systems in the northern and southern governorates, compared to only 7% and 3% in Greater Beirut and Bekaa, respectively [7]. This calls into question the possibility of planned water reuse under national regulations [7]. As a consequence, we are currently witnessing a wide array of modes of reuse that range from unplanned, small-scale use of raw wastewater for vegetable production in peri-urban areas of Morocco, Algeria, or Egypt, to the sophisticated use of ultra-purified water for sensitive crops such as vegetables in Italy. Box 5.1 below summarizes the main stages of standard wastewater treatment. Across the Mediterranean there are examples of all types of reuse levels, from no treatment at all to tertiary treatment. It should also be noted that a systemic evaluation of real performance of many treatment plants or disinfection technologies has not been undertaken and relevant information such as maintenance, costs, and safety is not available.

p0115 In the Mediterranean region, when urban areas expand without a concomitant increase in the wastewater treatment capacity, a large quantity of wastewater is discharged into surface water bodies with little or no treatment. Downstream irrigated areas then depend on these same water sources. The diverse modes of water reuse are summarized in Box 5.2. It should again be emphasized that the site-specific applicability of many disinfection technologies has not been evaluated and relevant information about maintenance, costs, safety, etc. is not available.

## s0025 **5.2.2 Key regional trends and figures**

p0120 In the following section, we have gathered a few key facts and figures regarding water reuse in four contrasted countries (Morocco, Jordan, France, and Algeria) to highlight the wide diversity of situations, issues, and current challenges. It is important to recognize the diversity because even though it is always possible for best practices to travel from one country to the next, local conditions should be duly analyzed: when it comes to water reuse, there can be no one size fits all.

### s0030 **5.2.2.1 Morocco**

p0125 Up until the beginning of the 21st century, public investments in urban water in Morocco focused mainly on universalizing access to drinking water, leaving aside the disposal and treatment of wastewater. However, informal reuse of raw water was common in many city peripheries including Meknès, Marrakesh, and Settat [12–14]. This

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### **BOX 5.2 Diversity of wastewater reuse on the Mediterranean rim.**

- Direct use of untreated wastewater occurs in areas where collective treatment plants are not in place and where alternatives are limited, usually in arid or semiarid areas. For example, these practices may involve direct pumping of raw wastewater into the pipe before it arrives at the treatment plant. The reasons for such uses may also be linked with the poor quality of conventional water resources (e.g., groundwater salinity) or the exorbitant cost of access to fresh water (e.g., pumping costs). Although officially banned in most countries, direct use of untreated wastewater occurs in many urban and peri-urban areas [8].
- Indirect or “de facto” use of untreated or treated wastewater is by far the most common type of use [2, 9]. In this case, untreated wastewater or wastewater from treatment plants is discharged into surface water streams and/or percolates to groundwater, where it dilutes and is subsequently used—most often unintentionally—by downstream farmers. For example, in the South of France, the estimated impact of wastewater effluents in the Montpellier river basin was estimated to vary between 1.5% and 51% on average, depending on flow conditions and seasons [10].
- The planned use of reclaimed water (treated wastewater) is typically driven by water scarcity, but where the environment is highly degraded, the reclaimed wastewater is also used to save fresh water and ecosystems. Reclaimed water can be used directly for many purposes such as irrigation, city landscaping, and golf courses. Along the Mediterranean rim, wastewater is rarely used for groundwater recharge or indirectly used for drinking purposes, as is the case of Windhoek in Namibia [11]. The planned use of reclaimed water is now one of the priorities in the Middle East and North African countries, as well as in the Eastern and Mediterranean countries.

changed markedly with the launching of the national sanitation plan in 2006 (French acronym PNA). The plan aimed to increase the overall treatment rate from a mere 8%–60% by 2020. This required building—and rehabilitating—some 187 plants by 2020, a target later increased to 330 by 2030, 145 of which were effectively operational in 2015 [15]. This opened up new opportunities for water reuse. The national water plan (French acronym PNE), released in 2009, forecasts a total volume of reusable wastewater of 424 Mm<sup>3</sup> by 2020 and 935 Mm<sup>3</sup> by 2030. The plan aimed to achieve a reuse rate of 19% by 2020 and 31% by 2030; at that time, this amounted to a total volume of reused water of 300 Mm<sup>3</sup>, later increased to 325 Mm<sup>3</sup>.

p0130 In 2017, 47.5 Mm<sup>3</sup> were effectively being reused in 24 different projects [16]; by far the most for golf resorts. The Cherifian Office of Phosphates also reuses treated water to wash its mineral rocks, while some cities, including Ouarzazate, use their treated water to irrigate their green spaces and green belts. After a number of small-scale experiments dating back to the early 1990s [17], three projects for agricultural use of treated water are now underway with treated water in Tiznit, Settat, and Oujda.

p0135 Aside from the national water plan, three different planning documents in 2017 dealt with wastewater reuse. The National Sanitation program for rural areas (French acronym PNAR) was prepared by the Ministry of the Interior. The National Plan for treated wastewater reuse (French acronym PNRUE) was drafted by the Water Department of the Ministry of Energy, Mines and Sustainable Development, and the National Plan for wastewater reuse in Agriculture (French acronym PDREUTI) issued by the Ministry of Agriculture. In 2018, these plans were merged into a single, comprehensive National Plan for Integrated Sanitation (French acronym PNAM). The new plan aims to reuse some 428Mm<sup>3</sup> of water by 2025, 474Mm<sup>3</sup> by 2030, and 573Mm<sup>3</sup> by 2040. This includes an objective of 134Mm<sup>3</sup> for agriculture to eventually irrigate a surface area of 15,363 ha.

p0140 Promising though these figures may seem on chapter, they overlook the fact that a significant amount of water is already being reused informally. Therefore, the claim that wastewater represents a previously “untapped” resource should be examined critically. As mentioned above, part of the difficulty involved stems from the lack of official, aggregate data on illegal uses. However, case studies in Settat, Marrakesh, and Tiznit have all shown that at least part of the raw wastewater is already used downstream. The new projects (for golfing resorts in Marrakesh, for agriculture in Settat and Tiznit) are undoubtedly safer, as they are formally organized around treatment plants. But they all entail some reallocation from previous users to new beneficiaries, and in one case at least (i.e., Marrakech) this reallocation clearly shifted upward, targeting wealthy international consumers. However, to go beyond such anecdotal evidence, we would need better aggregate data on *all* current uses, including information on the types and numbers of beneficiaries, and the incomes they derive from wastewater, whether directly (through productive uses) or indirectly (through the rental value of their land).

### s0035 5.2.2.2 Jordan

p0145 Jordan suffers from severe water scarcity, intensified by climate change and the continuous flow of refugees from Syria since 2011. Today the per capita supply of water is 140m<sup>3</sup>/capita/year while the threshold of severe water scarcity is 500m<sup>3</sup>/capita/year [18].

p0150 Water reuse in Jordan is not merely an option but a real necessity and most of the treated wastewater generated in the country is already used, directly or indirectly, for productive purposes, mainly in agriculture. The government is working to increase wastewater treatment capacity and the share of treated wastewater in its water budget. To this end, the government has created policies that allow better water (re)allocation across sectors in order to save more fresh water for domestic use [19].

p0155 There are 27 wastewater treatment plants in Jordan that currently serve 63% of Jordan’s population and produce 121 Mm<sup>3</sup>/year of treated wastewater [19]. The Al-Samra treatment plant alone generates about 80 Mm<sup>3</sup>/year, most of which is reused indirectly in

the Jordan Valley for unrestricted irrigation, after “dilution”<sup>b</sup> along the Al Zarqa Wadi and storage in the King Talal Dam. Much of the production in the Jordan Valley supplies international markets and preserving food safety in the valley is a government priority.

p0160 On the other hand, about 45 Mm<sup>3</sup>/year of treated wastewater is used in restricted irrigation to produce fodder crops and fruit trees in projects that experience low-cost recovery and whose long-term financial sustainability is questionable. There are opportunities to shift toward more economically efficient and productive reuse if economic barriers as well as formal constraints (rules and regulations) and informal constraints (behaviors and human capacity) are addressed [20].

### s0040 5.2.2.3 France

p0165 Currently, France only faces local and seasonal episodes of water resource deficits. Therefore, the reuse of wastewater is restricted to certain regions, and only about 40 treated wastewater (TWW) reuse projects were identified, most involving golf courses, production of turf and garden or agricultural irrigation. In 2014, the average daily volume of TWW reused in France was estimated at 19,200 m<sup>3</sup> (about 7 Mm<sup>3</sup> per year), representing about 0.1% of the total TWW produced and less than 0.3% of the all the water used for irrigation. The biggest agricultural projects are located in Clermont-Ferrand (central France), where 700 ha of seed maize, maize, red beet, and wheat are irrigated with 0.9 Mm<sup>3</sup> of TWW per year; and in Noirmoutier Island, where 320 ha of quality potatoes are irrigated with TWW, representing an average yearly volume of 0.38 Mm<sup>3</sup>. Actually, 20 golf courses are irrigated with TWW in France. The majority are located on the Atlantic coast where the main driver of these projects is the need to limit TWW discharge into the sea and the environment. The golf courses have access to this water resource all year round, whereas water restrictions often apply to conventional water resources in summer [21].

p0170 The use of TWW from waste water treatment plants (WWTPs) for agricultural irrigation, turf production, and garden irrigation has been regulated since 2010, but few projects emerged from the new water reuse regulation. The 2010 regulation introduced quality standards for TWW based on four quality levels (from A—high quality—to D).<sup>c</sup> The higher the risk of human exposure (valorization of the crops, type of irrigation), the higher the level of treatment required. The regulation was updated in 2014 to better account for the case of sprinkler irrigation techniques. It provides wind velocity limits at which irrigation should be stopped depending on the operating pressure in use, and stipulates safety distances that account for the maximum sprinkler range. Many new water reuse projects are planned for the coming years mainly concentrated close to the sea. In 2016, the Rhone-Mediterranean Water Agency launched call for projects to encourage local authorities

np0020 <sup>b</sup> Although dilution is actually negligible, particularly in the dry season, this practice enables the production of vegetables, which is forbidden by law in direct reuse schemes.

np0025 <sup>c</sup> French Law No. 2010-788 of 12 July 2010.



and industry to study and carry out projects to promote reuse. More than 47 projects were cofinanced. Many of the projects in this call remain experimental and research oriented. For example, setting up an experimental platform studies the impacts of water reuse on the agro-system in Murviel-Lès-Montpellier [22] or Saint Martin de Castillon.

s0045 **5.2.2.4 Algeria**

p0175 In June 2018, total production of domestic wastewater in Algeria was 1596 Mm<sup>3</sup>. Table 5.1 lists forecast indicators for the 2035 horizon based on the National Water Plan, which is used as a tool for water resources management in Algeria [24].

p0180 In 2018, the total volume of wastewater produced and managed by the Algerian wastewater treatment office (ONA) was more than 577 Mm<sup>3</sup>. The number of treatment plants also monitored by ONA was 148 for a treated volume of 123 Mm<sup>3</sup>.

p0185 The first legislative framework for the treatment of wastewater, named “Concession for the use of treated wastewaters for irrigation purposes,” dates from May 23rd, 2007 and provides a general framework for using these waters (definition of wastewater, sanitary controls, and financial agreement). An interministerial decree published in January 2012 lists the required properties of treated wastewater for irrigation purposes. It defines thresholds for microbiological parameters, physical parameters, chemical parameters, and heavy metals. These thresholds are inspired by WHO (World Health Organization) standards and are probably too inflexible for the Algerian context. Today, the number of treatment plants officially concerned by wastewater reuse is 17 and the volume reused is 8 Mm<sup>3</sup>. The formal reuse of wastewater for agricultural purposes started in 2007, meaning it is a relatively new practice. The total irrigated area covers more than 11,000 ha, particularly fruit trees (palm dates, olive, etc.) and some cereals. The most emblematic cases for controlled water reuse are Hennaya-Tlemcen in the North West and Guelma-Boucheouf in the north east, with 912 ha and 6980 ha of irrigated land, respectively. In both cases, water is released from an activated sludge plant into a river and then pumped to the plots.

p0190 Today, two major constraints on the expansion of reuse are the limited volume available for irrigation and the limitation to a secondary level of treatment in all the plants.

t0010 **Table 5.1** Predicted increase in the quantity of wastewater in Algeria [23].

Horizon	Total wastewater (Mm <sup>3</sup> /year)	Plant capacity (Mm <sup>3</sup> /year)	Treated wastewater (Mm <sup>3</sup> /year)
2020	1190 <sup>a</sup>	1060	650
2025	1360	1320	820
2030	1570	1510	1020
2035	1780	–	1625

np0010 <sup>a</sup>The expected volume was reached in 2012.

p0195 Unplanned reuse has not been officially quantified but a previous survey reported that 10% of the land in the high plains of Algeria received untreated wastewater [25]. This practice continued in many areas of the country until August 2018 when the use of wastewater was strictly prohibited due to an outbreak of cholera in the districts of Blida and Tipaza. Indeed, before this date, some drip irrigation systems used reclaimed wastewater to irrigate cucumber, tomato, and watermelon in Tipaza, particularly in the summer season (see Box 5.4). Much progress has been made in the last decade toward the safe use of treated wastewater to meet farmers' demand for irrigation water. However, further efforts are still required to bridge the gap between unplanned and planned practices.

### s0050 **5.3 The governance of wastewater reuse: Regulations, policies, and politics**

#### s0055 **5.3.1 A comparative overview of regulatory frameworks**

p0200 The 1970s were an important international landmark with respect to national regulations and guidelines for water reuse.<sup>d</sup> This critical juncture matters as it was also a period of increased awareness of both environmental and public health risks [26, 27]. The 1970s informed the way wastewater reuse has been framed up to now in international arenas of expertise, where concerns for possible effects on public health have fostered a cautious approach.

p0205 In 1973, the World Health Organization (WHO) released its first water reuse guidelines, which at that time, mostly targeted developing countries. In 1978, the State of California issued its own criteria for wastewater irrigation, which would soon prove to be very influential worldwide. By the end of the decade, the first national regulations specifically tailored for water reuse had been adopted in Tunisia, Italy, and Israel. These regulations subsequently increased in geographical scope and sophistication, with diffusion patterns in the Mediterranean displaying two notable features. First, temporally, government outputs intensified markedly following the second generation of WHO guidelines in 1989, and even more markedly from the beginning of the 2000s on. Second, spatially, no Mediterranean subregion appeared to advance more rapidly than the others. Thus, although scholars have found that at similar level of water stress, the adoption of *tangible projects* in wastewater reuse tended to be faster in countries with stronger economies [6], this does not appear to be the case for wastewater *regulations and policies*. Regarding the latter, national idiosyncrasies have mattered most, under the key influence of international standards and guidelines. Table 5.2 provides a timeline of selected water reuse regulations and national strategies in the Mediterranean region.

np0030 <sup>d</sup> Although the State of California, a pioneer regarding water reuse, originally introduced regulations in 1918.

10015 **Table 5.2** Timeline of selected water reuse regulations and strategies in the Mediterranean region.

1973	WHO releases water reuse guidelines that include quality thresholds (100 FC/100 mL) and treatment requirements for several uses, including crop irrigation and potable reuse ( <i>Reuse of effluents: Methods of wastewater treatment and public health safeguards</i> )
1975	The Tunisian Water Act (n° 75-16): the way for water reuse
1977	Italy regulates water reuse for irrigation and describes extensive treatment processes (CITAI, February 4th and February 21st 1977, n° 48)
1978	Following older regulations, the State of California issues its influential criteria for wastewater reclamation for reuse ( <i>Wastewater reclamation criteria, title 22, division 4: Environmental Health</i> )
1978	Israel issues regulations for water reuse in irrigation that define treatment requirements, quality limits (unrestricted irrigation: 12 FC/100 mL in 80% of samples; 2.2 FC/100 mL in 50% of samples), crops, and additional barriers
1985	FAO releases its “Water Quality for Agriculture” guidelines [28]
1987–1992	The fourth European environmental action program encourages water reuse
1989	First WHO revision of water reuse guidelines (unrestricted irrigation: 1000 FC/100 mL; <1 nematode egg/L) based on the conclusions of the previous reports [29]
1989	Tunisia issues standards for water reused in irrigation based on FAO (1985) and WHO (1989) guidelines for restricted irrigation (<1 nematode egg/l) and a multibarrier approach
1991	French recommendations for water reuse based on WHO guidelines (Circular n° 51 dated July 22, 1991, issued by the Ministry of Health)
1999	Revised Israel regulations: Unrestricted irrigation <1 FC/100 mL and a multibarrier approach [30]
2002	Moroccan regulations on water quality for irrigation (both for natural water and wastewater)
2003	WHO State of the Art Report on Artificial Recharge of Groundwater with Recycled Water [31]
2003	Revised Italian regulations for water reuse (Ministerial Decree n° 185/2003)
2005	Cyprus issues criteria for water reuse in agriculture (Decree n° 296/03.06.05)
2006	WHO releases its second revision of water reuse guidelines on Treated Wastewater in Agriculture: Risk analysis and management, which adopt a quantitative risk assessment methodology [32]
2006	Portugal releases regulations for water reuse (Portuguese Standard NP 4434)
2007	Spain issues water reuse regulations (Royal Decree 1620/2007)
2010	France sets out water reuse criteria ( <i>arrêté du 2 août 2010</i> )
2011	The National Health and Medical Research Council and National Resource Management Ministerial Council publish Australian Drinking Water Guidelines
2011	Greece issues water reuse regulations (the 145,116 Common Ministerial Decision, March 2011)

**Table 5.2** Timeline of selected water reuse regulations and strategies in the Mediterranean region—cont'd

	<b>WHO releases water reuse guidelines that include quality thresholds (100 FC/100 mL) and treatment requirements for several uses, including crop irrigation and potable reuse (<i>Reuse of effluents: Methods of wastewater treatment and public health safeguards</i>)</b>
<b>1973</b>	
2012	National Strategy for wastewater, including wastewater reuse, in Lebanon ( <i>Stratégie nationale du secteur de l'eau</i> )
2014	Revised French water reuse regulation ( <i>arrêté du 25 juin 2014</i> )
2017	World Health Organization, Geneva, Potable Reuse: Guidance for Producing Safe Drinking Water
2018	EU minimum water quality requirements for irrigation and aquifer recharge. An EU legislative proposal will be published in the near future

Based on A.N. Angelakis, T. Asano, A. Bahri, B.E. Jimenez, G. Tchobanoglous, Water reuse: from ancient to modern times and the future, *Front. Environ. Sci.* 6 (May) 2018; J. Fawell, K. Le Corre, and P. Jeffrey, Common or independent? The debate over regulations and standards for water reuse in Europe, *Int. J. Water Resour. Dev.* 32 (2016) 559–572; WWAP (United Nations World Water Assessment Programme), The United Nations World Water Development Report 2017: Wastewater, The Untapped Resource, UNESCO, Paris, 2017.

p0210 Although the timeline may give the impression that national regulations are broadly homogeneous, this is far from true. Rather, from the outset, the two benchmark guidelines, the California guidelines [33] and the WHO guidelines [29], have represented two contrasting approaches to water reuse. The California guidelines are stricter. They are based on the premise that pathogenic microorganisms can survive for weeks in the soil and on crops, implying that the detection of any of these organisms is sufficient to constitute a public health problem (see Section 5.4.1). This leads to stringent requirements regarding, for example, chlorine disinfection of any reused water that may come into contact with the edible portion of the crop [34]. This “zero risk” approach therefore calls for the “best available technology” [35]. By contrast, WHO guidelines are more flexible, following a “calculated risk” approach. They consider irrigation as an additional treatment stage in itself, while farming, harvesting, and hygiene practices are also considered as key components of risk mitigation [36]. This “multibarrier” approach involves a wider array of guidelines applying to all stages of the reuse process. It also tolerates up to 1000 fecal coliforms (FCs) per 100 mL for unrestricted irrigation of any crop, and for *Escherichia coli*, a limit of  $10^4$  colony forming units (CFUs) per 100 mL for wastewater used to irrigate vegetables consumed as fresh food [32, 37]. According to WHO guidelines, and different from Californian standards, this can be achieved through a series of stabilization ponds, for example [37].

p0215 National standards in the Mediterranean region derived either from the Californian model (e.g., Greece, Cyprus, and Italy), from the WHO criteria (e.g., France, Morocco, Tunisia), or from a combination of the two (e.g., Spain and Portugal) [38]. Italy is perhaps the best example of the “zero risk” approach. It defines limits

for 54 different parameters, 37% of which are not considered for drinking water analysis. This is in sharp contrast to Israel, the leading country in water reuse, which monitors less than a dozen parameters [39] but requires the construction of barriers to contamination based on a range of technical practices (level of treatment, type and contact with the crop/produce, type of irrigation technique). Some limits defined by the Italian regulations are very strict, such as the parameters for BOD5 (< 20 mg/L), total suspended solids (< 10 mg/L), and *E. coli* (< 10 CFU/100 mL for conventional treatment systems). Not surprisingly, the number of parameters to be monitored is said to have negatively affected the total volume of reused water in the country [40]. It can also push actors toward informal practices, as is apparently the case in Milan. The current proposal for a future European Directive on the “Regulation on minimum requirements for water reuse” [41] leans more on the stringent side for pathogens, beyond the bathing water quality regulation, albeit less so than the Italian case. At least 11 out of 22 Arab States have adopted legislation permitting the use of reclaimed wastewater, issued by the national institutions responsible for the use and discharge of wastewater, the ministries responsible for the environment in Kuwait, Lebanon and Oman, health in Iraq, agriculture in Tunisia, housing in Egypt, and the institutes responsible for standards in Jordan and Yemen [32].

p0220 National regulatory frameworks do not only vary according to their stringency. They also differ in the types of use authorized, as illustrated by Table 5.3.

p0225 For some observers, the high level of discrepancy between national standards may well be the single biggest impediment to the expansion of treated water reuse across the Mediterranean [39, 42]. As a consequence, the same authors commonly call for more international harmonization. In their opinion, harmonization should preferably occur around flexible and realistic regulatory frameworks that avoid unnecessarily restrictive standards [43]. More recently, a “one water” concept has been gaining momentum among sanitation engineers. It asserts that standards should be established as a function of the category of water use, independently of the water source or origin [44]. However, disagreements over regulations are only one type of institutional challenge that, in some cases, may hinder the expansion of treated wastewater reuse. The lack of clarity and/or dispersion of formal prerogatives, for example over who is in charge of setting rates, are another. They test the institutional capacity to design integrated policies around water reuse, beyond the accumulation of specific regulations.

### s0060 5.3.2 From regulations to policies

p0230 Wastewater reuse is, by definition, an issue that straddles many policy sectors including sanitation and plant management, water resources at a broader scale, public works, agriculture, the Interior, Public health and the Environment. The exact distribution of prerogatives among these sectors is far from straightforward. Rather, it tends to vary greatly, not only

t0020 **Table 5.3** Authorized uses for wastewater in the Mediterranean countries.

	Algeria	Cyprus	Egypt	France	Greece	Israel	Italy	Jordan	Lebanon	Morocco	Portugal	Spain	Syria	Tunisia	West bank
Agricultural irrigation	Authorized	Authorized	R+ P+E	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	R+ P	R	R
Landscape irrigation/ golf courses	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized
Aquifer recharge <sup>a</sup>	Forbidden	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	*	Authorized	Authorized
Environment	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized
Industrial recycling	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized
Urban use	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized
Domestic use	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized
Potable water	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized	Authorized

	Authorized
	Forbidden
	Unregulated

<sup>a</sup> Aquifers exploited for drinking water.

R, products eaten raw; F, fruit without pericarp; E, crops for export; P, pasture.  
Based on N. Condom, M. Lefebvre, L. Vandome, "La réutilisation des eaux usées traitées en Méditerranée: retour d'expériences et aide à l'élaboration de projets". Plan Bleu, Valbonne (Les Cahiers du Plan Bleu 11), 2012.

from country to country but also from one project to the next in the same country. For the sake of clarity, at least five key areas of prerogatives should be distinguished: (i) who proposes and designs the basic sociophysical parameters of the project (i.e., location, surface area, beneficiaries, mode of water reuse)? (ii) who authorizes the project after assessing its social desirability and whether it complies with existing regulations? (iii) who decides who pays what in upfront investments, operation, and maintenance? (iv) who operates and maintains the project? (v) who subsequently monitors water quality and its impacts on soil, crops, and human health? (vi) who assumes the responsibility of any unintended dispersion of contaminant?

p0235 In many countries, at least some of these areas of prerogatives lack clear lines of responsibility and accountability. In Morocco, for example, there is no formally agreed-upon process for formulating and designing new projects. Thus, in the case of Settat, near Casablanca, the governor and the river basin agency happened to play a central role in defining the basic components of the project, while in Tiznit, both the municipality and the agricultural administration happened to play a more prominent role [14]. This matters because even with the most up-to-date regulatory framework, insufficient guidelines (and “ownership” of their various steps) can impede projects. When responsibilities and criteria for decision-making are blurred, risk-averse public officials are more likely to reject a water reuse project due to concern for their own position and unwillingness to breach perceived water management norms on quality and safety [45].

p0240 Conversely, countries in which treated water reuse is more widely used are also those with clearer lines of authority.<sup>c</sup> In Tunisia, for instance, regional departments of agriculture (French acronym CRDA) built and have maintained their authority concerning water reuse for agriculture (Box 5.3).

### b0020 **BOX 5.3 Wastewater policy in Tunisia.**

p0055 Tunisia has been developing planned water reuse since the 1960s. In the aftermath of its 1975 water act, it launched an ambitious national program. More specific standards for the treatment, distribution, and quality control of the recycled water were set up in 1989 [46]. As these dates indicate, Tunisia closely followed the WHO guidelines and their focus on public health. It forbids the use of wastewater that is only treated to secondary level (which includes most Tunisian wastewater, which is treated at this level through activated sludge) for irrigating vegetables. Regional departments of agriculture (CRDA) supervise the treated water reuse projects for agriculture in their jurisdiction and collect water fees from water users' associations (GDA) based on the volume of water delivered.

p0060 As a consequence, in 2016, about 30% of reclaimed wastewater was being recycled, most of it to irrigate 8415 ha of farmland (industrial, fodder and tree crops, and cereals) and 1040 ha of golf courses. Many other projects are planned, with the objective of covering some 30,000 ha over the next few years. However, mainly because of restrictions on vegetables, many farmers continue to prefer to irrigate using well water. Farmers in the southern driest part of the country also express concern regarding the long-term effects of using salty wastewater on their soils. To address these problems, Tunisian policy-makers are currently rethinking their national regulations and strategy.

np0035 <sup>c</sup> Authority, here, should be taken in its original, Weberian sense as combining legitimacy to exercise decision-making power and a capacity to do so.

p0245 Aside from fuzziness in institutional prerogatives, lack of proper coordination can also be a serious impediment and, as such, has been widely criticized. It is linked to a lack of institutional arrangements concerning water cycle management in general, without which the potential for water reuse cannot be adequately assessed. At the national level, overcoming this shortcoming requires creating a functional interministerial committee, with a permanent secretary, regular follow-up meetings, and clear decision-making rules. Second-order coordination is also easier once an overarching policy has been adopted. This is why many Mediterranean countries are seeking to transition from mere regulatory frameworks to integrated national strategies. Lebanon is a case in point. Its national strategy for sanitation, passed in 2012, combined a program for building treatment plants (as only 8% of wastewater is currently safely treated) with a detailed list of priority reuse projects and financial mechanisms. Expenditures were expected to total US\$ 3.1 billion. However, program implementation was interrupted by political uncertainties and the fallout of the Syrian conflict. In February 2016, Jordan also passed a “national policy for water substitution and reuse.” It provides detailed guidelines for water rates, both for “pure” wastewater and for wastewater mixed with more conventional waters [47]. It also sets up specific decentralized arrangements for small cities.

p0250 At the local level, the efficiency of a reuse project can only be improved by incorporating water reuse projects in sanitation plans and master plans for water management at the basin level right from the outset. A number of reuse projects have been hampered or rendered impossible by the failure to plan wastewater treatment, reuse, and disposal together in a consistent way. Administrative reorganization may be necessary but in itself is not enough to prevent such situations arising. Rationalizing integrated water management and planning requires new tools: integrated technical-economic models and decision-making tools to work out and compare different water management scenarios, for example, technical-economic evaluation and comparing wastewater reuse options with other alternatives [48]. However, we should be fully aware that these optimization strategies have their limits: in so far as recycling projects allocate costs and benefits, while redistributing decision-making power and social legitimacy, they are inescapably political. The politics are managed differently depending on local, national, and even international political-institutional environments in Mediterranean countries.

### s0065 **5.3.3 Beyond optimization: The politics of treated water reuse projects**

p0255 So far, most studies of wastewater reuse have prioritized a technical focus, that is, the performance of treatment processes and, more recently, impacts on human health. As for the—more limited—social science literature, it has mostly operated under the assumption that treated water reuse was self-evidently beneficial, and therefore centered on explaining why it had not yet developed further. In so doing, it has largely framed its issue of concern as an acceptance problem (for a detailed review, see Ref. [49]).



p0260 For example, a recent public consultation report compiled by Deloitte for the European Commission [50] highlighted that, while around 70% of respondents thought water reuse was valuable for adaptation to climate change and resource efficiency, only 30% were in favor of water reuse involving contact with food and people. To overcome this social “barrier,” Po et al. [51] show that the worries harbored by the European population diminish notably when awareness and knowledge increase and residents can make an “informed choice,” with awareness campaigns and information seen as instrumental in moving away from seemingly emotional [52] public responses. However, this public acceptance literature has two limits.

p0265 First, it has focused mostly on advanced, especially European countries, leaving aside countries located on the southern and eastern shores of the Mediterranean. This matters because very often, in these countries, treated wastewater reuse replaces previous irrigation with untreated wastewater. Trajectories are therefore unmistakably positive, which can only increase the level of social acceptance. However, anecdotal evidence in Settat, Morocco, point to a 10%–15% discount for parsley irrigated with treated wastewater on the local market. Some farmers, however, reported increased prices because the parsley looked greener. In any case, the lack of traceability prevents any observation of consumers’ acceptance beyond local markets, as consumers are seldom aware of the mode of irrigation used for the product they buy.

p0270 Second, the social dimension of water reuse cannot be reduced to an acceptance problem, for it is, just like any infrastructure project, an inherently political issue. The first sensitive issue concerns the selection of beneficiaries: how to justify the inclusion of some and the exclusion of others, invoking a greater good in a way that might be broadly considered acceptable? This question arises especially in agriculture, where the production of new water resources with potentially important fertilizing properties is bound to generate strategies of appropriation and control by interested actors. In Settat, for example, the selection of beneficiaries caused considerable controversy, as before the treatment plant was built, the raw wastewater was collected by farmers who flanked the river. However, both the plant and the new perimeter were located downstream from this former territory, thereby depriving these farmers of irrigation water, and in the process cutting by half the rental value of their land. Financial compensations were discussed but not implemented. A similar process happened in Marrakech where wastewater used to irrigate golf courses no longer benefited farmers who used it to grow wheat and olive trees downstream [13].

p0275 Another issue relates to political accountability. Who should take the blame, and the related economic costs, if a project malfunctions, be it due to reduced water quality, a decrease in farm outputs due to an increase in salinity, an outbreak of cholera or complaints related to bad smells or even visual pollution (as happened in Marrakesh where clients complained about algae development on the ponds)? Given the difficulty of properly assessing risks and proposing adequate remedies, different stakeholders can be

expected to engage in blame avoidance strategies [53]. These strategies may include scapegoating (blaming others), passing the buck (forcing somebody else to take the blame), wholesale defection (starting to criticize the whole project as misguided), and circling the wagon (co-opting dissent to contain blame, even at the cost of not solving the problem).

p0280 However, the opposite dynamics, namely credit claiming, is also pervasive, in so far as treated water reuse projects deliver socially valued benefits. In this respect, initiating a project can be a way to enhance one's organizational standing, as may be the case for river basin agencies in Morocco, whose position within the water subsystem is structurally fragile. Likewise, leading a wastewater users' association can strengthen one's social visibility and status. Here the logic tends to be self-reinforcing: leaders tend to already be notables, as members trust them more to represent their interests vis-a-vis State agencies; but assuming these responsibilities leads them, in turn, to accumulate more social legitimacy. This legitimacy might be later used for other pursuits, including a local political career.

p0285 Finally, the politics of treated water reuse project revolves a lot around issues of political economy, as the way costs are distributed can be hotly debated (see Section 5.4.3).

## s0070 **5.4 Field issues related to sustainable water reuse**

p0290 The sustainability of water reuse in agriculture is strongly dependent on the farmer and irrigation practices, and more generally on the capacity of the irrigation system manager to control unintended impacts. Therefore it mainly relies on the irrigation technology selected, its design management, and maintenance that will result in homogeneous water distribution, in space (uniformity of water application) and over time (proper irrigation scheduling). The impacts on soil, plants, and the environment will then be easier to manage. These impacts need to be identified clearly, considered and managed transparently to improve public awareness and perception of WWR.

### s0075 **5.4.1 Irrigation technologies and reuse practices**

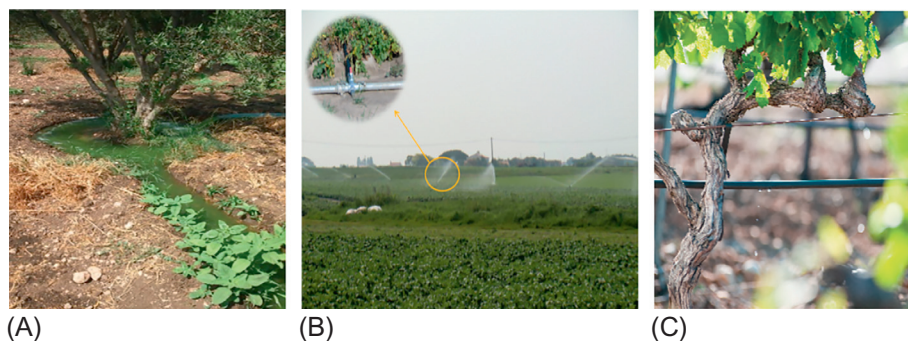
p0295 In Mediterranean countries, voluntarist policies for modernizing irrigation technologies used by farmers are being implemented, and may even provide comprehensive financial support for the purchase of said water-saving irrigation equipment. However, reality is never idyllic and performances are often far below expectations [54]. The same applies to old equipment whose distribution performance is so bad that water use efficiency can fall to under 50% (irrigation efficiency can be defined as the proportion of water applied that is effectively used by the crop for its growth). This poses environmental as well as agromonomical problems in the case of salty waters that will be reinforced when wastewater is reused in semiarid regions (i.e., where winter rainfall is not sufficient to leach out excess salt).

p0300 It is thus crucial to maintain, or achieve, a high level of water use efficiency in agriculture by implementing consistent resource management through: (i) well understood and applied scheduling methods, (ii) properly designed and managed irrigation systems, and (iii) adapted maintenance methods, preferably preventive rather than curative. When reusing wastewater, any drop in irrigation efficiency may result in pollution or contamination through unintended or prolonged contact with the product, dispersion or runoff of contaminated water, bad use of nutrients, and accumulation of salt or micropollutants that may later be leached to the groundwater.

p0305 The efficiency concept can apply at different spatial scales (from the irrigation block or perimeter to the river basin); here, we focus on the plot scale. It should be noted that the question of irrigation efficiency is still the subject of debate, as a high level of efficiency does not necessarily imply significant water savings. This will depend on the spatial scale addressed, for example in gravity irrigation, efficiency may be poor when up to 50% of the water flows out of the plot (5%–10% in drip irrigation), but is much better at a larger scale, given that the outflow will be used in plots downstream [55].

s0080 **5.4.1.1 Design and management of irrigation systems**

p0310 On the farm, the use of wastewater involves additional constraints. For example, depending on the treatment process, the irrigation systems need to be designed to take into account the rich nutrient concentrations and suspended solids [56], or the unintentional dispersion of pollutants (pathogens, bacteria and antibiotic resistance genes, etc.). In several of the Mediterranean countries, regulations for the use of wastewater were established based on an integrated approach to irrigation technologies (Fig. 5.1). This is the case in France where constraints inherent in irrigation technology were taken into account in the regulation (the law of August 2, 2010, revised on June 25, 2014); the same applies for Israel where the irrigation technology neither or nor plays a role of barrier. Three distinct irrigation methods are available for water application in agriculture:



r0010 **Fig. 5.1** (A) Surface irrigation on olive trees, Morocco, (B) sprinkler irrigation on potatoes, France, and (C) drip irrigation on vineyard with reclaimed wastewater, France.

surface/gravity irrigation, pressurized sprinkler irrigation, and drip irrigation. These three methods are able to reach good level of efficiencies (typically up to 90% for drip and sprinkler and up to 75% for surface irrigation). Cost is also highly variable, mainly human time for surface irrigation, mostly capital for pressurized. The observed life duration varies also greatly depending on maintenance, water quality, and sensitivity of the technique. Each has benefits and risks in the wastewater reuse cases. These sources of variability in technological performance of WWR projects can be effectively controlled applying suitable management and maintenance practices designed to decrease the potential level of hazards.

p0315 Gravity or surface irrigation (immersion, furrow, etc.) is still the most widely used technique in Mediterranean agriculture and in the world, despite billions of dollars of government subsidies for pressurized irrigation systems [55]. Gravity systems take advantage of the potential energy of water to flood the plots as homogeneously as possible through soil leveling, regulating plot inlet flow, and the length of the irrigation turn. This technology is the lowest cost technology, requires field practices that are well known traditionally, and restricts any pathogens or pollutants aerial dispersion. This technique is insensitive to any clogging related to water quality. In gravity irrigation, the main problems are avoiding (i) both under-irrigated and over-irrigated zones, to prevent salinization and water logging, which may result in progressive soil clogging and accumulation of different pollutants (this will be obtained through a consistent field or furrows leveling); (ii) direct contact with the product: root crops mainly and the farmer/operator. Consequently, surface irrigation with wastewater is usually limited to unplanned or indirect reuse.

p0320 Sprinkler irrigation, which tends to reproduce homogeneous rainfall over the entire plot (field crops) or restricted area explored by the roots (trees), limits potential contact between the irrigator and contaminated water. But hazards are related to the unintentional release of effluents in fine droplets that may contain pathogens or other harmful contaminants when sprinklers operate under different wind regimes [57]. National regulations generally require high water quality (pathogen reduction) and advanced treatments before permitting reuse of wastewater for agricultural purposes. In sprinkler irrigation, the point of concerns relate to (i) the quantification of airborne dissemination of fine droplets through drift and transport that may contain pathogens and pollutant [57], (ii) the management of instantaneous application rate (rainfall intensity and kinetic energy) that may result in runoff, (iii) the range of sprinkler and spacing between them to achieve a good uniformity, (iv) the setting of pressure to limit drift volume potential under windy conditions, (v) the position of sprinklers (over/under crop canopy) and resulting contact/contamination of leaves and production.

p0325 Drip irrigation is widely promoted as a way to improve plot-level water efficiency [58], which is true when the equipment is new but also depends on farmer practices

[54]. Drip irrigation has the potential for much greater efficiency than other irrigation techniques because water is applied directly in the immediate vicinity of the plant, thereby increasing water productivity [59]. Drip irrigation systems can also improve nutrient use efficiency (through fertigation), reduce energy requirements, and improve cultivation practices [60]. In water reuse, this technology is considered the best option in terms of protection against contact with and dispersion of pathogens. Nevertheless, the long-term sustainability of drip irrigation is not yet ensured. The presence of nutrients and ions in wastewater increases the possibility of chemical precipitation and of the development of biofilm in the drippers [61–65]. In addition, clogging due to sedimentation of suspended solids can rapidly lead to a significant decrease in distribution performance [66, 67]. At the field level, the additional concentration of solids in wastewater compared to conventional water is not necessarily taken into account in the design and installation of the equipment (high-flow rate drippers, filtration, etc.) or in the maintenance protocols for drip irrigation systems (by chlorination and acidification). This can mean rapid loss of investment and subsidies for drip installation or the massive use of disposable dripper systems (3–6 months of shelf life?), which is not environmentally satisfactory. A better understanding of clogging phenomena and maintenance solutions requires further research into flow topology within narrow labyrinth channels, biofilm characteristics, and response mechanisms that account for both nutrient transport and hydraulic shear forces, and into chemical precipitation. In addition, research is also required into the barrier or assumed “positive” effects of biological fouling of pipes and drippers by reducing pathogenic or chemical pollution [22].

s0085 **5.4.2 Environmental, agro-systems, sanitary and risk aspects**

p0330 The impact of the quality of irrigation water is the most important issue to address in the case of water reuse projects. The management of risks may determine the perception and hence the acceptability of these practices. Depending on the category of wastewater, impacts on health, the environment, agricultural yields, and economic-technological criteria can be positive or negative. The success and sustainability of water reuse projects in Mediterranean countries will depend to a great extent on controlling these factors.

s0090 **5.4.2.1 Environmental impacts**

p0335 From an environmental point of view too, the impacts of water reuse in agriculture can be positive and negative. Virtuous agricultural practices, consistent irrigation management, and efficient treatments will limit the impact of water reuse on the environment [5] and make it possible to reserve good quality water for more sensitive uses such as drinking water. Regarding impacts on the soil, reusing wastewater can progressively increase the salt content in the soil, jeopardizing soil stability and changing its osmotic properties. Excessive salt content will lead to dispersion of soil aggregates, reduce

hydraulic conductivity and aeration of the soil matrix [68]. Further, groundwater pollution is highly dependent on biogeochemical processes in the unsaturated zone. These points are critical for the protection of soil fertility against salinization, alkalization, and degradation of the soil structure. The influence of water reuse on agricultural soils properties is mainly due to its content: nutrients (mainly nitrogen and phosphorus), dissolved salts (sodium, boron, etc.), and other constituents such as heavy metals that may accumulate in the soil over time. Regarding salts, in arid or semiarid conditions, they may accumulate in the root zone because of the absence of leaching which occurs when winter rainfall exceeds the soil water holding capacity. Over time, the absence of leaching may have harmful impacts on soil biological and chemical activity and hence on crop yields. The problem of soil salinity and sodicity can be solved by increasing the soil mineral retention capacity through the application of natural (manure, compost) or artificial soil conditioners (e.g., polyacrylamide compounds [69]). However, such soil reclamation measures are costly, adding an economic burden that reduces in crop financial productivity.

p0340 At the other end of the scale, over-irrigation using wastewater can damage the quality of groundwater resources in the long run through the delivery of excess nutrients and salts caused by wastewater leaching below the plant root zone [70]. Particularly if the farmers' fertilization practices do not take the nutrient concentrations in wastewater into account. Pollution effects will also depend on factors including the depth of the groundwater table, soil hydraulic conductivity, and the quality of the wastewater used for irrigation. Thus, the potential for groundwater contamination needs to be evaluated before starting on a major wastewater irrigation program. In addition to the accretion of salts and nitrates, wastewater irrigation can, under certain conditions, transfer pathogenic bacteria and viruses to groundwater, that is, in karst systems. However, it should be noted that wastewater can be also reused for artificial groundwater recharge, as was the case of the coastal groundwater of Korba, Cap-Bon, Tunisia [71] or as a coastal barrier against seawater intrusion.

s0095 **5.4.2.2 Impacts on plants**

p0345 Concerning agronomic issues, several studies of water reuse in agriculture have been performed on different crops including some eaten raw, such as lettuce [72], lemon [73], eggplant, and tomato [40]. The authors of these studies concluded that, beyond the benefits of using reclaimed wastewater for irrigation, such as increased soil nutrients, increased crop yield and reduced doses of fertilizer, depending on the level of wastewater treatments, some drawbacks including soil salinization, contamination of sensitive crops (vegetable crops) by pathogens and loss of soil infiltration capacity remain a concern [73]. Regarding nutrients, in their study, Qadir et al. [74] reported that for every 1000 m<sup>3</sup> of reclaimed wastewater, from 4 to 24 kg of phosphorus, 16 to 62 kg of nitrogen, 2 to 69 kg of potassium, plus 18 to 208 kg of calcium, 9 to 110 kg of

magnesium, and 27 to 182 kg of sodium may have positive or negative effects when accumulated. If using wastewater is well managed, it is a form of a fertigation that can reduce the need for chemical fertilizer and save money. From an agronomical point of view, in a controlled experimental system under semiarid conditions in Sicily, Italy, Cirelli et al. [40] demonstrated that reclaimed wastewater can increase tomato yield by 20% in comparison with crops using conventional water. In contrast, eggplants were shown to be very sensitive (with a reduction in yield of around 22%) due to clogging of the drippers caused by calcium carbonate precipitation and high pH. Clogging resulted in plant water stress and a decrease in the quality of the eggplant produced. However, studies that account for farmers' adaptations and practices at the scale of large fields irrigated using wastewater in Mediterranean context and assess crop yield are rare, and farmers' practices and their effects on productivity call for further investigations involving extension services along with researchers.

#### s0100 **5.4.2.3 Health impacts**

p0350 Concerning the impact of irrigation with wastewater on health, as shown by the examples in different Mediterranean countries reported in this chapter, knowledge of wastewater reuse and management of health risk varies with the regional context and with the country concerned. In the many water reuse projects in Jordan or Tunisia with adequate treatment levels and appropriate irrigation practices, no diseases associated with wastewater reuse have been reported. In addition, current treatment technologies are able to reduce the concentration of pathogens in water below the level of detection used by the monitoring methods. However, national regulations require careful monitoring of parameters, usually based on WHO recommendations, but these can be difficult to apply in practice (too many parameters to monitor at reasonable cost, very few long-term experiments) and are not enforced in the case of unplanned or indirect water reuse. Where the wastewater treatment process is not effective or is absent, it is suspected that many pathogenic microorganisms (bacteria, parasites, viruses) are transported and disseminated by wastewater, which can lead to diseases or to the contamination of farmers and consumers. This is rendered even more complicated by the huge variability of wastewater microbiological composition depending on the season, the origin of the water collected, the health status of the population, and on the wastewater treatment process itself and its efficacy (see Box 5.4). In addition, the irrigation technologies and type of crop (e.g., if the edible part is in contact with the soil) will play a key role in the level of transmission of these pathogenic microorganisms. When distributed by sprinklers, dispersion on the soil and possibly on fruits and the aerosolization process are taken into consideration, while in the case of drip irrigation, contact with the soil is the point of vigilance. The detection and exhaustive quantification of these pathogenic microorganisms is very difficult. This is the reason why only indicators are to be monitored [36, 75]. In water reuse regulations or guidelines this mainly concerns [36]:

b0025

#### **BOX 5.4 Cholera crisis in Algeria summer 2018.**

p0065

In summer 2018, a severe cholera outbreak occurred in the small village of Sidi Kebir located in the district of Tipaza, and rapidly spread to the city of Blida not far from Algiers. The unplanned use of wastewater in agriculture was immediately suspected of being responsible for the death of a number of people. The Algerian authorities rapidly prohibited the use of wastewater for irrigation throughout the country but the consumption of summer crops particularly watermelon also decreased drastically. The halt to the unplanned reuse of wastewater did not account for the level of wastewater treatment, dilution with surface water, or after a sanitary analysis of real crop contamination by vibrio cholera.

p0070

Today, only state planned cases of wastewater reuse are authorized and the public policy is focused on developing the tertiary treatment stage in wastewater treatment plants. In conclusion, the general perception is that cholera is closely linked to poor wastewater reuse practices in agriculture and that farmers should find another resource when safe waters are not available. Yet, the validity of crop contamination remains to be analyzed.

u0045 • Bacteriophage viruses (Somatic Coliphages, RNA-F Coliphages),

u0050 • Bacteria (thermotolerant coliforms, *Escherichia coli*, intestinal Enterococci),

u0055 • Protozoa (*Clostridium perfringens*)

u0060 • Helminthes (*Ascaris* eggs).

p0375 The main factors involved in exposure to pathogens are ingestion of wastewater, consumption of food that has been in contact with wastewater, or inhalation of bioaerosols contaminated with pathogens. Several issues remain to be addressed, including the multiple barrier effects after treatment or storage, the dynamics of contaminants during water transport and irrigation [22, 76] and effects on soil microbiota, which have also been ignored in most water reuse irrigation studies. In a context of reusing untreated or nonoptimal wastewater, the effects of these biological contaminants (human and animal pathogens, phytopathogens, antibiotic-resistant bacteria, and antibiotic resistance genes) are rarely studied at large field scale.

p0380 In addition to microorganisms, it should be noted that despite national regulations, industrial wastewaters are rarely pretreated or separated from urban wastewater in the Mediterranean region. Microcontaminants are also widely found in urban wastewater, including pharmaceuticals, antibiotics, chemicals from personal care products, endocrine-disrupting compounds, plasticizers, flame retardants, surfactants, illicit drugs, transformation products, and pesticides. Although the concentrations are usually very low (in the nanomolar range), their impacts on ecosystems and human health have not been extensively studied to date. Of course, industrial wastewater may present a more serious threat because certain chemicals may be present at higher concentrations. In the case of endocrine disrupting compounds, for example, these can mimic the activity of certain hormones and interfere with endocrine system functioning. Concerning



micropollutants, in Europe, many discussions are underway to decide if it is necessary to add this list of pollutants in the water reuse regulations. Many of these substances are resistant to conventional wastewater treatment and persist in the environment. They are spread during irrigation on fields and can then reach surface water rivers or groundwater. Antibiotics and their metabolites are mainly detected in hospital effluents. The characteristics of this wastewater, which is also rich in microorganisms, can provide ideal conditions for ecosystem evolution, transfer, and the development of resistance genes [77]. Persistence of these compounds accelerates the development of resistance genes and of bacterial resistance that may increase the selection pressure on environmental microorganisms.

### s0105 5.4.3 Cost-effective risk management in wastewater use systems

p0385 Different approaches have been proposed to mitigate health risks. Traditionally, the approaches used have placed the emphasis on water quality and strict regulations at the place of use, making the treatment of wastewater essential for water reuse [29].

p0390 However, in low-income areas, stringent water quality standards for reuse are often perceived as unaffordable and consequently fail. The most recent WHO guidelines [35] for the safe use of wastewater acknowledge that reducing health risks is necessary and possible even in scenarios where wastewater is not treated at all or is treated improperly. In places where there are no viable alternatives to irrigation with contaminated water, the guidelines also enable the adoption of risk mitigation options on-farm and in postharvest operations [78]. This broader security concept follows the principles of the Hazard Analysis and Critical Control Point (HACCP) approach, which is widely used in the food industry and in drinking water safety management, and is in accordance with the Convention on Stockholm for the development of harmonized guidelines [35].

p0395 The WHO [35] guidelines propose the use of the multiple barrier approach along the food and sanitation chain, from the generation of wastewater to the consumption of food, instead of focusing only on the quality of the waters at the place of use (Fig. 5.2). For example, barriers can be placed at wastewater generation (low-cost treatment), on agricultural land (sedimentation lagoons, crop restriction, or safer irrigation techniques), in markets (washing crops with cleaner water), and even at the consumer level (disinfection, cooking, or dehulling). These practices must go hand in hand with people's exposure control (e.g., gloves and boots for farmers) and may require the participation of a wide range of stakeholders, beyond those responsible for wastewater treatment facilities. This approach is more cost-effective and feasible in countries or cities where the treatment and exhaustive disinfection of wastewater are failing, due to the high costs of construction, operation, and maintenance of the treatment plants, which also require high technical and management skills. The multiple barrier approach allows for a more flexible regulatory system, in tune with the socioeconomic realities of the country or locality. The

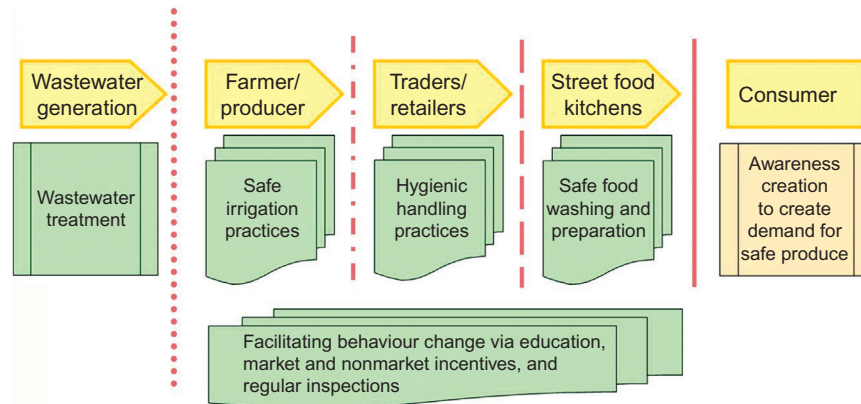


Fig. 5.2 The multiple-barrier approach as applied in wastewater irrigation [79].

reader will find examples of its application in countries with different levels of development in the guides published by the WHO [37].

## 5.5 Main conclusions

As the effects of climate change intensify, the levels of rainfall steadily decline and aquifers become systematically overexploited across the Mediterranean region, planned water reuse for agriculture is increasingly put forward by national governments as a valuable solution within a wider menu of options. There is little doubt that it costs less to produce and that it generates less environmental externalities than the other mainstream type of “unconventional water,” desalination. Additionally, the nitrogen and phosphorus contained in wastewater reduce the need for fertilizers by at least 50%. Also, by providing a regular and predictable volume throughout the year, water reuse can help maintain peri-urban agriculture, thereby containing urban sprawl.

However, many major challenges still lie ahead that prevent a massive upscaling. First, the water produced is expensive for most agricultural use. If the full operation and maintenance costs were to be recovered, wastewater could generally not compete with wells, especially when energy costs are subsidized. Water reuse for agriculture (as opposed to green spaces, golf courses, or water-intensive industrial processes) only makes strict economic sense for high-value crops and where there is no alternative resource readily available at a reasonable cost. Even then, operation and management may still need to be partly subsidized. Second, the risks for human health, however limited, have important implications: the procedures for monitoring water quality are expensive and often cumbersome, whereas State officials and agencies might be reluctant to authorize projects and assume formal responsibilities for fear of a public backlash if a health crisis ever erupted. The potential for barrier effects between treatment and use points (along the irrigation

systems and supply chains until final consumption) is a promising avenue but remains to be assessed. Third, as a crosscutting issue spanning many established policy domains, the governance of water reuse for agriculture is complex. However, this complexity can be reduced when wastewater is reused indirectly, for instance by being stored back in dams and mixed with conventional water like in Jordan, thereby reintegrating standard policy subsystems. This option should be considered whenever it makes economic sense.

p0410 Even then, it is useful to recall the obvious: water reuse is not a new water resource, or only secondarily so (when wastewater was previously discharged in the sea or when it evaporated in treatment ponds with no beneficial use). In this sense, it is fundamentally different from desalinization. The reallocation it entails is often innocuous, when wastewater was highly diluted in a river before being reused downstream. But it can be more contentious when wastewater was either already reused directly (typically informally), or when it played a major support role during periods of low river flow. In such cases, reuse projects can still be justified on an economic basis, but former users need to be compensated for their loss, either economically or by being allowed to access other sources of water.

p0415 Finally, much like the water cycle in general, the water reuse chain for agriculture has chemical, hydrological, agronomical, economic, social, and political dimensions that cannot be viewed in isolation from each other when it comes to tackling real-world problems and situations. Interdisciplinary approaches and interdisciplinary teams of researchers should be encouraged. For instance, many fields of expertise should be called for to conduct sensible cost-benefit analysis where all types of relevant costs and benefits are appropriately considered and weighted. Different backgrounds are also appropriate to assess the many social, economic, and agronomical implications of technological innovations such as small-scale, decentralized treatment facilities.

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### **Further reading**

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## Non-Print Items

### **Abstract**

Climate change, irrigation development, and a growing population across the Mediterranean region are increasing the pressure on water resources in terms of both quantity and quality. High-quality water should be primarily reserved to drinking water while water reuse is, and should be, a growing part of the water mix for other uses. This chapter provides an overview of the current water reuse situation in agriculture across the region, including planned projects and unplanned practices. It highlights the diversity of policy contexts (legal frameworks, national strategies, and governance arrangements) by reviewing the specific experiences of Jordan, France, Morocco, and Algeria. It also highlights the diversity of irrigation practices on the ground, and discusses health-related issues and agronomical performances. It concludes by stressing the potential for planned water reuse, both direct and indirect, while reminding that water reuse should not be primarily perceived as a new resource by policy-makers, but rather as a means to raise water productivity. Finally, an integrated approach is recommended, capable of including environmental, economic, and equity considerations.

**Keywords:** Unplanned and planned wastewater reuse, Irrigation, Governance, Environmental impacts, Sanitary and environmental impacts