Climate and Environmental Change in the Mediterranean Basin – Current Situation and Risks for the Future

First Mediterranean Assessment Report (MAR1)

Chapter 3 Resources | Subchapter 3.1 Water

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This chapter should be cited as: Fader M, Giupponi C, Burak S, Dakhlaoui H, Koutroulis A, Lange MA, Llasat MC, Pulido-Velazquez D, Sanz-Cobeña A 2020 Water. In: *Climate and Environmental Change in the Mediterranean Basin – Current Situation and Risks for the Future. First Mediterranean Assessment Report* [Cramer W, Guiot J, Marini K (eds.)] Union for the Mediterranean, Plan Bleu, UNEP/MAP, Marseille, France, 57pp, in press

(Final text before language edit and page editing for print)

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3.1 Water

Executive summary

Water resources in the Mediterranean are scarce. They are limited, unevenly distributed and often mismatching human and environmental needs. Three quarters of the resource are located in the northern Mediterranean while three quarters of the needs are in the south and east. As a consequence, approx. 180 million people in the southern and eastern Mediterranean countries suffer from water scarcity (<1000 m^3 $capita^{-1}$ yr^{-1}). The main water user is agriculture, in particular on the southern and eastern rim. The percentage of irrigated land of the total cultivated area is 25% for the Mediterranean Basin and is currently increasing, likely with higher rates under even drier climate conditions in the future. Water demand for both tourism and agriculture peak in summer, potentially enhancing tensions and conflicts in the future. Municipal water use is particularly constrained in the south and will likely be exacerbated in the future by demographic and migration phenomena. In parallel, northern countries face additional risks in flood prone areas where population and urban settlements are rapidly increasing.

Climate change, in interaction with other drivers (mainly demographic and socio-economic developments), has mainly negative consequences for the water cycle in the Mediterranean Basin, including reduced runoff and groundwater recharge, increased crop water requirements, increased conflicts among users, and increased risk of overexploitation and degradation. These impacts will be much more important for global warming higher than 2°C.

Strategies and policies for water management and climate change adaptation are strongly interconnected with all other sectors (e.g., the Water-Energy and Food Nexus). Technical solutions are available for improving water use efficiency and increasing reuse. Seawater desalination is increasingly used as adaptation measure to reduce (potable) water scarcity in arid and semi-arid Mediterranean countries, despite known drawbacks in terms of environmental impacts and energy requirements. Promising solar technologies are under development, potentially reducing emissions and costs. Reuse of wastewater is a solution for agriculture and industrial activities but also recharge of aquifers. Inter-basin transfers may lead to controversies and conflicts. Construction of dams contributes to combat water and energy scarcities, but with trade-offs in terms of social and environmental impacts. Overall, water demand management, which increases water use efficiency and reduces water losses, particularly in urban environments, is crucial for a sustainable development. Maintaining Mediterranean diet or coming back to it on the basis of locally produced food and reducing food wastes may save water but also carbon emissions while having nutritional benefits.

3.1.1 Water resources in the Mediterranean Basin

3.1.1.1 Water availability

The total renewable freshwater resources of the countries belonging to the Mediterranean Basin are estimated to between 1212 km^3 yr^{-1} and 1452 km^3 yr^{-1} (Ferragina 2010; FAO 2016a), distributed unevenly. Northern Mediterranean countries hold approx. 72 to 74% of the resources, while the eastern Mediterranean (including Turkey) and the southern Mediterranean countries (including Egypt and the Nile) share the remaining approx. 26 to 28% (Ferragina 2010; FAO 2016a). Besides the heterogeneous distribution of total freshwater resources, the partitioning of surface and groundwater differs as well. In northern Mediterranean countries, 96% of the renewable water is surface water, whereof 25% are contributing as base flow to river discharges after percolating to the aquifer. The 25% are referred to as shared surface/groundwater resource. Only 4% of the total water is recharging the groundwater (FAO 2016a). In the southern Mediterranean, the share of renewable groundwater resources is 11% of its total renewable freshwater. In eastern Mediterranean countries it even amounts to 20% (FAO 2016a). Especially in southern and eastern Mediterranean countries non-renewable "fossil" groundwater resources account for almost 66% of the total groundwater (MED-EUWI 2007; Lezzaik and Milewski 2018).

As aquifers and rivers are often situated across political borders, the dependency among countries concerning freshwater resources is common (Ganoulis 2006; Iglesias et al. 2007, 2011). In the southern and eastern Mediterranean, more than 60% of the surface water is transboundary and all Middle East and North Africa countries share at least one aquifer (World Bank 2018). Expressed as a dependency ratio, i.e. percentage of renewable freshwater resources originating in another country, the mean dependency of the northern Mediterranean countries is 22%, the eastern 27% and the southern 18% (FAO 2016a).

The total human population of Mediterranean countries is rising and is expected to increase from 466 million people in 2010 to 529 million people in 2025 (UNEP/MAP 2016). Thus, while only covering 2.6% of the freshwater resources, 7.4% of the world's population has to be supplied with water (MED-EUWI 2007). Contrary to the total population development of the Mediterranean region, some single country projections show a decrease in population of 1% to 5% until 2025 and even 16% to 62% until 2100. Most of the countries with a negative population growth rate are in the northern Mediterranean region (Albania, Bosnia and Herzegovina, Greece, Italy, Malta, Montenegro, Macedonia, Portugal) except for Lebanon, which belongs to the eastern part (UN 2019). Comparing available freshwater resources to the population of the Mediterranean regions, the northern part has 36% of the population and 72% to 74% of the renewable freshwater, the east 24% and 19.5% to 21% and southern Mediterranean 40% and 5% to 8.5% respectively (FAO 2016a). As a result, 180 million people in the southern and eastern Mediterranean suffer from water scarcity (<1000 m^3 $capita^{-1}$ yr^{-1}) and 80 million people from extreme water shortage (<500 m^3 $capita^{-1}$ yr^{-1}) (Ferragina 2010). In the northern Mediterranean however, an average water availability of 1700 m^3 yr^{-1} is given, in some Balkan states even a supply of 10000 m^3 $capita^{-1}$ yr^{-1} (Milano et al. 2013).

3.1.1.2 Rivers

River basins draining into the Mediterranean Sea cover an area of over 5 million km^2 including the entire Nile river basin but not the rivers draining Portugal into the Atlantic Ocean (Ludwig et al. 2009; Lionello et al. 2012). Portugal is considered a Mediterranean country and three large-scale river basins are shared between Spain and Portugal, i.e., Duero with 96,200 km^2, Tejo with 69900 km^2 and Guadiana with 65200 km^2 (Wolf et al. 1999). Besides a few major river basins (>80000 km^2, Figure 3.1), most catchments are medium to small-scale (Lionello et al. 2012).

In terms of discharge the ten largest rivers are the Rhône, Po, Drin-Buna, Nile, Neretva, Ebro, Tiber, Adige, Seyhan and Ceyhan rivers (Ludwig et al. 2009). Seven of these rivers are located in the northern Mediterranean countries, two in the eastern Mediterranean (Turkey) and one (the Nile) in the southern Mediterranean. Consequently, 71% of the mean annual discharge into the Mediterranean Sea originates from the northern part, whereas the eastern countries are contributing 12% and the southern 17% (Struglia et al. 2004). The large share of the southern countries comes mostly from the Nile, while 25% of the discharge in the northern countries is discharged by the Rhône and the Po River (Struglia et al. 2004; PERSEUS – UNEP/MAP 2015). Estimates of the total annual freshwater flux into the Mediterranean and Black Sea range from 305 to 737 km^3 yr^{-1} (Struglia et al. 2004; Ludwig et al. 2009).

The seasonal distribution of discharge is highly variable, depending on the climatic and geographical features of the river basins. Due to the Mediterranean climate, precipitation is mostly available for river discharge during autumn, winter and spring. Some Mediterranean rivers have an ephemeral or intermittent character (Argyroudi et al. 2009). In the mountain ranges of the Mediterranean region, precipitation mostly falls in form of snow in winter and is stored until late spring. During snowmelt in late spring this freshwater is contributing to the river discharge (Nogués-Bravo et al. 2008; García-Ruiz et al. 2011; Lionello et al. 2012). Most mountain ranges are more humid than lowland regions in the Mediterranean and therefore a source of water throughout the year (López-Moreno et al. 2008). A number of mountain ranges are almost entirely located in the Mediterranean Basin (Pyrenees, Apennines, Dinaric Alps, the Taurus and Pinthos mountain ranges and the Atlas Mountains), but also the main Alps contribute to the discharge into the Mediterranean Sea (e.g., through the Rhone, Adige and Po) (Lutz et al. 2016).

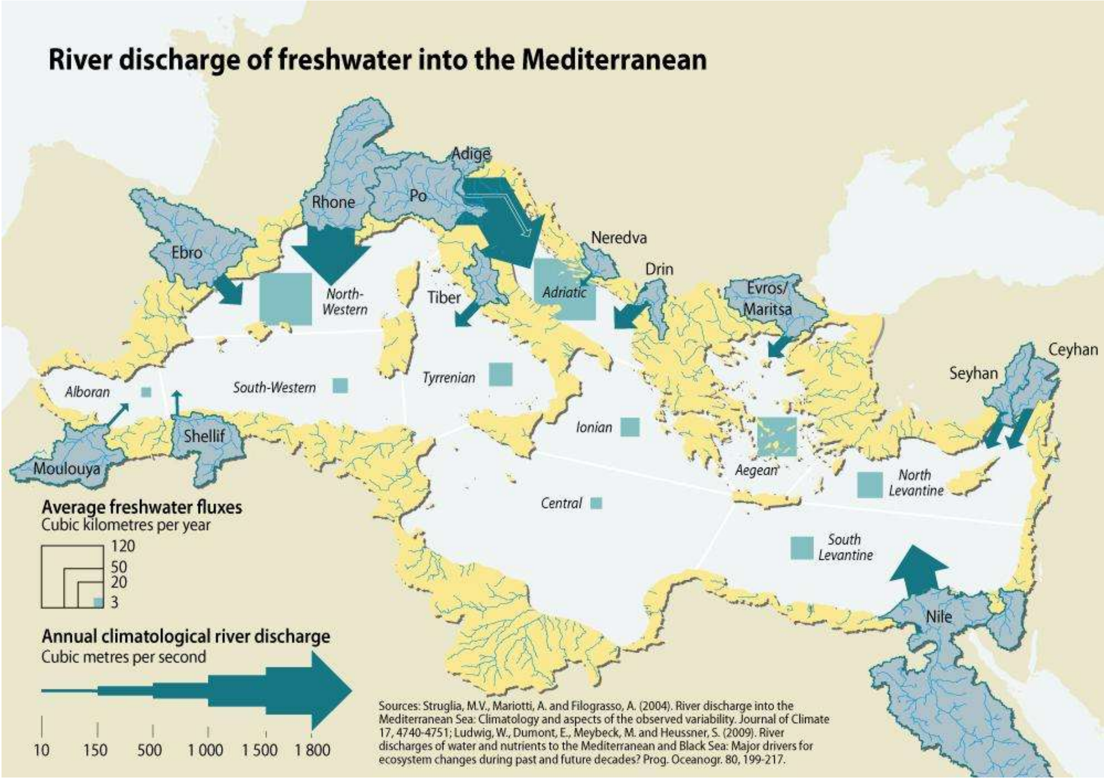

Figure 3.1 | Major river basins draining into the Mediterranean (Struglia et al. 2004).

Many Mediterranean river basins are transboundary. The Nile River crosses ten countries before entering Egypt and then the Mediterranean Sea. Only 9% of the total basin area belongs to Egypt (Wolf et al. 1999). The Jordan is another important transboundary river, subjected to great water scarcity and political tensions between riparian states (Hoff et al. 2011). The largest northern transboundary river basins flowing into the Mediterranean Sea are the Ebro basin in Spain, the Po basin (shared by Italy, Switzerland and France) and the Rhone basin (shared by France and Switzerland) (Wolf et al. 1999).

3.1.1.3 Groundwater

Groundwater resources are the main source of the water supply in many Mediterranean countries (e.g., Libya, Palestine and Israel) (FAO 2003; Leduc et al. 2017). Of the total abstracted 60,000 $km^3\ yr^{-1}$, 54% are supplying the northern Mediterranean, 18% the eastern Mediterranean and 28% the southern Mediterranean countries (MED-EUWI 2007). Accessibility to the groundwater resources depends on several factors, for example the aquifer type. Three aquifer types are most common in the Mediterranean region: The *karstic carbonated aquifer* is the most common aquifer type. It is mainly recharged by surface water drainage, springs or adjacent aquifers. The levels of the groundwater and the volumes of karstic aquifers are highly diverse. Nevertheless, they are frequently used for water abstraction. *Alluvial aquifers* emerge in valleys or deltas of large rivers, providing a distinct layer of interaction between surface water and groundwater, often with a water table close to the surface. The two major Mediterranean alluvial aquifers are located in Italy (Po delta) and Egypt (Nile delta). The third aquifer type originates from *sedimentary formations*. Usually it comprises a large volume at a great depth and is not renewable. Connections to surface water fluxes are therefore not common. Considering the fact that no recharge is given, the groundwater of this aquifer type is referred to as "fossil". The spatial distribution of fossil groundwater resources is mainly concentrated in the southern Mediterranean countries (e.g., the Nubian sandstone aquifer in southern Mediterranean) (Aureli et al. 2008).

The recharging of groundwater is spatially variable. In the total Mediterranean region, 92% of the total recharge is contributing to northern, 3% to the eastern and 5% to the southern countries. In the southern countries the abstraction of renewable groundwater resources is exceeded by 24% and so an overexploitation of mainly fossil groundwater is necessary to meet the demand. In northern as well as in eastern Mediterranean countries on average 31% and 92% of their renewable groundwater respectively is abstracted (Aureli et al. 2008). The situation in those regions also differs among countries. For example, overexploitation of renewable water resources is found in Palestine and Jordan, leading to depletion of the aquifers (Saghir et al. 2000).

Potential groundwater resources in the Mediterranean are not only subjected to pressures resulting from unequal distribution and accessibility but also quality issues. Agricultural activities, leakage from urban areas or saltwater intrusion are the main sources of groundwater pollution, which can lead the resource to become unusable (Garrido and Iglesias 2006; Ferragina 2010).

Further, aquifers are often crossing political borders making an integrated management difficult. 274 underground water fields (aquifers) are known in the Mediterranean (Ferragina 2010). One of the largest aquifers, the Nubian Sandstone Aquifer, is located in the southern Mediterranean region and is shared by four countries from which two are bordering to the Mediterranean Sea (Libya and Egypt). Approximately 37% of the water is located in Egypt and 34% in Libya, which obtains 90% of its water supply from groundwater (Margat and van der Gun 2013; Leduc et al. 2017).

3.1.1.4 Lakes and reservoirs

“Large dams” are all dams higher than 15 m from their lowest foundation to crest and also dams between 5 m and 15 m impounding more than 3 million m^3 and in the Mediterranean the countries with the highest numbers are Spain (1064), Turkey (974), France (720) and Italy (541) (ICOLD 2019). The two biggest dams in the European Mediterranean area are the Kremasta dam in the Aspropótamos River in Greece and the Alqueva dam in the Guadiana River in Portugal, whose capacity are 4.75 and 4.15 km^3, respectively. Although during the last two centuries the size and number of large storage capacity reservoirs have increased, it is now growing very slowly, due to the low availability of unused suitable places and the increase of environmental concerns (EEA 2018). The largest natural freshwater lake in Southern Europe is the Lake Skadar shared by Albania and Montenegro, which volume is 1.9 km^3 (Lasca et al. 1981).

3.1.1.5 Country-level water availability

Available and exploitable water resources of the Mediterranean region per country are listed in Table 3.1. It is important to differentiate availability and exploitability to assess the water situation of a country. Not all water can be used due to technical or environmental limitations, like a minimum required flow or uneconomical groundwater pumping (FAO 2003). The availability as well as the potential usable water vary among countries and so does ratio of water that can be exploited to the total available water.

Table 3.1 | Available and exploitable water resources in the Mediterranean region per country (Data Source: FAO, 2003, 2016).

	Population (x 1000)	Renewable water resources ($km^3\ yr^{-1}$)	Exploitable water resources ($km^3\ yr^{-1}$)	Renewable water resources per capita ($m^3\ yr^{-1}$)	Exploitable water resources per capita ($m^3\ yr^{-1}$)
Albania	2930	30.2	13	10307.2	4436.9
Algeria	41318	11.67	7.9	282.4	191.2
Bosnia and Herzegovina	3507	37.5	-	10692.9	-
Croatia	4189	105.5	-	25185.0	-
Cyprus	1180	0.78	0.54	661.0	457.6
Egypt	97553	57.5	49.7	589.4	509.5
France	64980	211	100	3247.2	1538.9
Greece	11160	68.4	29	6129.0	2598.6
Israel	8322	1.78	1.636	213.9	196.6
Italy	59360	191.3	123	3222.7	2072.1
Jordan	9702	0.937	-	96.6	-
Lebanon	6082	4.503	2.08	740.4	342.0
Libya	6375	0.7	0.635	109.8	99.6
Malta	430.8	0.0505	0.015	117.2	34.8
Monaco	38.7	-	-	-	-
Montenegro	629	-	-	-	-
Morocco	35740	29	20	811.4	559.6
North Macedonia	2083	6.4	3	3072.5	1440.2
Palestine	4921	0.837	0.715	170.1	145.3
Portugal	10330	77.4	13	7492.7	1258.5
Serbia	8791	162.2	-	18450.7	-
Slovenia	2080	31.87	-	15322.1	-
Spain	46354	111.5	46.3	2405.4	998.8
Syrian Arab Republic	18270	16.8	20.6	919.5	1127.5
Tunisia	11532	4.615	3.625	400.2	314.3
Turkey	80745	211.6	112	2620.6	1387.1

3.1.2 Water use per sector

3.1.2.1 Overview across economic sectors

In the southern Mediterranean countries most water is used for agriculture (76%) whereas the industrial consumption and the public amount only to 4% and 20%, respectively, of the total abstracted water (Hamdy et al. 1995; FAO 2016a). In the eastern part, agriculture uses 79% of the abstracted water, whereas the industrial and public sector have a relatively small share with 6% and 13%, respectively (FAO 2016a). The northern Mediterranean countries have also the largest water usage in agriculture (36%) (FAO 2016a). Industrial (incl. cooling 48%) and public use (16%) are much higher than the rest of the Mediterranean regions (Hamdy et al. 1995; FAO 2016a). Looking at country values, agricultural use dominates generally water demand with some prominent exceptions, for example Slovenia and France having predominant industrial water demand (Fig. 3.2) (Burak and Margat 2016).

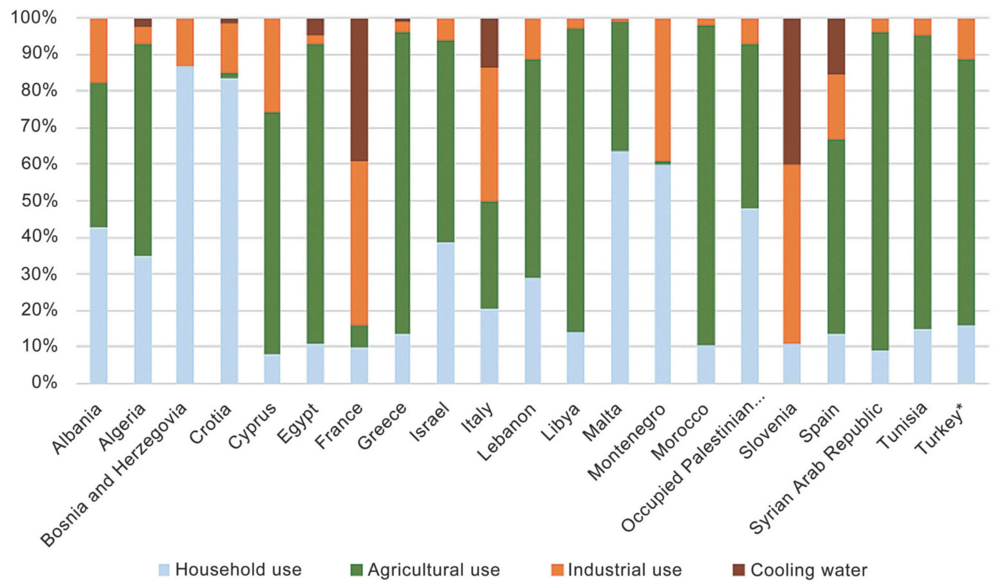

Figure 3.2 | Water demand per sectoral use as percentage of total water demand (Burak and Margat 2016).

The part of overall water abstraction for different uses from surface water and groundwater varies between countries, from 100% of groundwater resources in Malta to approx. 20% in France (Leduc et al. 2017). In most of the Mediterranean, water demand is satisfied by freshwater withdrawal but in northern Africa the proportion of demand covered with fossil groundwater is high, as are the use of treated municipal water in Israel and desalinated water in Cyprus and Malta (Fig. 3.3, Table S3.1). Water demand in Northern Africa is thus met increasingly by non-renewable water resources, estimated at 16 km^3 yr^{-1}, of which more than 60% is withdrawn from fossil resources and more than 30% is due to overexploitation of renewable groundwater (WWC 2009).

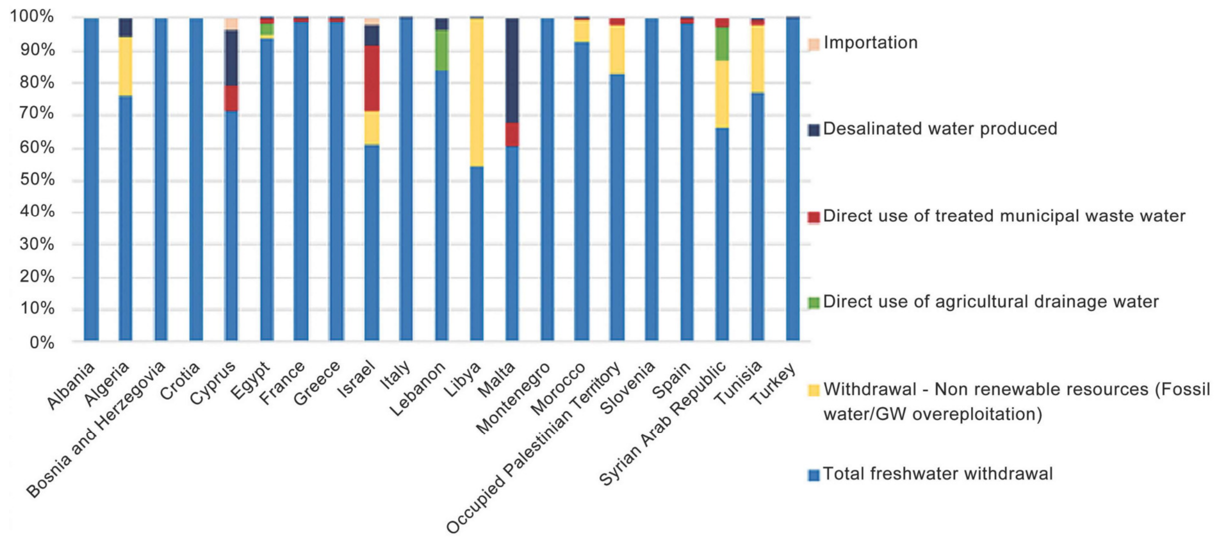

Figure 3.3 | Sources of water supply as percentage of total water supply (Burak and Margat 2016).

3.1.2.2 Agriculture

In the Mediterranean countries, water withdrawal for the agricultural sector is about 193 km^3 yr^{-1}, 64-69% of total water withdrawal (FAO 2016a; Malek and Verburg 2018). These amounts depend mainly on climate, from very low levels in some Balkan countries to more than 80% in the countries with arid and semi-arid climate. The quality of water used for irrigation is a matter of concern, as low water quality may cause water-borne diseases and crop damage which would reduce agricultural production (Etteieb et al. 2017). In some countries (e.g., Egypt), non-conventional, water is used in the agricultural sector from brackish water collected from drainage canals and municipal wastewater. Using municipal waste water, even after conventional treatment, while it is beneficial in regions suffering of water scarcity, should be applied only on selected plants and carefully monitored, because of the nutrient content, as well as bacteriological pollution, not to create sanitary issues (El Ayni et al. 2011).

The total area of the Mediterranean currently equipped for irrigation is about 27 million ha (FAO 2016a). Its percentage of agricultural land is the largest in Egypt (almost 100%), very high in Israel (76.3%), Turkey (71%), Lebanon (78.8%), Greece (70.9%), Cyprus, (65.6%) and Italy (60.7%). In a given year, only a part of the equipped area is actually irrigated (about 86% or 23.2 million ha) due to lack of water for irrigation, inadequate maintenance, operation and governance, obsolete irrigation systems, etc. Average water consumption for irrigation of the agricultural sector in the Mediterranean countries is estimated to about 8340 m^3 ha^{-1}. It goes from a few thousand m^3 ha^1 in the Balkan area (Albania, Montenegro, Bosnia and Herzegovina, Croatia and Slovenia) to much higher values, such as in Portugal (20,800 m^3 ha^{-1}), Egypt (18,000 m^3 ha^{-1}), Syrian Arab Republic (12,000 m^3 ha^{-1}), Lebanon (8700 m^3 ha^1), Malta (7900 m^3 ha^{-1}), Jordan (7500 m^3 ha^{-1}), Greece (6800 m^3 ha^{-1}), Tunisia (6500 (m^3 ha^1), Turkey (6400 m^3 ha^{-1}) and Morocco (6300 m^3 ha^{-1}). These differences are, besides the specific climatic conditions, due to different cropping pattern, irrigation methods, and overall efficiency of water withdrawal, storage, conveyance, distribution and application. Many Mediterranean countries widely use surface irrigation, such as Turkey (87.8% of irrigated area), Syrian Arab Republic (77.8%), Egypt (75.6%), Morocco (71.6%) etc.

There is a trend in several Mediterranean countries towards the substitution of surface irrigation with more efficient localized irrigation (Rodríguez-Díaz et al. 2011), e.g., in southern Spain and the Maghreb oases (Ibáñez et al. 2008), it is also reflected in the National Strategy for Irrigation Water Saving launched by the Moroccan government within the overall Green Morocco Development Plan. The trend towards more efficient irrigation systems may not have led to absolute water savings due to simultaneous changes towards water-demanding, more profitable crops (e.g., vegetables) and/or expansion of irrigated areas (Ward and Pulido-Velazquez 2008). Yet, the implementation of water-saving irrigation systems has led to higher water productivity in terms of tons and revenues produced per unit of water applied (Rodríguez-Díaz et al. 2011; Shah 2014). The implementation of pressurized systems has also led to higher energy requirements and, thus, higher greenhouse gas emissions. Daccache et al. (2014) state that irrigation modernization in the Mediterranean could save 8 km^3 of water per year, but it would also increase CO_2 emissions by 2.42 Gt CO_2e (+135%). The new development of solar pumps in drylands and desertic environments has created a substantial decrease of the fossil water table and increased the risk of salinization (Zammouri et al. 2007; Gonçalvès et al. 2013).

Changes in irrigation systems affect key variables of the water cycle such as soil evaporation, infiltration and percolation, water storage in soils, groundwater recharge, runoff and return flow. These changes affect the availability of water resources. For example, implementing drippers instead of flooding irrigation reduces in most cases soil evaporation, surface runoff, groundwater recharge and return flows (Cooley et al. 2009), potentially causing water scarcity in downstream areas. This transformation can also generate significant environmental issues in groundwater dependent ecosystems influencing the biodiversity and functioning of aquatic and terrestrial ecosystems (Kløve et al. 2011), in coastal aquifer vulnerable to seawater intrusion (Kouzana et al. 2009; Mazi et al. 2014), and in terms of soil salinization (Clemmens et al. 2008).

In some regions, there is still conversion of natural ecosystems to croplands, to non-natural grasslands/grazing areas and, especially, a widespread conversion of all uses to urban areas. This affects hydrological variables, such as soil evaporation, plant transpiration, infiltration, percolation, water storage in soils, groundwater recharge, runoff and return flow. For example, deforestation was found to reduce spring and summer evaporation by more than 1 mm day^{-1} and decrease precipitation in the western Mediterranean (Gaertner et al. 2001).

3.1.2.3 Tourism

Most tourist modalities are highly dependent on sufficient water resources and at the same time a major actor in water use that may contribute to the overexploitation of existing supplies and degradation of freshwater ecosystems (de Stefano 2004). In 2017, the Mediterranean received 289 million visitors (76% of which in the countries of the North of the basin including Turkey) reaffirming the position of this area as the largest single tourist destination in the world (UNTWO 2018). In the Mediterranean, tourist activity is at its highest in summer coinciding with peak demands by irrigated agriculture which may create tensions regarding water availability likely to be exacerbated in the future due to climate change (Toth et al. 2018).

Although usually higher than that of permanent residents, water consumption by tourism is strongly influenced by the tourist modality as well as location. Gössling et al. (2012) estimated wide variations of consumption, ranging from 84 l person^{-1} day^{-1} for campsites in Spain to close more than 2000 l person^{-1} day^{-1} in hotels in Thailand. A correspondence between hotel category and water consumption has been found with establishments in upper categories consuming more water than establishments in lower categories (Gössling et al. 2015; Rico et al. 2020) but hotel-based tourism shows also less consumption per capita than residential tourism based on house rentals (Rico-Amoros et al. 2009). High water use is related to the presence of outdoor amenities such as lawns, swimming pools or golf courses (Gössling et al. 2015). In the Mediterranean, small insular states dedicate a significant part of their total water supply to tourism (5% in Cyprus and more than 7% in Malta) while in the large countries, tourism represents at the most 1% of total water use at the country level but sometimes 5% or more of domestic use (Gössling et al. 2012).

Overall, tourism-related water consumption appears to decrease, at least in the developed mass tourism destinations of the northern part of the basin (Rico et al. 2020), due to increasing efficiencies and also to the use of non-conventional resources such as recycled water (Gabarda-Mallorquí et al. 2017), or due to the exchange between agriculture and tourism of water flows of different qualities (Rico-Amoros et al. 2013). These options respond to increasing episodes of water stress linked to climate change in the region which may also increase coastal erosion and jeopardize beaches and natural and cultural heritage sites, especially in the southern and eastern countries (Bocci and Murciano 2018).

3.1.2.4 Industry and energy

Water use in the industrial sector of Mediterranean countries is estimated at 59.6 km^3 yr^{-1}. Additionally, 38 km^3 yr^{-1} are used for the cooling of thermal power plants (Burak and Margat 2016). The two figures combined would represent around 30% of water use in the Mediterranean basin. Most of this consumption occurs in the large developed countries of the North (France, Italy and Spain) which concentrate 80% of water used in the industrial sector and 87.5% of water used for cooling purposes (France alone concentrates more than 60% of water used for cooling). In the East and South, Turkey represents 7% of industrial water use and Egypt 2% (Förster 2014; Burak and Margat 2016).

In most countries, chemical and especially petrochemical facilities are the main industrial users of water. More than 200 petrochemical plants and basic chemical plants are located along the Mediterranean coast and in adjacent river basins, including at least 40 major oil refineries with important concentrations in Spain, France, Italy, and some Northern African countries such as Algeria and Egypt (IDAEA 2015). Mining and manufacturing of basic metals is the main water-using industry in Serbia and Turkey while water use for food processing is present in most countries although in small quantities (Förster 2014).

The abstraction of water for industrial activities decreased in most of the developed North of the basin during the first decade of the 21st century and overall demand for water from the energy and industrial sectors is projected to decline in the following decades in these areas mainly as a result of improving efficiencies. Treated wastewater is increasingly used in some industrial sectors. For example, the petrochemical complex of Tarragona, Spain, the largest in the Mediterranean, will cover around 80% of the 27 10^6 m^3 of water used annually with reclaimed water in 2020 (Molist et al. 2011). In contrast, demand in the industrial sector of the South and the East is projected to increase significantly and could account for over 7% of the total water demand by 2025 (Verdier and Viollet 2015).

Hydropower constitutes a large part of the 228 GW (38%) of the installed capacity for electricity production in the Mediterranean. Around 80% of this capacity is located in France, Italy and Spain, although possibilities for further development in these countries are severely limited. Table 3.2 indicates the percentage of electricity produced from hydropower in several countries. Of these, the only country where electricity production from hydropower is expanding is Turkey, especially in the Tigris and Euphrates river basins. Hydropower is very sensible to climate change (Section 3.3.3.5). For example, the average flow of the Rhône River (supplying 25% of hydroelectricity in France) could be reduced to a third of its current flow by 2100 (European Water Movement 2018).

Table 3.2 | Percentage of electricity generated from hydropower in selected Mediterranean countries (Bocchiola and Rosso 2014; France Hydroelectricité 2018; OME 2018; Estado de los embalses, pantanos y presas de España 2019; TSKB Ekonomik Araştırmalar 2020).

Country	Electricity generated from hydropower (%)
France	12.5
Italy	25
Spain	20
Turkey	31.2
Egypt	9

3.1.2.5 Municipal water withdrawal

Municipal water withdrawal refers primarily to the direct use of water by the population, including renewable and non-renewable sources, treated, desalinated and drainage water. It is usually computed as the total water withdrawn by the public distribution network. Table 3.3 shows the municipal water withdrawal for Mediterranean countries. A fraction of 30%, on average, of total water withdrawal is consumed for municipal use in the Mediterranean. In absolute terms, Egypt and Italy have the largest municipal water withdrawal, while when computed as percentage of total withdrawal, Bosnia and Monaco have the largest values. However, values per capita may give a more accurate picture of the situation, since population numbers differ largely from country to country (Table 3.3, right column). However, national statistics about drinking and sanitation water use may differ from these numbers. According to the last national study on the supply of drinking water and sanitation in Spain, for 2017 (AEAS-AGA 2018), the total water use in Spanish households (drinking, washing, cooking, toilet, shower, cleaning, etc.) was, on average, 132 l $capita^{-1}$ day^{-1} (i.e. 48 m^3 yr^{-1} $capita^{-1}$, differing from the 105.5 m^3 yr^{-1} $capita^{-1}$ shown in Table 3.3).

Table 3.3 | Municipal water withdrawal in absolute values, in percentage of total withdrawal and per capita. The values shown are the most recent values present in FAO AQUASTAT Database from the period 2003-2017.

	Population (x 1000)	Total water withdrawal (10^9 m^3 yr^{-1})	Municipal water withdrawal (10^9 m^3 yr^{-1})	Municipal water withdrawal as % of total withdrawal (%)	Municipal water withdrawal per capita (m^3 yr^{-1})
Albania	2930	1.311	0.283	21.6	96.6
Algeria	41318	10.46	3.600	34.4	87.1
Bosnia and Herzegovina	3507	-	0.361	-	102.9
Croatia	4189	0.715	0.455	63.6	108.6
Cyprus	1180	0.311	0.110	35.4	93.2
Egypt	97553	77.5	10.750	13.9	110.2
France	64980	26.44	5.175	19.6	79.6
Greece	11160	11.24	1.991	17.7	178.4
Israel	8322	2.304	0.983	42.7	118.1
Italy	59360	34.19	9.488	27.8	159.8
Jordan	9702	1.044	0.457	43.8	47.1
Lebanon	6082	1.84	0.240	13.0	39.5
Libya	6375	5.83	0.700	12.0	109.8
Malta	430.8	0.0638	0.037	58.6	86.8
Monaco	38.7	0.005	0.005	100.0	129.2
Montenegro	629	0.1609	0.096	59.9	153.3
Morocco	35740	10.43	1.063	10.2	29.7
North Macedonia	2083	0.5235	0.278	53.0	133.2
Palestine	4921	0.3752	0.181	48.3	36.8
Portugal	10330	9.151	0.914	10.0	88.5
Serbia	8791	5.377	0.660	12.3	75.0
Slovenia	2080	0.9314	0.170	18.2	81.5
Spain	46354	31.22	4.890	15.7	105.5
Syrian Arab Republic	18270	16.76	1.475	8.8	80.7
Tunisia	11532	4.875	0.137	2.8	11.9
Turkey	80745	58.79	5.839	9.9	72.3

Domestic water consumption in the Mediterranean depends on regional socioeconomic and sociodemographic circumstances with large differences from place to place. Figure 3.4 shows the temporal evolution in municipal water withdrawal for selected Mediterranean countries according to FAO Aquastat database (FAO 2016a). Increasing withdrawal is reported for Cyprus, Jordan and Algeria during the last decades in the absolute values of municipal water, as well as in the fraction of municipal compared to total water withdrawal. On the other hand, the fraction of municipal water for France, Monaco and Spain shows a decreasing trend despite the relatively constant absolute values. Decreasing trends in municipal water use has also been reported in specific urban areas during the recent past, as for example in the city of Alicante from a combination of water saving as a response to water pricing and increased environmental awareness, as well as water reuse (Morote et al. 2016).

Municipal water distribution systems of many Mediterranean countries are old and as a result, losses and leaks are estimated of the order of 35% of the total water demand (UNEP/MAP and Plan Bleu 2020). Several Mediterranean countries have set specific targets for improving water use efficiency in the context of the Mediterranean Strategy for Sustainable Development.

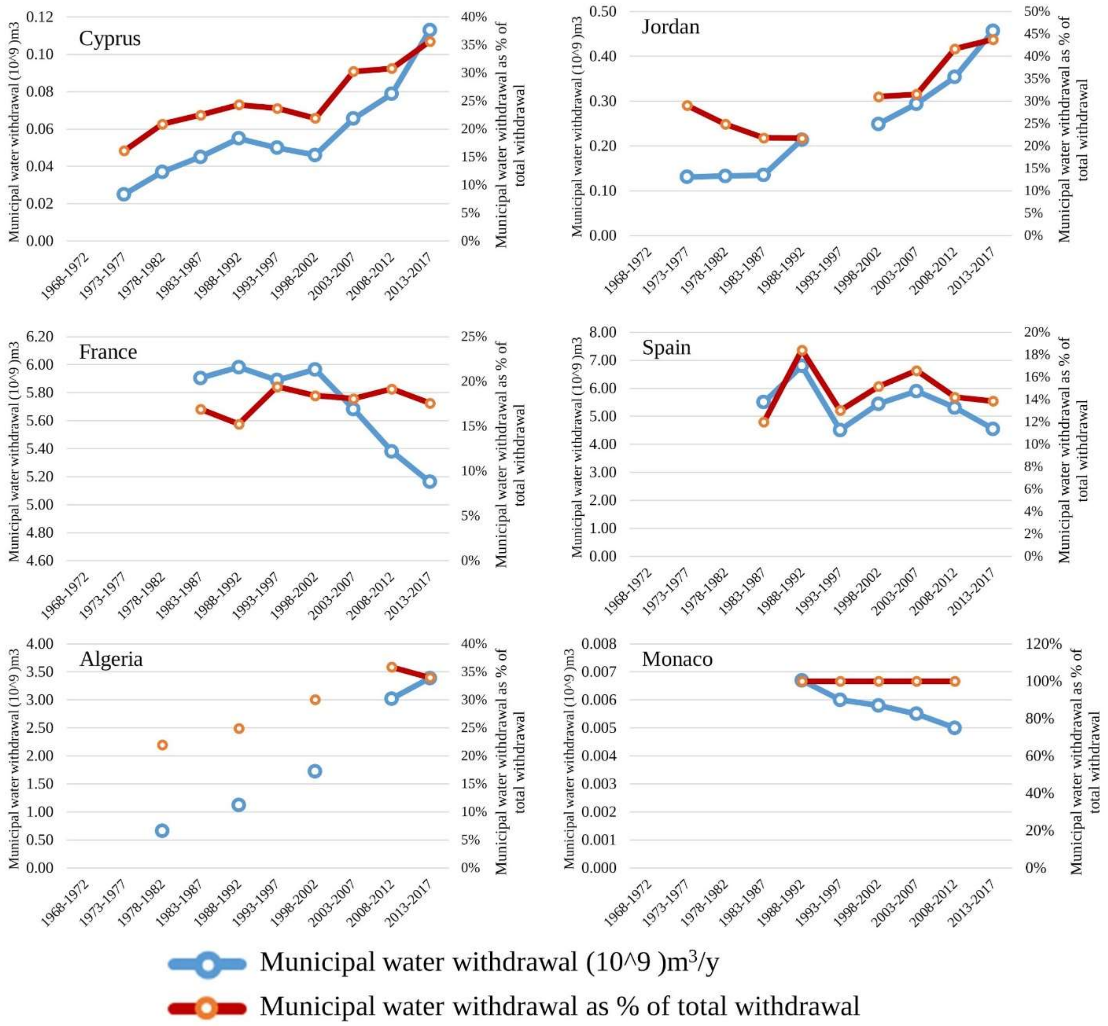

Figure 3.4 | Trends in municipal water withdrawal. Absolute (left y-axis) withdrawal values and in percentage of total withdrawal (right y-axis) for selected Mediterranean countries according to (FAO 2016a).

3.1.3 Past changes in hydrological variables

In order to isolate the impacts of climatic conditions on groundwater and surface water resources it is necessary to remove anthropogenic detractions from the results of monitoring. In many cases, this is performed by applying hydrological models (Escriva-Bou et al. 2017; Trichakis et al. 2017) that simulate first the link between the climatic driving forces and the hydrological variables in natural conditions for calibration, and then compare simulations with observations.

3.1.3.1 Evapotranspiration and soil moisture

The increasing Mediterranean temperatures translate directly into higher evaporative demand. However, observations denote a recent (1998 onwards) decline of land evapotranspiration in a global context that could be attributed to limitations in moisture supply (Jung et al. 2010). Evapotranspiration is controlled by water demand and supply limitation conditions, which are highly variable depending on the region and the season (Wang et al. 2010). Weather variables affecting evapotranspiration in arid and semi-arid climates range over a large interval making difficult the evaluation of actual evapotranspiration (Rana and Katerji 2000).

In several Mediterranean regions small trend changes of ±0.1 mm yr^{-1} in annual evapotranspiration have been detected from 1982 to 2008, with large regional variations. Positive multi-decadal evapotranspiration trends in Mediterranean have been found by several authors (Miralles et al. 2014; Zhang et al. 2016, 2019), as a consequence of increases in transpiration and interception components, counterbalanced by decreasing soil evaporation (Zhang et al. 2016).

Soil moisture is one of the most important water resources for agriculture, especially during the dry season, and it also affects temperature variability (D'Andrea et al. 2006). Mediterranean ecosystems respond to soil moisture shortage by directly reducing gross primary productivity (Piayda et al. 2014; Meza et al. 2018), hence soil moisture variability affects also long-term terrestrial carbon storage (Green et al. 2019). Sparse and uneven observations make it difficult to assess the past trends in soil moisture across the Mediterranean. Assessments mostly rely on hydrological and water accounting models driven by observed climate data. Such studies indicate a historical decrease in soil moisture in most of the Mediterranean region, particularly in southeastern Europe, southwestern Europe and southern France, as well as a substantial increase over western Turkey (Sheffield and Wood 2008; Kurnik et al. 2015). A progressive decrease in total soil moisture of the Mediterranean region during the twentieth century of about 2-3% that continues at an increased pace until today has been estimated through simulations (based on CMIP5 simulations) (Mariotti et al. 2015).

Spatially distributed soil moisture detection can be derived from remote sensed products. Feng (2016) analyzed the temporal trends of global soil moisture during 1982 to 2013 on European Space Agency's Climate Change Initiative soil moisture data. They found no significant trend in soil moisture in the coastal regions of south Mediterranean countries, except for Egypt that exhibits a marginally negative trend. Soil moisture in southwest Turkey decreased, but in increased in Southern Italy. Similar results were obtained by Dorigo et al. (2012) from microwave surface soil moisture measurements. These findings have to be interpreted with caution, as the depth of the soil moisture that can be detected with these equipments is limited to the first few centimeters.

3.1.3.2 Runoff and water resources

Several studies indicate an important reduction of streamflow in basins of the Mediterranean region during recent decades (Lutz et al. 2016; Suárez-Almiñana et al. 2017). For example, in the Jucar Basin (East Spain) streamflow in natural regime has experienced a reduction close to 40% since the 1980s (Suárez-Almiñana et al. 2017). Decreasing long-term flow trends are also detectable for a large part of the Mediterranean rivers (Su et al. 2018). The strong significant runoff decrease in the Mediterranean has also been identified by Gudmundsson et al. (2017) and is likely attributed to anthropogenic forces.

Overall, Mediterranean catchments are prone to drier climate and declining water resources apart from the alpine catchments in the north of the Mediterranean region, as for example in the Adige Region (Lutz et al. 2016). This reduction affects surface and groundwater resources.

3.1.3.3 Extreme events

Floods

Floods are the most frequent and among the costliest and deadliest natural disasters in the Mediterranean area (Swiss Re 2015; UNISDR 2015), where flooding has produced more than 85 billion euros of damages since 1900 (a 42.5% of total damages related to various disasters, EM-DAT)[1]. Floods and droughts present significant and increasing risks for water stress (OECD 2016) and can significantly erode poor people's assets and further undermine their livelihoods in terms of labor productivity, housing, infrastructure, and social networks (Olsson et al. 2014).

In recent decades, a mixed signal of increasing and decreasing trends in flood occurrence has been reported from many local studies over the European Mediterranean (Hall et al. 2014). In Spain and southern France, generally decreasing trends in annual maximum floods have been found (Renard et al. 2008; Stahl et al. 2010; Giuntoli et al. 2012; Mediero et al. 2014). Blöschl et al. (2019) show a

[1] http://www.emdat.be/

common negative change in mean annual flood discharge (between -5% and -24%) in the northern and eastern Mediterranean Basin for the period 1960-2010. Although flood trend attribution is uncertain, it is often possible identify the likely key drivers of this negative trend (Merz et al. 2012). As there is not a common negative trend in precipitation, neither in maximum precipitation in those regions, causes may be related to other changes in rainfall-runoff processes at the catchment scale, such as changes in water tables caused by either overexploitation or recharge of aquifers, or land use changes, such as deforestation or forestation, urbanization, wildfires and agricultural use changes (Mediero et al. 2014). As an example, the abandonment of agricultural activities in Catalonia (northeastern Spain) has led to an increase of the forest density in the region from 30% to 70% in less than 100 years (Boada and Gómez 2011). Finally, structural flood protection measures like flood-control reservoirs have led to a decrease in flood probability although in some cases have reduced preparedness. This is known as the "levee effect" (di Baldassarre et al. 2018).

For the Po River (Italy) there is no clear trend in annual maximum floods (Montanari 2012). In Greece, around Athens, an increase in flood frequency has been observed in recent decades (Diakakis 2014). For the largest rivers in Mediterranean basins, Blöschl et al. (2017) indicate later winter floods and Mangini et al. (2018) noted a tendency towards increasing flood magnitude and decreasing flood frequency. Studies of historical flood series for more than 500 years show the great dependence of floods on land use changes and increased exposure in Mediterranean flood prone areas since the 18th century (Barriendos et al. 2003; Wilhelm et al. 2012). Flood-rich periods associated to climate anomalies (e.g., the Little Ice Age), can often be explained by natural climate variability (Glaser et al. 2010; Barrera-Escoda and Llasat 2015).

Disastrous flash floods are much more frequent in some parts of the Mediterranean region than in the rest of Europe, affecting mainly the coastal areas, where population and urban settlements are rapidly increasing in flood-prone areas (Gaume et al. 2016). Flash floods and minor floods have increased since 1981 in regions of Italy, France and Spain (Llasat et al. 2013). This increase is mainly associated to non-climatic factors such as increasingly sealed surfaces in urban areas and suboptimal storm-water management systems (Gaume et al. 2016). In the eastern Iberian Peninsula, observations points to an increase in convective and heavy precipitation concentrated in fewer days, consistent with climate change expected for this part of the basin (Llasat et al. 2016) and that could explain the positive trend found in flash floods.

Droughts

In the Mediterranean region the frequency and intensity of drought has increased since 1950 (Seneviratne et al. 2012), but more severe droughts have also been recorded in the past (Quintana-Seguí et al. 2016). Gudmundsson and Seneviratne (2016) and Gudmundsson et al. (2017) suggest that anthropogenic climate change has substantially increased the probability of drought years in the Mediterranean region and conclude that there is medium confidence that enhanced greenhouse forcing contributed to increased drying in the entire Mediterranean region. This is coherent with the increasing length of dry spells observed in the Mediterranean region (Turco and Llasat 2011; Turco et al. 2017; Hoegh-Guldberg et al. 2018).

3.1.3.4 Groundwater

In the Mediterranean area there is a wide range of hydrogeological contexts, aquifer recharge conditions and groundwater exploitation rates. With changing climate and growing scarcity of water, groundwater could act as a buffer during shortages of surface water supply, as aquifers have a high storage capacity and respond with a certain time lag to climatic changes. However, increases in population, rise of living standards, development of irrigated agriculture, and new activities, especially tourism, have drastically increased groundwater depletion in many countries of the regions, and the overall very high rates of withdrawal of groundwater (FAO 2015; GEF 2015). The growing exploitation, favored by many technical innovations, is the most important driver of the change in Mediterranean groundwater resources that have been reduced significantly during the last 50 years, mainly to satisfy agricultural demand, tourism and coastal cities (Leduc et al. 2017). Declining freshwater availability due to groundwater overexploitation over the Southern Mediterranean basin is detectable from large-scale satellite gravity data (GRACE) (Gonçalvès et al. 2013; Rodell et al. 2018).

An additional factor affecting trends is that the intensification of groundwater use for irrigation has occurred without governmental control during decades, affecting both the quantity and quality of the resources (Llamas et al. 2015). In the EU countries the implementation of the Water Framework Directive (WFD 2000) and the specific Directive for protection of groundwater (Directive 2006/118/EC) have helped to strengthen the governmental control for sustainable management of water resources, including groundwater and dependent ecosystem issues (Garrido et al. 2006; de Stefano et al. 2014). Nevertheless, there are frequent cases of extreme overexploitation in which to recover a sustainable use will be difficult (Leduc et al. 2017). In southeastern Spain drawdowns up to several hundred meters have been observed (Custodio et al. 2016). Particularly severe examples are known from Libya, where a very significant drop in water levels due to pumping volumes exceeds renewal resources by nearly one order of magnitude (Wada et al. 2012). Figure 3.5 shows the available information about renewable water resources (positive values) and their exploitation in the Mediterranean countries. Despite significant uncertainties (Leduc et al. 2017), there are huge differences between big northern countries and southern countries (Libya and Tunisia). At a country scale, the figure only shows overexploitation for Libya and Tunisia, mainly since the late 1970s (Gonçalvès et al. 2020), although there are aquifers with significant overexploitation problems also in other Mediterranean countries (e.g., Spain).

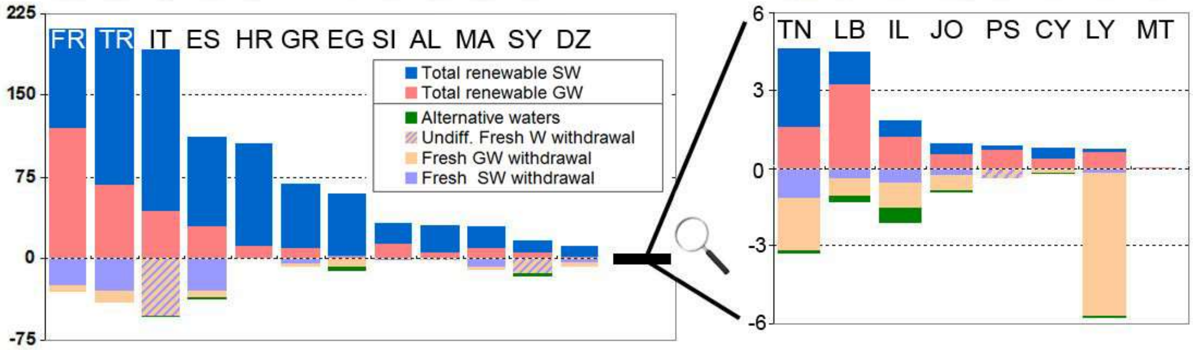

Figure 3.5 | Potentially renewable water resources (positive values) and their official exploitation (negative values) for surface water (SW) and groundwater (GW) in the Mediterranean countries in 10^9 m^3 yr^{-1}. Source: Leduc et al. (2017), based on AQUASTAT database (FAO 2016a). Country codes are: FR France, TR Turkey, IT Italy, ES Spain, HR Croatia, GR Greece, EG Egypt, SI Slovenia, AL Albania, MA Morocco, SY Syria, DZ Algeria; TN Tunisia, LB Lebanon, IL Israel, JO Jordan, PS Palestine, CY Cyprus, LY Libya, MT Malta.

3.1.3.5 Water quality

Inland water pollution and seawater pollution have different characteristics (Section 2.3.1). Continental water discharging in the sea carries the most dangerous pollutants such as heavy metals, Polychlorinated Biphenyls (PCBs), aromatic hydrocarbons etc. (EPA 2001). Here, the reasons and sources of land-based pollution will be assessed, bearing in mind that 75-80% of the sea water pollution in the Mediterranean Basin is land-based generated (EPA 2001; Civili 2010) (Fig. 2.21).

There are two types of pollution sources, point source and diffuse source. Point sources can be enumerated as untreated municipal wastewater and industrial discharges whereas diffuse sources are generated by irrigated agriculture, with river discharges carrying both point and diffuse sources. Table 3.4 summarizes existing major environmental problems for water quality along the coastal zone of Mediterranean countries and shows the spatial heterogeneity of water quality problems. It can be observed that urban effluents are an important problem for all Mediterranean countries with the exception of Monaco.

Inland waters such as lakes and rivers have high importance for drinking water supply. Therefore, monitoring of inland water quality is done with more stringent standards with respect to some parameters that are a constraint for human consumption (e.g., pesticides) (WFD 2006). The European Commission has launched in 2005 an initiative in order to control the most important polluting sources in the Mediterranean (i.e., industrial discharges, urban solid wastes, and urban wastewater), while reinforcing the capacity of non-EU neighboring countries with regard to pollution abatement actions (MSFD 20082008/56/EC).

Table 3.4 | Major environmental problems for water quality along the coastal zone of Mediterranean countries (+: Important problem; +/–: Medium problem; –: Minor problem). Source: EEA (2006).

Country	Urban effluent	Urban solid waste	Industrial effluent	Oil effluent	Chemical toxic product	Coastal eutrophication	Coastal urbanization
Albania	+	+	-	-	+	+/-	+/-
Algeria	+	+	+	+	-	+/-	+
Bosnia and Herzegovina	+	+	-	-	+/-	-	+
Croatia	+	+	-	+ (expected)	-	+	+
Cyprus	+/-	-	+	-	-	-	+/-
Egypt	+	+	+	+/-	-	+	+
Spain	+	-	+	-	-	+/-	+
France	+	-	+	-	-	+/-	+/-
Greece	+	+	+	-	-	+/-	+/-
Israel	+	-	+	+/-	-	+/-	+/-
Italy	+	-	+	+	-	+	+
Lebanon	+	+	+/-	-	-	-	+
Libya	+	+	+	+/-	-	-	-
Malta	+	+/-	+/-	+/-	-	-	+
Morocco	+	+	+	+	+/-	+/-	+
Gaza	+	+	+	-	-	+/-	+
Monaco	-	-	-	-	-	-	+
Slovenia	+	-	+	-	-	+/-	+
Syrian Arab Republic	+	+	+	+	-	+/-	+/-

Transboundary pollution is a severe concern with regard to persistent organic pollutants (POPs) as their transmission can be long distances away from their sources since these are not biodegradable in water but in fatty acids of living organisms and can, thus, enter the food chain (Section 2.3.3.4). In the Mediterranean region, PCBs have been used throughout urban and industrial areas (Pozo et al. 2016). In Italy, for example, PCBs were widely used as insulating fluids in electrical equipment and for many other uses (Breivik et al. 2007). In Europe, lindane usage has been estimated at 287,160 tons between 1950 and 2000 representing 63% of the total world consumption (Vijgen et al. 2011).

In the Mediterranean Sea inputs through rivers and wadis can be relevant during flash flood events, which may represent a significant portion of the yearly input of organic pollutants (Velasco et al. 2006). The total input of polyaromatic hydrocarbons (PAHs), organochlorinated phenyls (OCPs) and PCBs during two flash flood events in the coastal lagoon Mar Menor (Spain) was estimated at 0.98 kg, 1.32 kg and 0.34 kg respectively (León et al. 2017). Emerging POPs contamination has also been studied in the

Albufera Natural Park (Spain), a recognized Ramsar site after 1989, where the largest contribution is via the Turia and Jucar Rivers, and also from some major irrigation channels. Emerging POPs, such as Perfluoroalkyl Substances (PFASs) and Organophosphate Flame Retardants were found in multiple environmental compartments of the Albufera wetland introduced mainly from point sources like wastewater treatment plants (WWTPs) and diffuse sources conveyed by the two rivers and irrigation channels (Lorenzo et al. 2019).

Tourism activities lead to water pollution problems as the infrastructure facilities have to comply with an increase of polluting load by 5-fold in many cases, during the summer season (Burak et al. 2004). In several coastal settlements of eastern and southern Mediterranean countries, this issue is a big challenge for the municipal management in the sense that sudden increase in population must receive the corresponding services in good quality in order to sustain touristic activities, which constitute the major income in such cities.

Eutrophication is the result of the enrichment of water bodies with nutrients such as nitrogen and phosphorus compounds which exist mainly in domestic wastewater and industrial wastewater generated by e.g., fertilizer industries and non-point sources generated from agricultural irrigation waters that carry fertilizers rich in nitrogen and phosphorus compounds (see Section 2.3.4). The problem emerges when overfeeding of aquatic ecosystems depletes the dissolved oxygen in water during their decomposition (decay) phase. When water becomes euthrophic, change in the initial (baseline) conditions of water quality is perceived to be detrimental and harmful for the ecosystem. Eutrophication causes the degradation of the water quality, which results in negative impacts on living and non-living environment of the receiving water body. This becomes increasingly a threat for receiving water especially in semi-enclosed bays and estuaries, coastal lagoons and deltas having high productivity. Coastal eutrophication is of medium or important significance in 13 Mediterranean countries (Tab. 3.4, Sections 2.3.3.1 and 4.2.2.1).

Bacteriological contamination of bathing water in particular is a threat to human health, therefore sea-outfalls have to be designed and operated in order to ensure that there is no adverse impact of pathogen microorganisms on human health. Monitoring of bathing water and the EU Directive EU 76/160/EEC on this subject has been a significant achievement for Mediterranean countries (EEA 2017), either member-state or non-member state since the quality of bathing water is a prerequisite for sustainable tourism, a major income source for all the coastal cities of the Mediterranean region.

Spreading of marine mucilage, which is an aggregate of mucus-like organic matter found in the Mediterranean Sea, is linked to climate-driven sea surface warming. The presence of mucilage makes the seawater unsuitable for bathing because of its smell and its adherence on the skins of the bathers. The mucilage can act as a controlling factor of microbial diversity across oceanic regions and could have the potential to act as a carrier of specific microorganisms, thus increasing the spreading of pathogen bacteria (Danovaro et al. 2009).

3.1.4 Projections, vulnerabilities and risks

3.1.4.1 Impacts of 1.5-2 °C global warming and associated socio-economic pathways on water

Evapotranspiration and soil moisture

Evapotranspiration is an important part of the water balance at the catchment scale, especially for the Mediterranean region where around 90% of the annual rainfall can be lost through evapotranspiration (Wilcox et al. 2003) (Section 2.2.5.3). In the Maghreb region, Tramblay et al. (2018) reported that under RCP 4.5, potential evapotranspiration (PET) is projected to increase (+6% to +11%) for 2036–2065 period and (+7% to +14%) for 2066–2095 period compared to historical period (1976–2005), in most areas. The relative potential evapotranspiration increase is the most important during the winter and spring months. Similar projections comparing the Temperature-based PET formula and Penman Monteith equations were reported, which indicate that the main driver of change is the temperature increase. In contrast, the projected changes in actual evapotranspiration in the Maghreb region are negative from −10% up to −35%, under RCP4.5. The strongest decline is observed in spring. This change in actual evapotranspiration is correlated to the decrease in precipitation (Tramblay et al. 2018) (Section 2.2.5.3).

Overall, soil moisture is expected to decrease by the end of this century, with a significantly lower risk at 1.5°C warming as compared to higher levels (Stocker et al. 2013; Lehner et al. 2017). Under RCP2.6 and RCP 6.0 scenarios and global warming by roughly 1.3°C and 2.4°C degrees relatively to the recent past, the European Mediterranean region is expected to exhibit increase in area affected by soil moisture drought by 14.1% and 16.3%, respectively. Most of affected areas are expected to be in Greece, the southern Iberian region (Grillakis 2019) and Mediterranean area of Iberian Peninsula (Savé et al. 2012). Likewise limited to the European Mediterranean (Portugal to Greece) and warming of 1.5°C and 2°C, an increase in soil moisture drought area by 34% and 38% is expected (Samaniego et al. 2018).

A general decline of mean soil water availability is expected at the beginning of the growing season in Sicily, due to the expected reduction of winter rainfall. Higher water stress is likely to reduce the optimal rooting depth, possibly favouring a transition toward shrubs at the expense of forests (Viola et al. 2008). Bioclimatic and evapotranspiration projections for 2070 in Malta, under a RCP 6.0 scenario, show that arable lands of the country would need at least an additional 6 m^3 ha^{-1} day^{-1} of water to make up for the expected increased water loss. The already existent scarcity of surface water supply through reservoirs and ground water is likely to limit the future potential for irrigation, which has critical implications for future crop production (Galdies and Vella 2019).

Runoff

Several studies show that future reduced precipitation, associated with increased evaporation will lead to a decline of runoff in the Mediterranean region (Droogers et al. 2012; Mariotti et al. 2015; Marx et al. 2018; Thober et al. 2018) (Section 2.2.5.3). The median reduction in annual runoff is projected to almost double from about 9% (likely range 4.5–15.5%) at 1.5°C to 17% (likely range 8–25%) at 2°C (Schleussner et al. 2016; Donnelly et al. 2017) and yet higher levels corresponding to stronger warming (Döll et al. 2018; Thober et al. 2018). Overall, these projections are considered robust, since all models of the multi-model ensemble agree on the same decreasing trend (Tramblay et al. 2016).

Marx et al. (2018) found that the Alpine region shows the strongest low flow increase, from 22% at 1.5°C to 30% at 2°C, because of the relatively large snowmelt contribution. For the Mediterranean region, Thober et al. (2018) project significant decreases in high flows of −11% and –13% at 1.5°C and 2°C, respectively, mainly resulting from reduced precipitation.

Several studies have shown a future potential decrease in water resources for the southern Mediterranean region (Tramblay et al. 2013b; Ruelland et al. 2015; Seif-Ennasr et al. 2016; Marchane et al. 2017; Dakhlaoui et al. 2019a, 2019b). The projected decline in surface water in the Maghreb region is significant in winter and spring (Tramblay et al. 2016). In snow-dominated catchments in the Atlas Mountains (Morocco) a stronger climate change signal points to a major decrease in spring runoff associated with reduced snow cover (Marchane et al. 2017). This could have serious consequences since these arid regions depend to a large extent on the water resources provided by the mountain ranges (Tramblay et al. 2016).

Extreme events

Floods

Flood risk, associated with extreme rainfall events, are likely to increase due to climate change, but also due to non-climatic factors such as increasingly sealed surfaces in urban areas and ill-conceived storm water management systems and major exposure and vulnerability in flood-prone regions (Alfieri et al. 2015). Floods also affect the supply of drinking water, because in circumstances of very high flows, sewage treatment plants cannot operate and, usually, pollutants are discharged into watercourses or directly to the sea. In countries such as Spain, where hydroelectric production dams are also used for flood mitigation, the forecast of heavy rains and floods obliges partially to evacuate part of the dammed water, decreasing the energy resource.

There may be important local effects beyond the effects of land use. In a study on the impacts of climate change on floods in central Italy, basins with permeable soils have been found under greater flood risk (Camici et al. 2017). In Sardinia impermeable and flat sub-basins are predicted to experience more intense flood events in future scenarios, while more permeable and steep sub-catchments will have an opposite tendency (Piras et al. 2014). The timing of floods is changing. High flows are expected to occur up to 14 days earlier per decade in the north of Italy, the south of France and eastern Greece, or later (1 day per decade) near the north-eastern Adriatic coast, eastern Spain, the south of Italy and Greece (Blöschl et al. 2017).

There are systematic differences between projections of changes in flood hazard in the south of Europe (Italy, Greece and Iberian Peninsula) in most European and global studies using large-scale hydrological models (Kundzewicz et al. 2017). Flood events with occurrence interval larger than the return period of present flood protections are projected to increase in all continents under all considered warming levels (1.5°C, 2°C and 4°C), leading to widespread increment in flood hazard (Alfieri et al. 2017). A future increase in floods corresponding to a 10-year return level in southern French basins has been projected using the ISBA land surface scheme with different downscaling methods, but with different magnitudes depending on the basins (Quintana-Seguí et al. 2011). Other studies suggest a decrease (Donnelly et al. 2017; Thober et al. 2018). This is due to different climate model types, scenarios and downscaling approaches (Section 2.2.1.2 and Box 2.1), but also the use of large-scale hydrological models often not calibrated and validated for all basins. This type of global (or large scale) hydrological models (LISFLOOD, VIC, HYPE…) is not well adapted to small river basins (<500 km²) which is the typical catchment size found in the Mediterranean region.

In the western Mediterranean, the lower Rhône Basin and the Po catchment, the 100-year flood is projected to mainly increase in height (Dankers and Feyen 2009; Rojas et al. 2012; Dumas et al. 2013). For the upper Soca River in Slovenia, increasing high-flow magnitudes have also been projected as well (Janža 2011). For 2°C warming, river flood magnitudes are expected to increase significantly in Mediterranean Europe except for Bulgaria and southern Spain (Roudier et al. 2016). In contrast, Thober et al. (2018) has identified significant decreases of −11% (-13%) in high flows in the Mediterranean Region at 1.5°C (2°C) scenario, mainly resulting from reduced precipitation.

Droughts

Drought affects both the quantity and the quality of water resources. Enhanced evapotranspiration and reduced rainfall (4% decrease of precipitation per degree of global warming, Section 2.2.5.2) both reduce water availability (Baouab and Cherif 2015). In the Mediterranean, water availability could be reduced by 2-15% for 2°C warming, among the largest decreases in the world (Schleussner et al. 2016). Regional climate simulations project (medium confidence) an increase in duration and intensity of droughts in the Mediterranean, by the end of the 21st century, for different kind of drought such as streamflow droughts (Feyen and Dankers 2009; Forzieri et al. 2014; Prudhomme et al. 2014; Giuntoli et al. 2015; Quintana-Seguí et al. 2016), meteorological droughts (Koutroulis et al. 2011) or generally low water availability (Tsanis et al. 2011). Decreased low-flow was also projected by Marx et al. (2018) using a combination of three hydrological models with five climate models and three scenarios (RCP2.6, RCP6.0, RCP8.5). They found a decrease for Euro-Mediterranean areas (France, Spain, Italy, Balkans and Greece) ranging from -12% with +1.5°C warming up to -35% with 3°C warming. Liu et al. (2018) suggest that more urban populations will be exposed to severe droughts in the Mediterranean, and the number of the affected people will escalate further the larger will be the temperature increase.

Basin-scale studies arrive to similar results. Summer low flows are reduced between -15% and -25% for the Jordan River basin (Smiatek et al. 2014). The intermittent flow regime of the Guadiana River (south of the Iberian Peninsula) may intensify in climate change simulations, according to the JULES land surface model with an ensemble of Euro-CORDEX simulations under RCP8.5 (Papadimitriou et al.

2016). Overall, most studies conducted with hydrological models forced by climate models in different basins, found in future projections an increase of the low flow period during summer, an increased frequency of no-flow events in France (Lespinas et al. 2014), Italy (Senatore et al. 2011; Fiseha et al. 2014; Piras et al. 2014), Spain (Majone et al. 2012), Portugal (Mourato et al. 2015), Morocco and Tunisia (Tramblay et al. 2013a, 2016; Marchane et al. 2017).

Future scenarios are most extreme when both climate and human drivers are considered. For the Durance River in southern France, regulated by large reservoirs, decrease of mean annual renewable water resources has been demonstrated, with a decrease in summer low flows, associated with a greater pressure on water demand (Andrew and Sauquet 2017). For the Mediterranean Basin in southern Europe an increase in discharge intermittency is likely to be exacerbated in the future since large amounts of water are already withdrawn for irrigation purposes (Schneider et al. 2013). For the Ebro (Spain) and Herault (France) basins an integrated modelling framework considering both hydrological processes and water demand has been applied. According to the scenarios built from nine GCM under RCP8.5 it has been found that a future increase in human activities (tourism, agriculture etc.) may have more impact on water demand than climatic changes (Grouillet et al. 2015). To conclude, water demand is already large and may severely increase in the future, in particular in North Africa, and impact water resources, and subsequently low flows (Droogers et al. 2012; Milano et al. 2013).

Projected frequency and magnitude of floods and droughts at the global scale are smaller under a 1.5°C versus 2°C of warming (*medium confidence*) (Hoegh-Guldberg et al. 2018). There is medium confidence that a global warming of 2°C (1.5°C) would lead to an increase of the area at global scale with significant increases in runoff as well as an increase in flood hazard in some regions, as compared to conditions at 1.5°C global warming (present-day condition) (Hoegh-Guldberg et al. 2018). Human exposure to increased flooding is projected to be substantially lower at 1.5°C as compared to 2°C of global warming, although projected changes create regionally differentiated risks (medium confidence) (Hoegh-Guldberg et al. 2018). The risks (with current adaptation) related to water deficit in the Mediterranean are high for a global warming of 2°C, but can be substantially reduced if global warming is limited to 1.5°C (Guiot and Cramer 2016; Schleussner et al. 2016; Donnelly et al. 2017).

Groundwater resources

Aquifer recharge is also likely to be affected by climate change. In the semi-arid zone of the Mediterranean, several regions show important reductions in future potential recharge for most of the considered projections. For example, decreases of net aquifer recharge by 12% on average over continental Spain in the horizon 2011-2045 under the highest emission scenario (RCP8.5) are expected (Pulido-Velazquez et al. 2018a). The standard deviation of annual mean recharge is expected to increase by 8% on average in the future, and the spatial distribution of the reduction is quite heterogeneous. Approx. 6.6% of the territory would have reductions of more than 20%, 52.3% of the area would suffer reductions between 10% and 20%, and the reduction would be between 0% and 10% over 40.9% of continental Spain. For some climate models, the simulations predict total recharge increases over the historical values, even though climate change would produce a reduction in the mean rainfall and an increased mean temperature (Pulido-Velazquez et al. 2015).

Overexploitation of groundwater is often the most important factor in lowering of groundwater levels as compared to climate change. In Tunisia, groundwater depletion is projected to reach -28% by 2050 (Requier-Desjardins 2010). Reductions in groundwater recharge and levels, independently of the drivers, might produce significant hydrological impacts, especially in the aquifers with higher vulnerability, as for example coastal aquifers where the salt-water intrusion could be exacerbated (Pulido-Velazquez et al. 2018a).

Water quality

Important challenges to groundwater quality in coastal areas will probably arise from salt-water intrusion driven by enhanced extraction of coastal groundwater aquifers and sea-level rise, as well as from increasing water pollution in the southern and eastern Mediterranean (Ludwig et al. 2010). Serpa et al. (2017), evaluating the impacts of climate change on nutrient and copper exports from a humid Portuguese Mediterranean catchment (São Lourenço), found that climate change could lead to a decline in annual total nitrogen, total phosphorus exports mostly due to a decrease in runoff and erosion induced by a reduction in rainfall, but it hardly affected copper (Cu) exports largely due to its strong immobilization in soils. The changes in water quality varied markedly according to the scenarios considered. A substantial decrease in total nitrogen, total phosphorus and Cu exports was simulated under intermediate scenario A1B (rapid economy growth with balanced energy sources). Under lower emission scenario B1, however, total phosphorus exports decreased much less while total nitrogen exports hardly changed, Cu exports also remained the same (Sections 2.3.2 and 2.3.3).

3.1.4.2 Impacts of higher end global warming on water

A number of recent studies of potential hydrological impacts of climate change are focusing on the ambitious warming targets of the Paris Agreement (UNFCCC 2016). Given the current trends in greenhouse gas emissions, the remaining challenges for mitigation and the risk of crossing planetary stabilization thresholds (Steffen et al. 2018), the target of limiting global warming to 1.5°C (and 2°C) is becoming increasingly more difficult to achieve (Mitchell et al. 2018). Higher levels of global warming are associated with significantly increased risks and vulnerabilities in the Mediterranean freshwater resources. The present section deals with the impacts of higher end global warming levels on water variables. Since the majority of climate-change impacts assessments have tended to be framed in terms of future time horizons, rather policy relevant warming level studies (Betts et al. 2018), the context of this assessment is also framed with impact studies using time horizons. These studies consider the high emission scenario RCP8.5 and examine hydrological impacts in time horizons close to the end of the 21st century, given that 80% of the CMIP5 models are crossing the 4°C global level above the pre-industrial period before 2100 under RCP8.5 (see Section 2.2.4.2).

Soil moisture

There is high agreement in the degree of change of the soil moisture in the Mediterranean region (Table 3.5). High warming scenario RCP8.5 projections for the end of the century (2070–2099) show an overall soil moisture drying pattern, more pronounced in western Mediterranean and mainly in the Iberian part but also in the Aegean and Eastern Mediterranean regions. The already dry regions of Tunisia, Libya and Egypt are projected to be less impacted (Berg et al. 2017). A scenario for 2°C warming relative to the pre-industrial for Mediterranean Europe shows an increase in drought areas with 38.4% of surface area affected and 3.7 months of drought conditions per year (Samaniego et al. 2018).

Table 3.5 | Projected changes (%) of soil moisture for the different Mediterranean regions as indicated in Berg et al. (2017), Ruosteenoja et al. (2018). * = reported only in Berg et al. (2017) .

Region	**Soil moisture change (%)**
Iberian Peninsula	-6 / -14
Italy	0 / -6
Aegean	-4 / -10
Major emerging changes	-4 / -8

Runoff

There is a high level of agreement for decreased discharge of the order of -10% to -50% over the Mediterranean region during the 21st century (Jiménez Cisneros et al. 2014; Schewe et al. 2014). Such reductions in mean discharge have also been found by Koirala et al. (2014) who applied a high-resolution routing scheme on the runoff output from 11 CMIP5 GCMs. In the same study, a significant decrease in high flows (Q5, i.e., flows exceeding 5% of time within a year) and more exaggerated in low flows (Q95, exceeded 95% of time within a year) is foreseen under high-end climate change. Assessments of higher resolution hydrological projections have been made by Betts et al. (2018), Koutroulis et al. (2018) and Papadimitriou et al. (2016) in order to assess hydrological changes at different levels of global warming (1.5°C, 2°C and 4°C relative to pre-industrial), under high-end climate change (RCP8.5). A set of high-resolution AGCM projections has been used to drive a land surface model (Papadimitriou et al. 2017) and simulate regional transient hydrologic responses (Wyser et al. 2016). Figure 3.6 shows regional patterns of changes in multi-model mean simulated annual runoff production at different levels of global warming, relative to the 1981-2010 mean runoff states, Table 3.5 contains the corresponding spatially averaged values over the Mediterranean SREX domain.

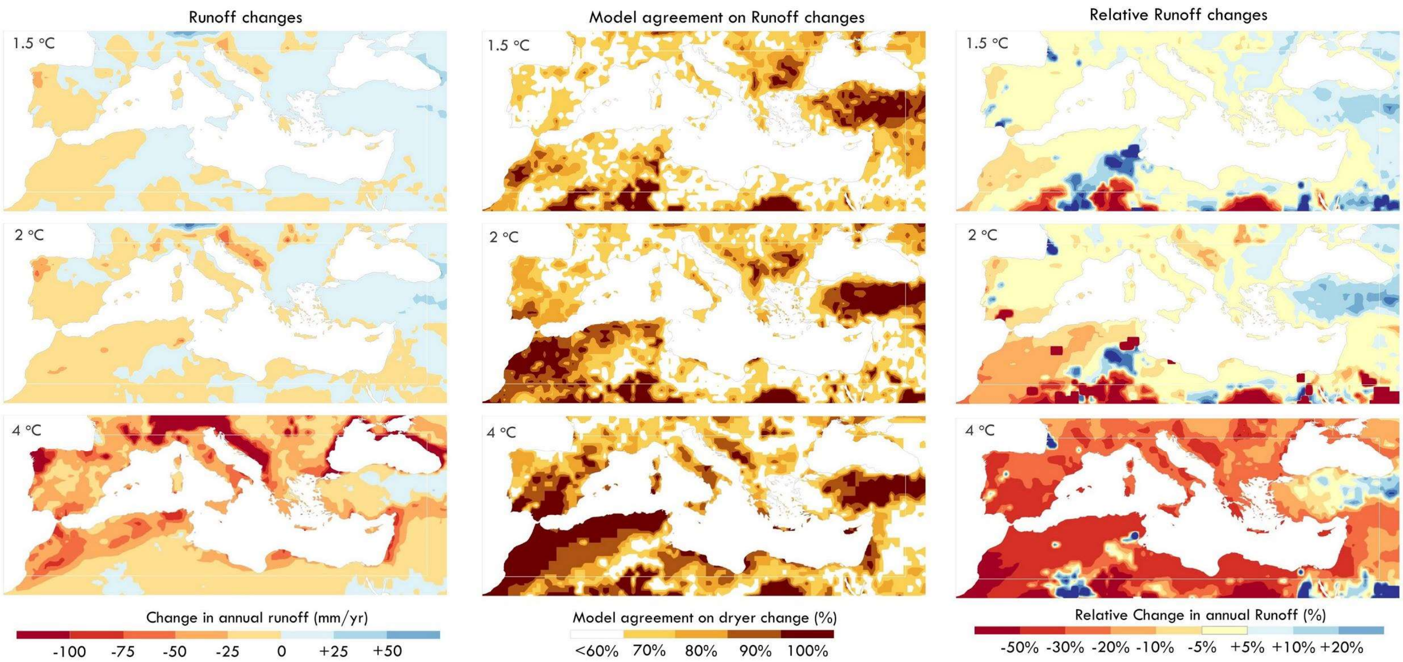

Figure 3.6 | Regional patterns of changes in multi-model mean simulated annual runoff (in millimetres of rain equivalent – left panel, and relative values [%] – right panel) at different warming levels (1.5°C, 2°C and 4°C relative to pre-industrial) relative to the 1981-2010 mean runoff states. The corresponding degree of agreement towards drier conditions in a set of high-resolution climate projections is shown in the middle panel (Papadimitriou et al. 2016; Wyser et al. 2016; Betts et al. 2018; Koutroulis et al. 2018).

With global warming level of 4°C above pre-industrial conditions, these high-resolution projections project precipitation to be reduced by a median of 10.4% relative to 1981-2010 (-6.0% to +21.1% between ensemble members). With these precipitation changes, and combined with rising temperatures and thus higher evaporation demand, runoff is expected to be 7.4% less (-4.4% to -21.1% between ensemble members) (Table 3.6). There are large local uncertainties in hydrological impacts, but in most locations, hydrological response indicates drier conditions at 4°C, with an increasing level of agreement between ensemble models.

Table 3.6 | Simulated changes in spatially averaged multi-model mean annual runoff (in millimeters of rain equivalent and relative values) at different warming levels (1.5°C, 2°C and 4°C relative to pre-industrial) relative to the 1981-2010 mean precipitation and runoff states. Percent changes are calculated based on the spatially averaged values over the Mediterranean SREX domain (Papadimitriou et al. 2016; Wyser et al. 2016; Betts et al. 2018; Koutroulis et al. 2018).

	Precipitation change						**Runoff change**					
	[mm]			[%]			[mm]			[%]		
	Median	Max	Min	Median	Max	Min	Median	Max	Min	Median	Max	Min
1.5°C	-2.9	26.4	-37.80	-0.6%	5.5%	-7.8%	1.6	13.4	-11.1	1.3%	10.4%	-8.6%
2°C	-20.1	14.3	-44.69	-4.2%	3.0%	-9.3%	-4.6	11.5	-12.5	-3.6%	8.9%	-9.7%
4°C	-50.1	-28.9	-101.56	-10.4%	-6.0%	-21.1%	-9.8	5.6	-27.3	-7.6%	4.4%	-21.1%

The severe drying is particularly apparent over the southern Mediterranean, southern and western Iberian Peninsula and France, Italy and south Greece and the Levant, with relative changes in mean annual runoff up to -50%. Global and regional scale studies show consistent patterns toward a drier Mediterranean, even if different in magnitude. Gaps in the spatial scale of these assessments are covered by a wealth of local and watershed scale studies on the simulated impacts of climate change on runoff and streamflow. Gosling et al. (2017) compared global hydrological simulations with catchment level models for the Tagus basin and found consistency in the median values and spread of mean runoff between the two ensembles. For 3°C global warming, mean runoff is projected, by both ensembles, to decline by approx. 40% relative to 1980-2010. For high flows (Q5) the projected median decrease is also similar, 28% and 32% between the global and the basin scale multi-model ensembles, respectively. On the other hand, for low flows (Q95) the median decrease is considerably lower (35% vs 50%) as projected by the catchment hydrological model ensemble compared to the global hydrological model ensemble.

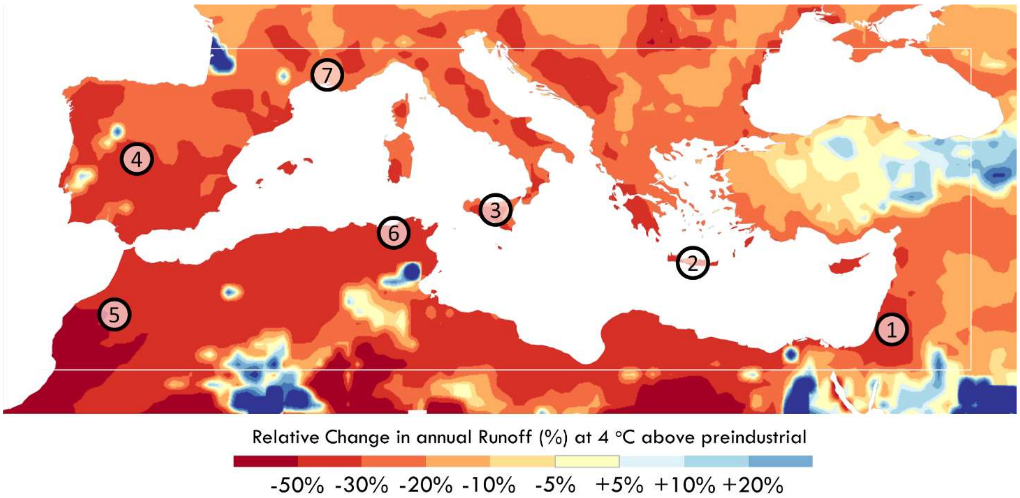

Figure 3.7 | Same as Figure 3.6 for the relative changes in multi-model mean simulated annual runoff at 4°C above pre-industrial with the locations of selected basin scale assessments. Source: see Table 3.7

Basin scale assessments include local scale information and thus can provide detailed impact projections not only in terms of spatial scale but also on plausible developments of local socioeconomic and environmental conditions (i.e., land use changes and human management). A number of recent such studies, listed in Table 3.7, project runoff reduction across the Mediterranean, with regionally variable magnitude. The mean and the range of the relative projected changes (Table 3.7) are largely comparable with the regional changes simulated by the higher resolution hydrological projections (Figures 3.6 and 3.7).

Table 3.7 | Characteristics and relative changes in runoff and discharge under high-end climate change as reported by a number of recent basin scale assessments. The ref. no is a cross-reference with Figure 3.7.

Ref. No Fig. 3.7	Country	Watershed /Region	Size (km^2)	Future/baseline period of reported changes	No of climate models	Relative changes			Reference
						Mean	Max	Min	
1	Israel	Lake Kinneret watershed	800	2050-2079/ 1979-2005	15	-35%	-9%	-51%	(Givati et al. 2019)
2	Greece	Crete	8320	2047-2076/ 1990–2011	5	-27%	-37%	-3%	(Koutroulis et al. 2016)
3	Italy	Imera Meridionale river basin	1782	2080-2100/ 1990-2010	32	-50%	-25%	-80%	(Viola et al. 2016)
4	Spain	Tagus	80000	2071-2100/ 1971-2000	5	-60%	-50%	-75%	(Lobanova et al. 2016)
5	Morocco	Rheraya catchment (high Atlas)	225	1979–2005/ 2049-2065	5	-50%	-35%	-65%	(Marchane et al. 2017)
6	Tunisia	North Tunisia (5 catchments)	81-315	1970-2000/ 2070-2100	8	-50%	-37%	-57%	(Dakhlaoui et al. 2019a, 2019b, 2020)
7	France	Rhône at Beaucaire	98000	1970-2000/ 2070-2100	8	-17%	-30%	-5%	(Dayon et al. 2018)

Extreme events

Floods

Global projections of river flood risk at a 4°C warming indicate that countries representing 70% of the world population and GDP will likely face an increase in flood impact above 500% (Alfieri et al. 2017). Countries of the northern Mediterranean like Italy, France and Portugal belong to this list. For southern Mediterranean countries projections rather indicate an average decrease in impacted population and expected damage at a 4°C above preindustrial levels. In a pan-European study based on Lisflood model simulations of Euro-CORDEX projections, Alfieri et al. (2015) found a general increase in 100-year daily peak flow and in average frequency of peak flow events for the majority of the northern Mediterranean river network, but the projected changes had large uncertainties under high-end climate change. An opposite (decreasing) signal was found for southern Spain caused by an overall reduction in the components contributing to river runoff. Using both socioeconomic and heavy precipitation scenarios for 1.5°C, 2°C and 3°C, Cortès et al. (2019) have demonstrated an increase in the probability of damaging events due to flash floods in the Eastern part of the Spanish Mediterranean region that can arrive to be above 60% for an increase of 3°C.

Droughts

Regarding the evolution of drought occurrence, progressively drier conditions may be expected, based on outputs from a variety of studies, from the catchment to the global scale (Orlowsky and Seneviratne 2013; Prudhomme et al. 2014). For the RCP8.5 emission scenario, a significant increase in frequency of droughts is projected by the end of the 21st century for the Mediterranean basin, where droughts are projected to happen 5 to 10 times more frequently not only for a global warming of 3°C, especially in Northern Africa (Naumann et al. 2018).

Groundwater

The assessment of changes in rainfall recharge in the more pessimistic emission scenarios shows reductions even higher than 55%. The heterogeneity described for the 1.5-2°C global warming scenarios, is expected to increase in higher end warming scenarios (Pulido-Velazquez et al. 2015).

Water quality

Climate change may affect water quality, through changing precipitation, temperature variability, frequency and occurrence of extreme events. For example, floods may result in the contamination of water sources (receiving media) with wastewater and solid waste leachate. Droughts can also affect water quality because lower water flows reduce dilution of pollutants (e.g., organic matter, heavy metals) and increase contamination of remaining water sources (Wilk and Wittgren 2009). Floods, for example, may magnify the risk of contamination in case sewerage network is composed of combined sewers collecting also rainwater. These systems are designed generally with overflow chambers to provide the security of the sewerage network by discharging the surplus water mixed with sewage into the receiving media (e.g., river, lake, sea). Leachate generated at solid waste dumping areas may contaminate water resources with hazardous pollutants disposed in such areas.

Surface waters are threatened by various kinds of point source pollution including municipal sewage discharges, industrial wastewater loads, and nonpoint source pollution from agriculture, inducing a metallic, nutrient and organic pollution, particularly cytotoxic emerging micropollutants, in river waters that can even be used for drinking purposes at a large scale (Etteieb et al. 2016; Khaled-Khodja et al. 2018) (Section 2.3.3).

Vulnerabilities and risks in the water-food-energy nexus

Global sustainability is intertwined with freshwater security. The combined dynamics of climate and socio-economic changes suggest that although there is an important potential for adaptation to reduce freshwater vulnerability, climate change exposure cannot be totally and uniformly counterbalanced. In many regions, socio-economic developments will have greater impact on water availability compared to climate-induced changes. However, under a global warming level of 4°C, freshwater vulnerability in the Mediterranean is expected to increase, regardless of the level of adaptation potential as formulated by the different Shared Socio-Economic Pathways (SSPs) (Section 2.7).

Changes in hydrological variables affect the functioning of all economic sectors, especially the food and the energy sector (Fader et al. 2018). For example, reduced river flows lead to large (>15%) declines in hydropower potential as projected for southeastern Europe (Balkan countries) (van Vliet et al. 2015). This, combined with strong increases in water temperature, makes the use of water for cooling purposes more difficult and challenging (Section 3.3).

The agricultural sector will also be severely affected by reduced water availability and increased drought under high-end climate change (van Vliet et al. 2015). Agricultural expansion in the Mediterranean region will be limited by the generally lower levels of productivity and water resources. More frequent and prolonged droughts in combination with heat stress is estimated to be the major limiting factor in crop yields, causing increased crop stress and failure in parts of central and southern Europe, especially in the European Mediterranean (Berry et al. 2017). Policy support will be increasingly important to maintain rural agricultural employment in southern Europe as increasing water scarcity and decreasing land suitability impact production and profitability (van Vliet et al. 2015). The water scarcity pressures are not homogeneous across Mediterranean and local management at the basin level is of crucial importance, but the potential benefits depend on the appropriate multi-institutional and multi-stakeholder coordination (Iglesias et al. 2007) (Section 3.2.3).

3.1.5 Water management and adaptation

Risk, vulnerability and impacts of climate change and other anthropogenic interventions on water resources are not static variables depending only on the strength and characteristics of human interventions. Robust design, construction and operation of infrastructure can alleviate climate-driven hazards (e.g., appropriate location of landfill sites equipped with liner and well-operating on-site leachate drainage system can reduce possible flood-induced contamination of water resources as explained in the above paragraph). This approach can be a no-regret measure for climate change adaptation.

Regulatory frameworks for water quality management vary between and within countries, also in degrees of efficiency. Few legal and regulatory texts directly consider the impacts on water quality (Cross and Latorre 2015). Understanding that different uses require different water qualities provides an opportunity to increase water use efficiency (WUE) by developing an integrated framework regulating water qualities ‘fit for purpose’, drawing from the wide range of water quality standards and guidelines currently available (UN-Water 2015). Through (water, landscape, land use, etc.) management and adaptation measures, impacts, vulnerabilities and risks may be potentially reduced. This section shortly analyses strategies for management and adaptation in the water domain, divided into two subsections: (i) Integrated Water Resources Management and (ii) adaptation measures (supply and demand-side).

3.1.5.1 Integrated Water Resources Management (IWRM)

Definition, components and link to climate change adaptation

Integrated Water Resources Management (IWRM) has been defined as a “process which promotes the coordinated development and management of water, land and related resources in order to maximize economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems and the environment” (Global Water Partnership 2011). The three main principles of IWRM are economic efficiency, equity and environmental sustainability. Based on them, three pillars should be developed: developing management instruments for institutions and stakeholders, establishing an enabling environment that supports IWRM implementation, and putting in place an institutional framework needed for the implementation of policies, strategies and legislation (Hassing et al. 2009). Through management of the resource at the most adequate level, the organization of participation in management practices and policy development, and assuring that the most vulnerable groups are considered, IWRM instruments directly assist communities to cope with climate variability.

There are similarities and differences between IWRM and adaptation to climate change. The main difference between the two is the focus on current and historic issues of IWRM compared to the (long-term) future focus of adaptation. Water management systems design has been based on historical climate and hydrological data assuming stationarity of systems behavior (Ludwig et al. 2014). However, future changes in the climate system no longer allow for such assumptions and historical data are no longer sufficient as the only source of information to plan for variability and extremes (Milly et al. 2008; Ludwig et al. 2009). Thus, climate change impacts will require new approaches to guarantee sufficient water resources and also to ensure that current investments will not become obsolete. In the Mediterranean Basin, where water distribution is uneven in time and in space and some regions suffer from structural drought, appropriate planning and management considering climate change impacts is the key issue. IWRM is increasingly viewed as comprising the best available framework for building the resilience needed to adapt to climate change. Any deficiency in pertinent decision-making process may result in severe shortfalls in the water management system, which may have adverse impacts on resource availability, including water supply.

Uncertainty management is crucial for the water sector given the marked inertia, which prevails as a result of the predominance of the long-term sectoral planning timeframes and in the lifespan of investments (de Perthuis et al. 2010). Many decisions relating to water, including adaptation, are sensitive to uncertainty and imply a particularly high risk of “maladaptation” when certain solutions are excessively structured or proven rather rigid (Plan Bleu 2011). However, the uncertainty surrounding impact and risk assessment should not be seen as hampering action. On the contrary, it should encourage the emergence of a dual approach: “no regret” actions and adaptation.

A challenge for implementing IWRM or adaptation measures is assuring the coverage of investment costs and long-term funding for functioning. Public-private partnerships (PPPs) can be an adequate approach for the implementation of some of the measures. This financial approach can be applied for example for local and targeted projects (IPEMED 2018), and for the construction and operation of “centralized” wastewater treatment plants (WWTP), that require a significant technical and financial support (e.g., the As-Samra WWTP that was built according to the Build-Operate-Transfer model over 25 years in Morocco). Although PPPs are developing, they remain marginal in medium-sized cities and almost non-existent in peri-urban and rural areas, especially in southeastern Mediterranean countries.

3.1.5.2 Adaptation measures

The existence of uncertainties in the evaluation of future climate change impacts (Pulido-Velazquez et al. 2018b) should not be an excuse for delay or inaction in the analysis and implementation of adaptation measures, especially in the Mediterranean region, which has been identified as one of the most vulnerable areas (Milano et al. 2013). However, due to these uncertainties, adaptation must be flexible, and adopt a comprehensive approach, considering not only climate change, but also other potential socioeconomic and environmental changes (UN 2009). The impacts will affect the private (for example irrigation communities), and the public (e.g., environmental impact, quality, and supply reliability) context. For this reason, the market for technologies for adaptation to climate change grows rapidly, given that "the cost of repairing damages is estimated to be 6 times greater than adaptation costs" (H2020WATER-2014/2015, Part 12 - Page 23 of 76).

Different approaches are applied to define adaptation scenarios. In a “top-down” approach, adaptation scenarios are developed based on expert criteria that considering the assessment of potential physical vulnerability obtained by simulating/propagating future potential scenarios within a modeling framework. Examples of application of this procedure can be found in many Mediterranean systems. Pulido-Velazquez et al. (2011) and Escriva-Bou et al. (2017) show that the systems are vulnerable to future climate change scenarios and suggest different adaptation strategies, for example, demand management alternatives or the introduction of complementary resources (additional pumping or water transfer), which can save important quantity of money (3–65 million € yr^{-1} in the Jucar Basin). “Bottom-up” approaches include definition of scenarios through participatory processes assessing social vulnerability (Culley et al. 2016). In this case, seminars are designed to involve the main stakeholders in the process of defining the adaptation scenarios. There are also combinations of both approaches (Brown et al. 2012; Girard et al. 2015), integrating the advantages of both of them (Serra-Llobet et al. 2016).

Adaptation measures can also be classified in measures on the demand side and on the supply side of water resources. The first group has the aim of control water demand and use through for example efficiency management, modernization in irrigation (Sanchis-Ibor et al. 2017), and application of economic instruments (prices policies, markets and subsidies) to reduce demand. In the group of measures on the supply side, we observe measures oriented to obtain complementary resources (water reuse, desalination, water transfers, etc.), measures to improve allocation and availability of water resources (for example building new small dams or channels), and conjunctive strategies, including Management Aquifer Recharge techniques.

Supply-side adaptation measures

In this section we include a short introduction to desalination, wastewater treatment and reuse, artificial recharge of groundwater, inter-basin transfer, dams and virtual water trade.

Desalination

The conversion of seawater or saline groundwater into drinking water increasingly provides a source of potable water in almost all Mediterranean countries, particularly in the eastern basin, the Arabian Peninsula and North Africa. Of the currently almost 16,000 operational desalination plants that are found in 177 countries, about half are located in the Middle East and North Africa region (Jones et al. 2019). In the Mediterranean Basin, desalination capacity has increased over the last few decades and the production of desalinated seawater in the MENA region is projected to be thirteen times higher in 2040 than 2014, the most advanced countries being presently Algeria, Egypt, Israel, Italy and Spain (UNEP/MAP and Plan Bleu 2020). Given the anticipated increase in demand as a result of growing population pressures in most Mediterranean countries on the one hand and diminishing supply resulting from precipitation decreases due to climate change, seawater desalination as an alternative source of (drinking) water will grow in importance for the region.

Desalination technologies fall into two basic groups and involve either (Younos and Tulou 2005):

- a phase change process of the water-salt mixture through the boiling of feed water; the evolving steam is subsequently cooled and condensed, leaving salts, minerals and pollutants in a highly enriched brine solution, which is separated from the clean condensed water; or
- the employment of semi-permeable membranes to separate the solvent or solutes from the water by including pressure, electric potential, and concentration to overcome natural osmotic pressures and effectively force water through the membrane, leaving all substances other than water behind.

For each group a number of different technologies have been developed (Miller 2003; Younos and Tulou 2005; Khawaji et al. 2008). Common to all of these technologies are a number of challenges. Most of them are relatively energy intensive, which is mainly due to the need for extensive pretreatment and post-treatment steps, implying a strong correlation between electricity prices and the price for the water produced (Semiat 2008; Elimelech and Phillip 2011). Utilizing conventional, hydrocarbon sources for electricity production results in the emission of air pollutants and greenhouse gases that further exacerbate climate change (Elimelech and Phillip 2011). The impingement and entrainment of marine organisms associated with the seawater intake of a desalination plant represents a further disadvantage (Elimelech and Phillip 2011). The discharge of high-salinity brines as well as of the chemicals used in the pretreatment and membrane-cleaning protocols into the sea adjacent to a desalination plant adversely affects near coastal marine ecosystems and represents an environmental problem that is increasingly recognized (Lattemann and Höpner 2008; Elimelech and Phillip 2011; Missimer and Maliva 2018; Jones et al. 2019).

Addressing particularly the first two challenges, there have been numerous efforts to improve existing technologies (Khawaji et al. 2008; Shannon et al. 2008; Elimelech and Phillip 2011; Subramani and Jacangelo 2015). More experiments and field monitoring are needed to assess adverse impacts of brine discharge from desalination into the ocean (Elimelech and Phillip 2011).

New solutions have been proposed, particularly with regard to the high demand for energy for desalination (Papanicolas 2010; Lange 2013, 2019; Georgiou et al. 2016). In this regard, utilizing renewable energies for desalination appear to be particularly promising. Given the environmental conditions in the Mediterranean Basin, solar energy appears to be the most suitable alternative related to other renewables (Li et al. 2013). Solar desalination can be achieved either directly by coupling a solar collector with a distilling mechanism through a one-stage cycle (García-Rodríguez 2003; Kalogirou 2004; Qiblawey and Banat 2008) or indirectly by connecting a conventional distillation plant to a solar thermal system (Eltawil et al. 2009; Li et al. 2013). It is also possible to combine electricity production with seawater desalination by utilizing concentrated solar power (CSP) (El-Nashar 2001; Trieb and Müller-Steinhagen 2008; Papanicolas et al. 2016). While these technologies offer the advantage of providing "clean" electricity and potable water from one plant by utilizing cost-free solar energy in regions were solar radiation is plentiful and water availability is scarce, there are a number of significant challenges including the requirement to improve existing technologies, the relatively high capital cost to build such plants, the need to build CSP plants close to the sea, where prices for land are usually particularly high, adding to the aforementioned capital cost, and the risk of enhanced corrosion of the plant's technical installations through sea spray and relatively high dust loads that reduce the efficiency of the CSP mirrors.

Despite these challenges, solar technologies in general and the co-generation of electricity and potable water in integrated CSP plants, in particular, appear as a viable alternative to conventionally driven seawater desalination (Lange 2013; Georgiou et al. 2016; Papanicolas et al. 2016; Bonanos et al. 2017). Seawater desalination thus clearly represents an adaptation measure to reduce (potable) water scarcity in arid and semi-arid Mediterranean countries. Desalination capacity in the Mediterranean is increasing. While promising new (solar) technologies are being developed, they still have their drawbacks and need to prove their economic feasibility. Importantly, operators will have to deal with the environmental repercussions of desalination and significant adverse impacts on near-coastal marine ecosystems (Missimer and Maliva 2018; Jones et al. 2019).

Wastewater treatment and reuse

The volume of wastewater produced in southern and eastern Mediterranean countries (SEMCs) was estimated at 8134 km^3 (with the exception of Israel), which makes it a valuable source with regard to its quantity (IPEMED 2018). In order to reuse wastewater, the first requirement is to have access to sewerage network connected to wastewater treatment plants (WWTPs) and network for reuse complying with the corresponding standards (IPEMED 2018). Not all effluent qualities match with the required reuse. According to the World Bank (2019)[2], 90 and 97% of Mediterranean populations (southeast and European Mediterranean, respectively) had improved access to sanitation services in 2015. However, these figures do not mean that there is available treated effluent for reuse. The situation is complex with regard to efficient interception of the sewage and treatment. Although in coastal urban areas, sewerage network is satisfactory, in general, in inland areas, less developed settlements have poor sanitation networks, with often leaking septic tanks, combined sewer system with overflow structure, illegal connection to streams etc. (EPA 2001; IPEMED 2018).

Figure 3.8 shows the sectors in which treated wastewater can be reused (Lautze et al. 2014). Agricultural, industrial and watering activities present together approx. 70% water reuse potential. The heterogeneity of goals connected to reuse of wastewater shows that the quality of the treated water may differ for end-users accordingly. Most importantly, reclaimed water use practices are finding more users as a reliable alternative and low-cost resource in line with improved treatment technologies and standards in parallel with awareness raising campaigns with regard to cultural and social acceptance. Israel and Jordan have a leading role in SEMCs with a reuse rate of over 85% of their collected wastewater. Cyprus and Malta have high levels with 90% and 60%, respectively, of their treated wastewater re-used.

Wastewater reuse should be considered not only as a reduction of losses, but also as an improvement of water quality and a change in water fluxes inside a watershed, in accordance with the principles of circular economy. For example, grey water reuse, as partial recycling inside the buildings comprises flushing water for toilets from recirculated wastewater that has been treated. Introducing this system is recommended in newly constructed, smart buildings in Istanbul (Turkey). Some research work is being carried out in residences in order to work out the conversion of grey water into water source for flushing in some new buildings at planning level.

Artificial recharge of groundwater

Groundwater, which underlies most of earth's surface, represents one of the most important sources of freshwater. It is protected from evaporation by the overlying soil cover and is naturally replenished/recharged by percolation of surface water and during precipitation events. Percolation through the soil reduces impurities and thus improves water quality (Racz et al. 2012). Being protected from evaporation, groundwater resources are also less sensitive to annual and inter-annual rainfall fluctuations than surface water (Giordano 2009). For these reasons, aquifers with high mean residence time can play a significant role as buffer values to reduce the impacts of meteorological droughts (Foster et al. 2017).

[2] https://donnees.banquemondiale.org/indicateur/SH.STA.BASS.ZS

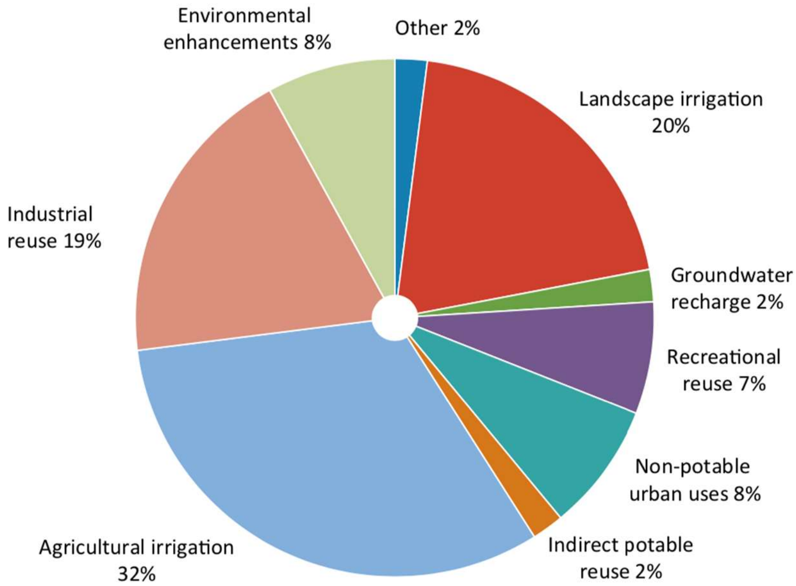

Figure 3.8 | Potential wastewater reuse per sector (Lautze et al. 2014).

Many groundwater aquifers in the Mediterranean, particularly in the eastern basin, are overexploited by groundwater extraction that exceeds surface water extraction (FAO 2016a; Jódar-Abellán et al. 2017). Satellite observations confirm these trends (Voss et al. 2013; Rodell et al. 2018). In order to mitigate groundwater depletion, artificial recharge of aquifers has been used worldwide since the 1960s and 1970s (de Giglio et al. 2018). For this purpose, surface water has been pumped underground in order to re-fill the aquifer. More recently, more efficient techniques have been developed, referred to as Managed Aquifer Recharge (MAR) (de Giglio et al. 2018). These techniques include the use of treated waste water or saline water for aquifer storage and recovery (Foster and Chilton 2004; Koussis et al. 2010; Maliva et al. 2011; Djuma et al. 2016), building underground dams (Nilsson 1988; Onder and Yilmaz 2005; Chezgi et al. 2016), using groundwater in combination with other sources to minimize its usage and implementing water saving technologies (Giordano 2009), and groundwater recharge by check dams (Hashemi et al. 2015; Steinel et al. 2016).

The recharge of groundwater aquifers with treated wastewater is often seen critical because of potential water quality problems. Application of this technique is therefore often restricted by regulatory authorities and lacks public acceptance (Kazner et al. 2012). Nevertheless, it is used to counter seawater intrusion in order to maintain heavily exploited coastal aquifers (Koussis et al. 2010). For example, in Tunisia a Treated Waste Water (TWW) recharge in the aquifer in order to counter its salinization due to seawater intrusion and pollution due to agricultural activities has shown a reduction in groundwater salinity. Contamination by nitrate and bacteria remained a major problem of the aquifer (Cherif et al. 2013). In Israel a tertiary treated wastewater was used for the recharge of an aquifer during a 300 days experiment. The resulting water met irrigation standards with unrestricted use since no bacteriological contamination was found in the aquifer (Idelovitch 1978). This technique not only allows the exploitation of a high amount of non-conventional water resource that is TWW, but also enables the remediation of over-exploited aquifers by increasing the water table level, and its relative quality.

A less frequently applied technology is the use of underground or subsurface dams, which are claimed to enable management of groundwater in a more sustainable manner (Onder and Yilmaz 2005). Underground dams represent subsurface barriers across a stream and can be compared to check dams or sand-storage dams (Nilsson 1988; Onder and Yilmaz 2005). The construction of subsurface dams restricts the natural groundwater flow of the system and enables the storage of water below the surface. Such dams can contribute to meet demands during droughts or heavy irrigation periods (Nilsson 1988). This is often used in near-coastal situations, where groundwater would otherwise be discharged into the sea and lost for utilization. Similarly, subsurface dams are being employed in restricting salt-water intrusion into coastal aquifers.

Recharge check- or sand-storage dams represent barriers that are placed across a river or channel to slow the movement of water, encouraging groundwater recharge (Djuma et al. 2017a). Various materials have been used to build the barrier (Onder and Yilmaz 2005). Recharge behind the check dam depends on the build-up of sediment. More specifically, a growing layer of sediment reduces the volume of stored water that eventually recharges underground aquifers. Sediment accumulation is a result of riverbank erosion or erosion in the upstream watershed area. This is affected by land use, climate, topography and soils (Abedini et al. 2012; García Lorenzo et al. 2013; Djuma et al. 2017a, 2017b). Only few studies quantify the groundwater recharge efficiency of check dams. Djuma et al. (2017b) applied a water-balance approach for the Peristerona, an ephemeral river located on the northeastern hill slopes of the Troodos Mountains, Cyprus. They found that check dams can be valuable structures for increasing groundwater resources in semi-arid regions.

Inter-basin transfers

The movement of water through artificial conveyance schemes between river basins is called inter-basin transfer (IBT). IBT is mainly employed in order to ease water shortages in the receiving basin and can be traced back to ancient times (Shiklomanov 1999; Gupta and van der Zaag 2008; Pittock et al. 2009; Boddu et al. 2011). Ever since dams have been built during the last half of the 1900s more than 364 large-scale inter-basin water transfer schemes have been established (Pittock et al. 2009). These IBTs transfer around 400 km³ of water per year (Shiklomanov 1999) and are considered viable solutions to meeting escalating water demands in water scarce regions. Pittock et al. (2009) estimate that the total number of large-scale water transfer schemes may rise to between 760 and 1240 by 2020 and will transfer up to 800 km³ of water per year (Shiklomanov 1999).

While potentially solving water supply issues in regions of water shortage, IBTs have significant social and environmental costs usually for both the river basin providing and the river basin receiving the water (Pittock et al. 2009). The large scale of most IBTs usually renders them expensive and thus economically risky. From an environmental point of view, IBTs interrupt the connectivity of river systems and therefore disrupt fish spawning and migration. Natural flow regimes are usually altered, sometimes with great ecological cost to threatened aquatic species or protected areas. IBTs often also modify river morphology and contribute to salinization. Finally, IBTs may also enable the transfer of invasive alien species between river basins. Short, medium and longer-term impacts of moving water from one community (the donor basin) and providing it to another (the recipient basin) are often overlooked in IBT development (Pittock et al. 2009). This may lead to controversies and conflict.

In the Mediterranean Basin, Spain has a long history of water transfers and one of the largest systems of IBTs. Despite general agreement among the main water decision-makers and stakeholders on projects and plans regarding water distribution and management, several factors have thrown this old system into crisis (Hernández-Mora et al. 2014). The Ebro inter-basin transfer, which was the main project of the Spanish National Hydrological Plan, was initiated because of pervasive pressures, scarcity, and degradation of southeastern basins in Spain (Albiac et al. 2006). The project caused heated political debates, and ultimately failed due to difficulties in achieving a sustainable management of water resources, which was caused by conflicting interests of stakeholders and regions. Hernández-Mora et al. (2014) conclude that currently no technical, territorial, political, or social agreement exists on how to allocate water in Spain despite significant public and private investments in water supply infrastructure. These challenges, while depicted for Spain, are of a more general nature and can be seen in other countries of the Mediterranean Basin as well (Donta et al. 2008). They include increasing interregional conflicts and water allocation demands, the appearance of new water users who challenge the long-term privileges of large historic water holders, and a lack of understanding of water scarcity as a risk to be managed, not as a geophysical imbalance or a structural hydrological deficit (Hernández-Mora et al. 2014).

Water transfer projects have also played a major role in Turkey (Karakaya et al. 2014). The 25 main watersheds of Turkey have distinct characteristics regarding their water potential, their economy, culture, and demography. Since some of them do meet growing, but also conflicting water demands, inter-basin water transfer projects have been planned and implemented. IBTs in Turkey primarily supply water to watersheds that contain big cities, major industries, and significant agricultural activities (Karakaya et al. 2014). While water resources in Turkey are considered state property, their utilization is guaranteed for any user. Conflicts nevertheless arise between different donor/source and receiver/user basins as well as between various water consumer groups. Economic costs in the source basins have partly been met through financial compensations, and/or transfer of wealth associated with use of water resources from the user basins to the source basins. In order to address short- and long-term socio-economic implications of inter-basin water transfers, integrated assessments and specific studies are needed (Karakaya et al. 2014).

In Cyprus, groundwater was the main source of water supply for both drinking and irrigation until the 1970s. This resulted in almost all aquifers being significantly depleted because of overpumping. Seawater intrusion was observed in most of the coastal aquifers. Population increase, as well as rising numbers of tourist arrivals on the island exacerbated this problem. Already in the early 1960s, Cyprus engaged in a program to build dams to enable the collection of rainwater in surface reservoirs (see next subsection). While this somewhat eased the supply shortage of irrigation water to the agricultural sector, the gradient in precipitation values from relatively copious amounts in the central and western part of the island versus the eastern regions of Cyprus required additional measures (Nikolakis 2008). This led to the implementation of the Southern Conveyor Project, which was seen as a necessity and a basic prerequisite for the further agricultural and economic development of the island (Water Development Department Cyprus 2000). The Southern Conveyor Project is the largest water development project ever undertaken by the Government of Cyprus (Figure 3.9). Its main objective is to collect and store surplus water flowing to the sea and convey it to areas of demand. Major components of the project, aside from the pipeline transporting the water to the east, are the Kouris Dam in south-central Cyprus, river diversions and underground tunnels. The project aims at the agricultural development of the coastal region between Limassol and Famagusta, as well as to meet the domestic water demand of Limassol, Larnaca, Famagusta, Nicosia, a number of villages and the tourist and industrial demand of the southern, eastern and central areas of the island (Water Development Department Cyprus 2009). The project area extends along the southern coast, between the Dhiarizos River in the west and the Kokkinokhoria irrigation area in the east (Figure 3.9).

Large-scale IBTs are often seen as a technical solution to restore perceived imbalances in water distribution between neighboring basins. However, the disadvantages and pitfalls that often accompany such infrastructures cast doubts on the ultimate usefulness of IBT (Pittock et al. 2009). While providing irrigation water to agriculture, IBT can also be considered to promote unsustainable and subsidized cropping practices. In planning, implementing and constructing IBTs, alternatives to the IBT that may mean delaying, deferring or avoiding the costs (in every sense) of an IBT are often overlooked or omitted. In addition, poor to non-existent consultation with affected stakeholders frequently characterizes IBT development. Finally, sufficient and adequate consideration to the environmental, social and cultural impacts of the IBT, in both the donor and recipient basins are often neglected.

Dams

Freshwater flowing into the sea is “water lost” to arid and semi-arid countries. Reservoirs and dams play a crucial role in water resources management, but also in flood abatement, mitigating the adverse effects downriver from these structures (Sordo-Ward et al. 2012, 2013). Dams are thus built to store water, but also to divert rivers so that the bulk of their water can be used by various consumers. Dams also serve as major elements of hydropower generation in several large Mediterranean rivers.

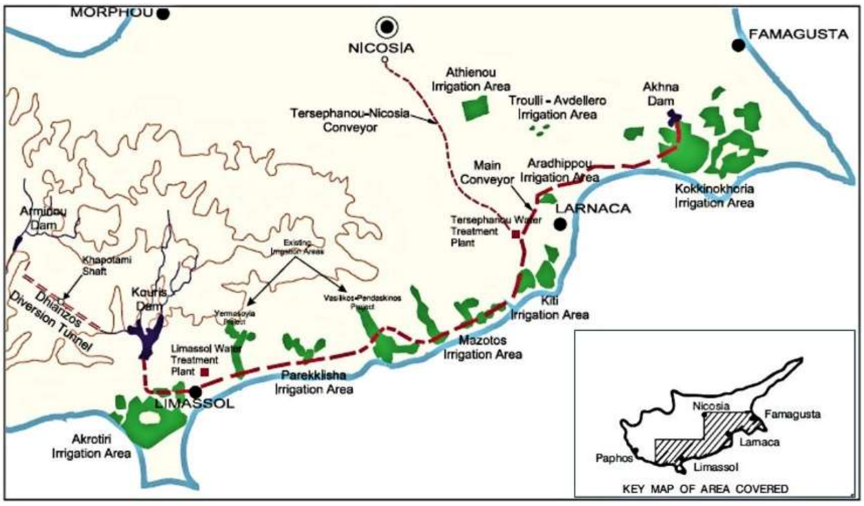

Figure 3.9 | Example for a large-scale IBT project is the Southern Conveyor Project on the island of Cyprus (Water Development Department Cyprus 2000).

The first evidence for dam building dates back to the early and middle Bronze Age (2500–1600 BC). One of the oldest records of dam building are found in the ruins of the Saad el Kafara dam near Cairo indicating that it was built in around 3000 BC (Water Development Department Cyprus 2009). Roman dams were the first that were used to create reservoirs of fresh water to secure a permanent drinking water supply for urban settlements over the dry season, and also the first to introduce dam-construction types that are being used until today (Schnitter 1978, 1987; Hodge 2000). Throughout the following millennia, relatively little progress was made and it was not until the 19th century when engineering skills and construction materials available were capable of building the first large-scale arch dams. The era of building large dams was initiated by the construction of the Aswan Low Dam in Egypt in 1902 by the British.

The abatement capacity of a dam depends on the hydrologic load, the dam and reservoir characteristics, the existing operational rules, the volume to abate and other foreseen uses related with socioeconomic activities, which in some cases may lead to conflicts. Those conflicts are particularly important in those dams that are multipurpose, usually involving flood control and other purposes such as hydropower, ecological discharges, water supply or irrigation, which may be in conflict (Labadie 2004; Dittmann et al. 2009; Bianucci et al. 2013). To reduce conflicts, the decision-making process can be improved by applying a combined approach, including simulation of predefined rules (modeling without considering any inflow forecast) and optimization programming (i.e., from stochastically generated floods or flood forecasting), taking into account the different purposes through indices such as minimizing the expected deficit of water availability (for a certain purpose), or maximizing the reliability of satisfying downstream requirements (Bianucci et al. 2015). In all cases, to minimize the conflict between consumptive demands and flood abatement, the participation of users is crucial (Martín Carrasco et al. 2007). A final consideration refers to the use of meteorological forecasting to improve dam management in Mediterranean context. As the flood events are relatively short (fast response basin) and are usually due to heavy precipitation, short-term forecasting facilitated by the combination of mesoscale models and radar imagery is needed, while to manage droughts or water resources for irrigation, seasonal forecast gives substantial added value (Marcos et al. 2017).

Large dams are defined to be of at least 15 m in height, impounding more than 3 million m^3 of water (ICOLD 2019). In the Mediterranean Basin, the World Register on Dams lists 5731 dams (ICOLD 2018), both single- and multi-purpose dams. In both, the single- and the multi-purpose dams, irrigation stands out as the most frequent purpose for dam building (50% and 24%, respectively), followed by hydropower (Figure 3.10).

Many North African countries, particularly Algeria, Egypt, Libya and Morocco, but also other Mediterranean countries including Cyprus, rely on dams and reservoirs to provide irrigation water (AQUASTAT

Programme 2007; Water Development Department Cyprus 2009). While the importance and benefits of dams for the provision of water and hydroelectric power for many of the Mediterranean countries is obvious, there are a number of adverse impacts that need to be considered (Scudder 2006; Tortajada et al. 2012).

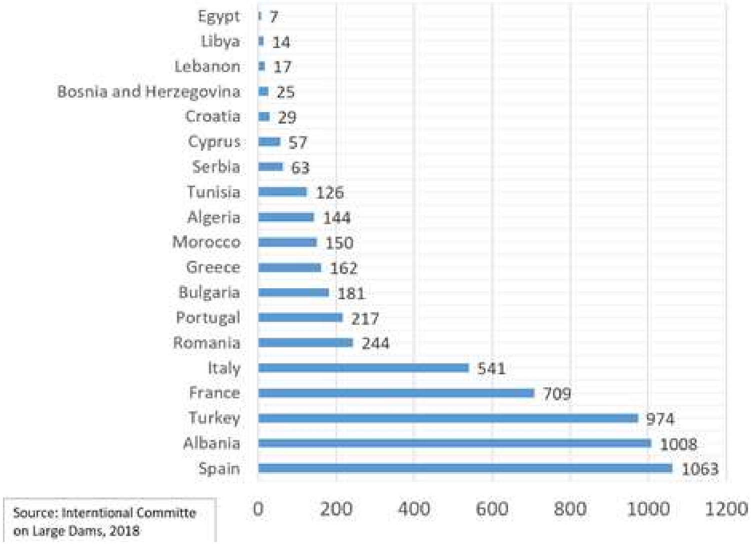

Figure 3.10 | Number of large dams in Mediterranean countries (ICOLD 2018)**.**

The reservoirs created by a dam affect many ecological aspects of a river. The impacts of large dams on ecosystems, biodiversity and downstream livelihoods have been debated for many year and include the loss of forests and wildlife species and habitats, due to inundation, and the loss of aquatic biodiversity of upstream and downstream fisheries, amongst others (World Commission on Dams 2000).

On balance, the ecosystem impacts of practically all dams are considered more negative than positive, but enhancements of ecosystem values through the creation of new wetland habitat and the fishing and recreational opportunities provided by new reservoirs have also been observed. Most efforts to counter the ecosystem impacts of large dams have had limited success. This has led to increased attention to legislation aimed to avoid or minimize ecological impacts. This includes setting aside particular river segments or basins in their natural state and the selection of alternative projects, sites or designs (World Commission on Dams 2000).

The impacts of dam building on people are also significant (Scudder 2006; Tortajada et al. 2012). In many cases, dam construction requires the state to displace individual households or entire communities in the name of the common good, leading to hardships and conflicts. In some cases, these negative effects have not been assessed nor accounted for by the relevant authorities. In addition, large dams frequently cause significant adverse effects on cultural heritage through the loss of cultural resources of local communities and the submergence and degradation of plant and animal remains, burial sites and archaeological monuments. The World Commission on Dams (2000) concludes that the poor, other vulnerable groups and future generations are likely to bear a disproportionate share of the social and environmental costs of large dam projects without gaining a commensurate share of the economic benefits. Nevertheless, if this report is cited in the context of negative impacts, Schulz and Adams (2019) conclude that neither the impacts nor the controversy over large dams have ended.

Virtual water trade

Water (or any other resource) scarcity produced through an imbalance between demand and supply, leads to price increases or negative consequences for the sectors and stakeholders that need that resource. This, in turn, typically induces several societal adaptation mechanisms, such as increased efficiency through technological development, and the opportunity to import water-intensive products from other markets. More difficult is the import of the large water volumes required for local food production due to its weight and bulkiness. The strategy of trading the commodities that would be produced with the lacking water is called "virtual water trade" and can be considered an adaptation option. "Virtual water" (VW), as defined by Allan (1998), is the volume of water used to produce a good in the various steps of the production chain. Agricultural commodities require large amounts of water from rainfall (green water) or from freshwater resources (rivers, lakes, reservoirs, canals, etc.) (blue water) (Fader et al. 2011). The third main component of the anthropogenic water cycle is grey water, defined as water released from those activities, generated in households or office buildings from streams without fecal contamination, i.e. all streams except for the wastewater from toilets affected by the consequent degree of pollution. The trade of any commodity, but in particular of agricultural ones, is associated with a virtual transport of the green and blue water used and the grey water generated for their production (Hoekstra and Chapagain 2008). Water footprints (WFs) are the other side of the medal, indicating how much water (virtual or real) a country needs to produce the products consumed by its population.

Virtual water trade, even if widely disputed as it neglects fundamental strategic and national security issues (Fader et al. 2013), supports global food security (Merett 2003). Not only the trade of water embedded in agricultural products has gained the attention of scholars and media, but also the phenomena of "appropriation" of resources across the globe has emerged under the label of "land grabbing", i.e. large-scale acquisition of farmland in developing countries by international investors (privates of sovereign funds). Scarcity of water, food and biofuels may partially drive the international trade of commodities, or otherwise stimulate the direct acquisition of resources where they are with a phenomenon, which is currently in the order of tens of million hectares (Land Matrix Initiative)[3]. It has been argued that this phenomenon should be better named as water grabbing, since water is the resource that lacks and drives the acquisitions, more than land (Johansson et al. 2016).

Hoekstra and Mekonnen (2012) calculated and mapped the green, blue and grey water footprints. They assessed both national footprints and the international virtual water flows deriving from trade of agricultural and industrial commodities. According to their analysis, most countries of the Mediterranean Basin and the Middle East are hotspots of virtual water imports (Fig. 3.11). Countries such as Portugal, Spain, Italy, Greece, Israel and Turkey are among those with the highest WF of national consumption (above 2000 m^3 $year^{-1}$ $capita^{-1}$) (not shown). Hoekstra and Mekonnen (2012) also found that cereal products have the largest contribution to the WF of the average consumer (27%), followed by meat (22%) and milk products (7%).

Antonelli et al. (2012) focus on 11 Mediterranean countries, critique earlier approaches for virtual water 'flow' calculations, and propose an input-output approach to account for both direct and indirect (e.g., irrigation schemes providing water to households and livestock) consumption of blue and green water. In their calculations, consideration of indirect water consumptions increases the values calculated for national WF, with remarkable differences in results for countries like France (higher WF and higher estimated VW imports), ending up with consideration that focus should be on blue water and on the economic potential for re-allocating water from agriculture (low marginal value) to other uses (households, industry), where the marginal value is higher. They also affirm that, since "green water cannot be moved" there should be no interest in saving it. In their analyses countries like Morocco and Tunisia appear to be much less blue water intensive than Egypt, with the latter showing very high potential for blue water saving. Antonelli and Tamea (2015) calculated the average VW imports of the MENA countries as 601 m^3 cap^{-1} yr^{-1}. Sebri (2017) suggests that the Maghreb countries are already relying on non-conventional water sources, such as waste water reuse and desalination and that they should invest more and more on strategies focused on increasing virtual water trade and enhancing water desalination technologies with the use of renewable energy as a means for abating energy costs. The author affirms that those countries do not benefit enough from virtual water trade, but that it

[3] https://landmatrix.org/

should be considered as an important policy instrument with great care, given the relevant strategic issues related to dependency on foreign countries for basic population needs.

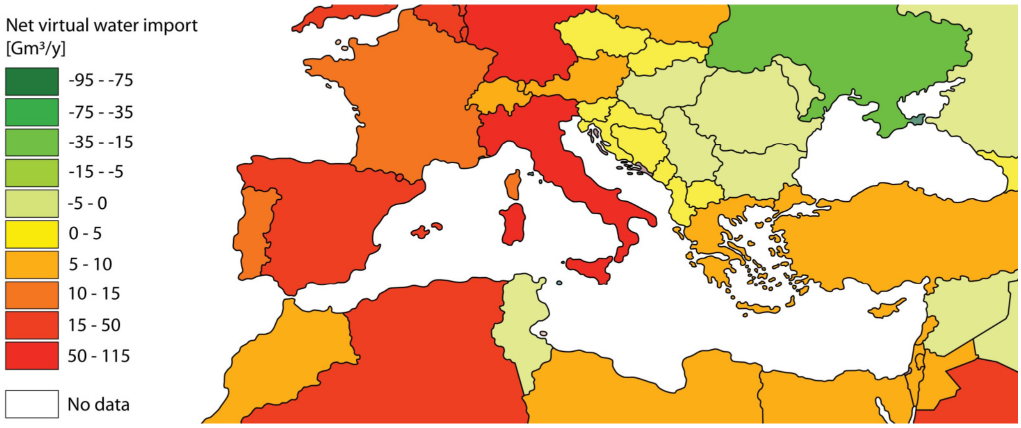

Figure 3.11 | Net virtual water imports of countries, after Fig. 2 of Hoekstra and Mekonnen (2012).

Demand-side adaptation measures

Water demand management (WDM), seen as any method that saves water, or at least saves water of higher quality, is central to the reduction of water losses. WDM incorporates, (i) improving the efficiency of water used to achieve a specific task; (ii) adjusting the nature of the task or the way it is accomplished with less water or with lower quality; (iii) minimizing the loss in water quantity or quality as it flows from source through use to disposal; (iv) shifting the timing of use from peak to off-peak periods and (v) increasing the ability of the water system to continue to supply water to the users at times when water is in short supply (Brooks 2006). This embodies technical, economic, administrative, financial and/or social measures. This section assesses some demand-side measures aiming at reducing the demand for water, such as efficient water use in households and economic sector, agricultural management for water conservation, reduction of water losses, and returning or maintaining the Mediterranean diet.

Efficient water use in households and economic sectors

Water plays an important role in the context of the UN Sustainable Development Goals (SDGs, UN 2015) and is key in several SDG targets. While water for households is dealt by Target 6.1 (Achieve safe and affordable drinking water) and 6.2 (Achieve access to sanitation and hygiene and end open defecation), consideration of efficient use of water by different sectors means focusing on Target 6.4 (Increase water-use efficiency and ensure freshwater supplies), and in particular on Indicator 6.4.1 measuring water use efficiency (WUE) to address the economic component.

A recent report produced by UN Water (UN-Water 2018) provides a comprehensive assessment of the state of SDG 6 targets across countries. Concerning Target 6.1, the proportion of population using at least basic drinking water services in 2015 appears above 90% for all Mediterranean countries, with the exception of Morocco (75-90%), and almost the same happens for 6.2, regarding the proportion of population using at least basic sanitation services, with Morocco and Algeria being between 75 and 90%, with all the other countries being above 90%. Nevertheless, there is ample room for improvement of the current situation, by adopting both innovative technologies complemented by targeted education strategies.

On the technological side of possible solutions, Campisano et al. (2017) examine opportunities for improving household water management, with focus on the potential domestic Rain Water Harvesting (RWH) systems in multi-story buildings, demonstrating that in the case study of the old town of Lipari (Aeolian Islands) there is potential for yearly water savings between 30% and 50%. Regarding household behavior, Gul et al. (2017) point out that water consumption habits are quite similar across countries and that awareness campaigns and marketing policies could both contribute to more conscious tap water use in households.

The analysis of the situation of the productive sectors is more complicated, as it requires the quantification of the various components of WUE. As suggested by FAO (2017), the WUE is defined as the value added per unit of water withdrawn over time (showing the trend in water use efficiency over time) and is calculated in US$ m^{-3} of abstracted water as the sum of the three main sectors (agriculture, industry and services), weighted according to the proportion of water withdrawn by each sector over the total withdrawals. UN-Water (2018) provides a global map of WUE per country. Mediterranean countries appear grouped into three classes of WUE (Figure 3.12). Morocco, Syria Egypt and Albania show WUE below 10 US$ m^{-3}. On the contrary, France and Croatia have a WUE between 40 and 80 US$ m^{-3}, while all other countries are between 10 and 40 US$ m^{-3}.

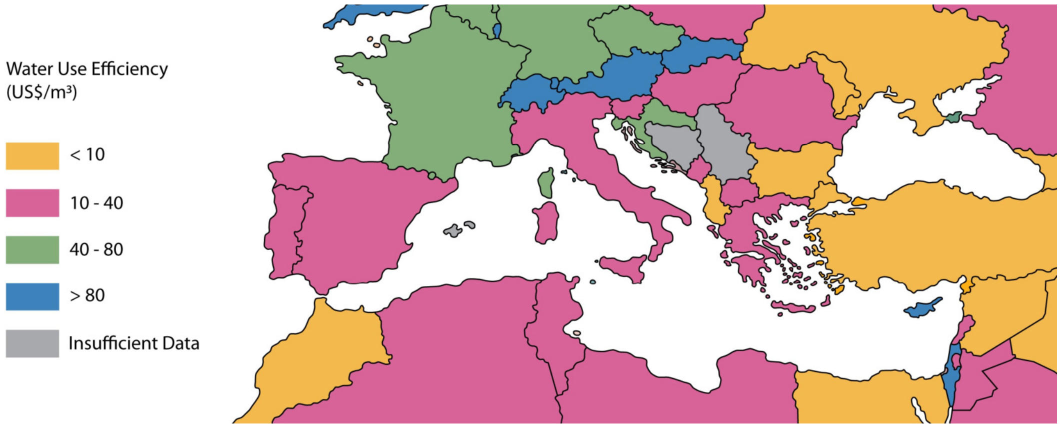

Figure 3.12 | Water-use efficiency per country (US$ m^{-3}) (UN-Water 2018).

Maximizing WUE means optimizing water allocation, in order to use the scarce resource for those uses that generate the highest value added. Wimmer et al. (2014) studied future scenarios of water allocation in Europe. Their results indicate that significant physical water shortages may result from climate and socio-economic change in many regions of Europe, particularly in the Mediterranean. Therefore, specific policies will be necessary in order to prevent conflicts among users and negative economic and social, but also environmental consequences. They also point out that cross-sectoral impacts can be limited if higher priority is assigned to the domestic or industry sectors, instead of to agriculture.

For Mediterranean tourism, Hadjikakou et al. (2013) examined five cases of holiday destinations in semi-arid eastern Mediterranean, and found that food tourists' consumption is by far the most significant contribution to the sector's water footprint, but they recommend also considering the links with energy use (Section 3.3.4.1). Moresi (2014) explored environmental impacts of the food industry, with focus on the carbon footprint, pointing out that agricultural production appears as the hotspot in the life cycle of food products, but also that Mediterranean-type diet may have positive effects on both the environment and health. Hence, prioritizing increases water use efficiencies in the tourism and food sector may contribute substantially to the adaptation potential of the region.

Agricultural management for water conservation

Water saving in agriculture includes a set of different actions (technical, socio-economic, environmental and institutional) that should be governed and adopted at each specific location according to the effective needs, priorities and probability of success. Therefore, the solutions differ for different regions and consider both rainfed and irrigated agricultural systems. In marginal rural areas, which are usually among those most vulnerable to climate change, the overall objective beside durable improvement of the agricultural water management is the stabilization of yield and a broader socio-economic development. In this context, there is a need to integrate the traditional knowledge of cultivation with the modern technical achievements and application of new technologies. For example, the adoption of minimum-tillage in suitable soils and crops can be accompanied with a series of synchronized activities that include residue cover during the off-season, appropriate crop rotation program, adequate sowing machines, use of varieties tolerant to abiotic stresses, proper sowing, planting time and density, optimized water, nutrient inputs, weed and plant disease control, harvesting, yield storage and economic evaluation of the products.

In the ACLIMAS project (www.aclimas.eu), selected crop cultivars and best management practices were implemented in five Mediterranean countries (Lebanon, Jordan, Tunisia, Algeria and Morocco) at 109 farms over a total area of about 287 ha (Section 3.2.3.1). Overall, yields increased by 19-33% compared to traditional cultivation and water saving and water rose by 20-50%. These results are in line with the findings obtained in small Mediterranean basins[4], where it has been shown that the increase of water use efficiency at basin level provide more water for all involved stakeholders, and also important economic, social and environmental benefits.

Traditional water harvesting techniques are already widely applied in the Mediterranean and they include interventions in micro and macro catchments, i.e. floodwater diversion to agricultural fields and construction of storage reservoirs, tanks, ponds and cisterns (FAO 2016b). Traditional techniques are assessed and designed by the application of modern technologies (GIS, digital land cover data, elevation models and satellite images) and implemented on the ground by new technologies for land preparation (Grum et al. 2016). Water saving and increase of water productivity can be achieved manipulating the microclimate of growing conditions by the application of different types of shelters (Ilić et al. 2012; Tanny 2013) and windbreaks (Lasco et al. 2014).

In the case of irrigated agriculture, the use of modern technologies, including remote sensing, for monitoring of crop water status and optimization of irrigation scheduling can contribute to more efficient use of water, nutrients and energy (El Ayni et al. 2012; Abi Saab et al. 2019) (Section 3.2.3.1). Water conservation and water productivity enhancement can be achieved applying supplementary irrigation and deficit irrigation strategies as regulated deficit irrigation and partial root drying (Kang et al. 2017). Other water conservation solutions, still under investigation, include plant conditioners (Boari et al. 2015; Ćosić et al. 2015; Cantore et al. 2016; AbdAllah et al. 2018) like anti-transpirants, bio-stimulants and plant growth regulators, which regulate crop transpiration and mitigate the effects of abiotic stresses, and soil conditioners (Guilherme et al. 2015), which aim to improve soil physical properties.

Some techniques of sustainable intensification, such as mulching, zero tillage, etc. increase the water retention capacity of soils making them more capable of coping with dry spells and increasing the water amount accessible to plants (Kassam et al. 2012) (Section 3.2.3.1 and 6.4). Also, more efficient irrigation systems, shifts towards drought tolerant crops, adaptation of sowing dates, application of deficit irrigation schemes, land reclamation, and land management for carbon sequestration (Almagro et al. 2016; Funes et al. 2019) may reduce water needs for agriculture and increase water use efficiency in terms of m^3 per tons. For example, the yearly water withdrawal for irrigation in the Mediterranean region amounts to ~223 km^3 (Fader et al. 2015), but there is a water saving potential of 35% through implementation of efficient irrigation systems (Fader et al. 2016). This would, however, increase the energy costs of farmers substantially (Rodríguez-Díaz et al. 2011), driving among others changes towards more profitable but more water-intensive crops such as citrus (Fernández García et al. 2014), and potentially increasing carbon emissions of energy generation. Also, the water saving effect of efficient irrigation systems may be counterbalanced by expansion of irrigated areas.

Another important factor under Mediterranean conditions relates to soil management (Section 3.2.3.2). Water scarcity, soil disturbance and nutrient deficiencies limit net primary productivity in agriculture and consequently reduce soil organic carbon (SOC) stocks, since carbon inputs, such as litter, roots or crop residues, are limited. Soil carbon sequestration occurs if the balance between carbon inputs and outputs (through emissions from respiration and mineralization) is positive and finally leads to increased SOC stocks. Future increases in temperatures linked with a decrease in available soil water

[4] http://medacc-life.eu/

content, and the corresponding decrease in yields (Waha et al. 2017) may, hence, decrease soil carbon inputs. However, although it is widely known that warming increases microbial activity, soil moisture could act as the main driver of soil biomes in Mediterranean environments, limiting SOC losses by microbial mineralization. Also, agricultural management practices can significantly affect soil hydraulic properties and processes in space and time. These responses are coupled with the processes of infiltration, runoff, erosion, chemical movement, and crop growth (Green et al. 2003). All of them promote low soil water availability for crops. In all cases, water management (irrigation or soil water harvesting and storage) is critical to the feasibility of the agricultural sector in Mediterranean regions and the avoidance of SOC losses, since available water for crops increases biomass productivity, turnover of organic matter timing and humus formation (Funes et al. 2019). More information improved water management may be found in Section 3.2.3.2.

Reduction of water losses

Reduction of water losses in all sectors of water use is crucial for sustainable management and adaptation strategies by alleviating pressure on freshwater supplies and protecting quality. Increasing water efficiency by reducing physical losses, is the basic principle in urban water use. This measure requires adequate monitoring between supplied and consumed water in order to minimize the non-revenue water (NRW) ratio. NRW is composed of water produced but not consumed i.e. not metered, not billed (wasted), and non-physical portion (consumed) not metered, not billed which is unauthorized consumption (Table 3.8) (Alegre et al. 2006). This indicates the presence of illegal connections to the municipal water network.

The water use efficiency index indicates how to measure progress in water savings through demand management, by reducing losses and wasteful use during its transmission and distribution. It covers total and sectoral efficiency in domestic (municipal), agricultural and industrial water use (Blinda 2012). The municipal water use efficiency index is defined as the ratio of the ‘total drinking water volume billed’ to the ‘total volume supplied (abstracted/treated and distributed)’ to customers by the municipalities.

A good information basis about the sources of non-revenue water (NRW) is important for water demand management, avoiding both physical (real) and commercial/non-physical (apparent) losses. In Turkey, where municipal water use has significant NRW, comprehensive rehabilitation encompassing both physical/technical and administrative improvement has decreased NRW considerably. NRW losses have been reduced by measures including the installation of bulk water meters at source to precisely measure the volume of water supplied to the city; water balance calculations by reading source, bulk and customer meters regularly; preventing reservoir overflows; synchronizing district water supply and district meter readings (establishing controlled supply zones); conducting regular leak detection studies; replacing outdated pipes and repairing leaking house connections; detecting, correcting and preventing illegal connections; and others (Burak and Mat 2010). Eliminating illegal connections in itself will not directly conserve water because consumers will still require the water they previously acquired illegally. However, once legally connected, the consumer will be subject to tariffs, which in turn should reduce the previously unmetered levels of consumption. A further benefit of legalizing these connections will be that they are properly made: illegal connections are often sub-standard and lead to high losses.

Table 3.8 | Water loss definitions and classifications (Alegre et al. 2006).

System input volume (corrected for known errors) (Water Produced + Water Imported)	Authorized consumption	Billed authorized consumption	Billed metered consumption (including water exported)	Revenue water
			Billed unmetered consumption	
		Unbilled authorized consumption	Unbilled metered consumption	Non-Revenue Water (NRW)
			Unbilled unmetered consumption	
	Water losses	Apparent losses	Unauthorized consumption	
			Customer metering / billing inaccuracies	
		Real losses	Leakage on transmission and/or distribution mains	
			Leakage and overflows at utility's storage tanks	
			Leakage on service connections up to point of customer metering	

Water losses that could be recovered losses by improved network efficiency for drinking water and irrigation have been estimated to be 56 km^3 for the whole Mediterranean region covering the northern, eastern and southern rims in 2005 (Margat and Blinda 2005). This estimate is based on improvement of drinking water (municipal) network efficiency raised to 85%, end-user (customer connection) efficiency to 90%, irrigation network efficiency increased to 90%, and plot efficiency increased to 80%. Although particularly the targeted irrigation efficiency seems to be ambitious, the corresponding saved water volume appears to deserve almost any affordable effort. An overall water use efficiency index of 74% was adopted for 2015 to be one of the desirable goals by the Mediterranean countries as part of the Mediterranean Water Strategy. In that spirit, Turkey government has decided that municipalities and water administrations had to reduce the rate of water loss, averaging 25% by 2023[5]. Tariff structures should seek to cover the operation and investment costs whilst at the same time trying to strike a balance with what is considered fair and socially acceptable.

Box 3.1 Impacts of structural aging and climate change on water infrastructure

Climate change and structural aging poses challenges for the functioning and security of water infrastructure, sometimes reducing water availability and quality. This subsection shortly summarizes this aspect with respect to dams and pipelines.

Dams

In the Mediterranean region, dams are important structures for the storage capacity of water for municipal and industrial use, irrigation purpose and energy production. Although they do not have environmental acceptance in recent years, these structures are also very important for water management in the Mediterranean basin where available water quantity does not exist where and when required. Therefore, they are also key water structures for flood control and for maintaining water readily available for inter-basin transfer projects that have been widely implemented in several water-scarce regions in recent years (Gohari et al. 2013).

The security of dams in the face of climate change impacts is very important with respect their structural security due to increase in extreme conditions (heavy storms and flooding), changing runoff conditions (Alcocer-Yamanaka and Murillo-Fernandez 2016), and also any changes in storage capacity due to siltation (Burak and Margat 2016). It is estimated that actual capacities of dam reservoirs in Maghreb

[5] https://sustainabledevelopment.un.org/content/documents/23862Turkey_VNR_110719.pdf - page 75

will decrease by 50% by 2100 due to siltation (Burak and Margat 2016). Permanent flow from upstream riparian countries (e.g., Turkey, Sudan) may not be ensured due to drought conditions (Margat 2011).

Pipelines

Pipelines are the closest infrastructure to the users; therefore, robust and well-operating water network pipelines are very important. It is quite common that water supply utilities face operational difficulties within their distribution network. Significant challenges are encountered for both rehabilitating and replacing aging infrastructure in response to growing population and new development patterns and/or shifting population (Grayman et al. 2009). In old systems, it is possible that asbestos cement pipelines (ACPs) exist even at present in some parts of the region. In Turkey, for instance, this material has been replaced in several municipal networks with ductile iron and/or high-density polyethylene (HDPE) pipes (e.g., Istanbul, Bursa and Adana) because they are low-standard pipes and because of their possible carcinogenic effect in the water network, even though there is no proven studies as stipulated by some researchers and by the WHO guidelines (Polissar et al. 1984; WHO 2003). Also, starting in 1990 in Istanbul and in other cities in the following years, investments for rehabilitation of existing water network in the new service area have been implemented in order to reduce physical losses (World Bank 2016). However, with regard to possible health risks generated by the use of ACP, practices vary from one country to another (Polissar et al. 1984).

End Box 3.1

Box 3.2 Water use and the specific Mediterranean diet[6]

The choice of diets influences the amount of water needed to produce and process the corresponding food (Section 3.2.1.2). Similarly, food waste is, at the same time, a waste of the water that was used to produce that food. Hence, influencing diet choices can be regarded as an adaptation option.

Countries like Spain are making significant efforts to reduce food loss and waste, reverse growing obesity trends, and promote the adoption of healthier food habits like the recommended and traditional Mediterranean diet. This is recognized as a key strategy to improve the population´s health with locally grown, traditional, and seasonal products like fruits, vegetables, olive oil, and fish. Nevertheless, current Spanish consumption patterns (especially among younger generations, and urban and/or low-income citizens) appear to be shifting towards unhealthier diets. The largest share of the WF of current Spanish diet, as occurring with for example North American diet, is always linked to green water, which implies that the largest impact of dietary shifts is also linked to land use. Grey water in the US is 67% higher than in Spain. Only few products account for the largest share of the total WF of the two dietary options in both countries, being meat, fats, oil, and dairy products the food items with the largest WFs.

For the year 2014, the total WF of current consumption in Spain was equivalent to around 3302 l per capita per day (of which 2555 are green, and 400 blue WF). The products that account for the largest share in the total WF are once again meat, animal fats, and dairy products. Likewise, roughly 41% of the total WF linked to household diets is foreign, i.e. imported Virtual Water, and the main countries of origin are Tunisia, Portugal, and France. The Total WF of food waste at households' level is estimated at 131 l per capita per day (of which 97 are green and 19 blue WF), equivalent to 4% of the Total WF of current consumption. In addition, regarding nutritional analysis, the nutrients wasted (because of food waste) per capita year were 40385 kcal, almost 7.5 kg of macronutrients (proteins, fats, and carbohydrates), 483 grams of fiber and almost 160 grams of micronutrients (vitamins and minerals).

Current Spanish household diet is shifting away from the recommended Mediterranean towards alternative diet containing three times more meat, dairy and sugar products, and 1/3 fewer fruits, vegetables and cereals. The Mediterranean diet is also less caloric, as it contains lesser amounts of proteins and fats, and is richer in fiber and micronutrients. Due to the high water content embedded in animal

[6] This box is based on the PhD thesis and related research papers by Alejandro Blas (Blas et al. 2016, 2018).

products, a shift towards a Mediterranean diet would reduce the consumptive water use by about 753 l per capita per day (of which 34 are blue WF). In addition, the Mediterranean diet has higher water-nutritional efficiency than current consumption: more energy, fiber, and macro- and micro-nutrients are made available per liter of consumptive water used. In conclusion, a shift back to a locally produced Mediterranean diet (in which fruits, fish and vegetables account for a larger share of the food intake) and lessening food waste, would deliver large water savings (753 and 116 liters of consumptive water per capita per day, respectively) and nutritional benefits.

End Box 3.2

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