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Reclaimed water to face agricultural water scarcity in the Mediterranean area: An overview using Sustainable Development Goals preliminary data

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## 31 Abbreviations

AEAI	=	<i>Area Equipped for Full Control Irrigation: Actually Irrigated</i>
AET	=	<i>Area Equipped for Full Control Irrigation: Total</i>
AOPs	=	<i>Advanced Oxidation Processes</i>
AWW	=	<i>Agricultural Water Withdrawals</i>
BATs	=	<i>Best Available Technologies</i>
CA	=	<i>Cultivated Area</i>
CWW	=	<i>Collected Wastewater</i>
DR	=	<i>Dependency Ratio</i>
EEA	=	<i>European Environmental Agency</i>
EU	=	<i>European Union</i>
FAO	=	<i>Food and Agriculture Organization</i>
GWW	=	<i>Generated Wastewater</i>
IWR	=	<i>Irrigation Water Requirement</i>
MDG	=	<i>Millennium Development Goal</i>
MDG 7.5	=	<i>Millennium Development Goal Indicator 7.5</i>
P	=	<i>Population</i>
RW	=	<i>Reclaimed water</i>
SDGs	=	<i>Sustainable Development Goals</i>
SDG 6.4.2. WS	=	<i>Sustainable Development Goal 6.4.2. Water Stress Indicator</i>
STWW	=	<i>Safely Treated Wastewater</i>
TRWR	=	<i>Total Renewable Water Resources</i>
TWW	=	<i>Total Water Withdrawals</i>
UN	=	<i>United Nations</i>
WHO	=	<i>World Health Organization</i>
WEI	=	<i>Water Exploitation Index</i>
WS	=	<i>Water Supply</i>
WSI	=	<i>Water Scarcity Indicator</i>
WWTPs	=	<i>Wastewater Treatment Plants</i>

33 **FIGURE CAPTIONS**

34 Fig. 1 - Global surface land air temperature anomalies (°C), 1980 – 2020, [29].

35 Fig. 2 - Global average annual precipitation (mm year<sup>-1</sup>), 2016, [29].

36 Fig. 3 - Mediterranean population growth rate graph, 1950 – 2100, [27].

37 Fig. 4 - Total renewable water resources per inhabitant (m<sup>3</sup> capita<sup>-1</sup> year<sup>-1</sup>) in the Mediterranean area, 2019,  
38 [35].

39 Fig. 5 - Dependency Ratio (DR) - Contribution of transboundary water to the total renewable water resources  
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41

42

43 **TABLE CAPTIONS**

44 Table 1 - Population, water indicators and availability of total renewable water resources in the Mediterranean  
45 area.

46 Table 2 - Inventory of legislation on water reuse in the different Mediterranean countries.

47 Table 3 - Analysis on the reuse of RW for the Mediterranean area.

## 48 1. Introduction

49 Water is a valuable resource that has been increasingly used for commercial, industrial, domestic, public  
50 supply, irrigation, livestock, mining, and thermoelectric power purposes worldwide. Nowadays, it is a limited  
51 source, especially for Mediterranean countries that are presently experiencing water stress [1–3]. Water  
52 resources are not equally distributed in space and time [4], and they are currently under pressure due to  
53 human activities and economic development. The progressive population growth has led, on the one hand, to  
54 an intensification of urbanization and to an expansion of both water supply and sanitation systems [5]; on the  
55 other hand, it has caused an increase in the global food production in order to meet the demand of a growing  
56 population [6]. This has resulted in an increased water demand. Furthermore, different climate change  
57 scenarios have projected temporal and spatial variation of dynamics associated with the hydrologic cycle,  
58 further aggravating the already existing discrepancies between water supply and water demand. In addition  
59 to water scarcity issues, industrial development has also led to the pollution of uncontaminated water  
60 resources, affecting their quality and, thus, limiting their use [7]. If this situation is not remedied soon, this  
61 trend will make the availability of water in sufficient quantity and quality even more of a worldwide challenge  
62 in the future, and especially in the Mediterranean area.

63 Within this context, different countries are exploring ways of using the so called “non-conventional” waters,  
64 mostly desalinated seawater or highly brackish groundwater and the use of treated wastewater from urban  
65 and rural settlements. The use of RW has been increasingly practised in the last years across the world,  
66 especially in arid or semi-arid areas [8], where it is necessary to preserve and use more effectively the available  
67 water resources. Furthermore, it is now widely recognised that global climate changes are progressively  
68 aggravating water shortages, resulting in a progressively unpredictable supply [9]. Generally, the use of RW  
69 can be intended as i) direct potable use, ii) indirect potable use, and iii) use for non-drinking purposes including  
70 agriculture irrigation [10]. It has been estimated that agriculture accounts for over 70% of global freshwater  
71 withdrawals [11], and therefore irrigation by means of RW would have the potential to preserve freshwater  
72 resources by avoiding their abstraction, reducing the usage of drinking water for non-potable purposes. In  
73 addition to the mentioned benefits, the use of RW might be an effective-cost and energy-safe strategy for  
74 wastewater treatment, due to the recovery of valuable nutrients from the treated wastewater [12], playing  
75 thus a key role in satisfying the main criteria for a Circular Economy strategy [13].

76 Therefore, the use of RW is increasingly practiced in Mediterranean countries, which appear very vulnerable  
77 to climate global change, with multiple potential impacts due to reduced precipitation and increased  
78 temperatures [14–16]. However, social acceptance for the use of RW is a goal to be fully achieved [17].

79 Nevertheless, different attempts have been made by international organizations worldwide (i.e. World Health  
80 Organization (WHO) [18], United Nations Environment Programme (UNEP) [19,20], United Nations Water  
81 Decade Programme on Capacity Development (UNW-DPC) [21], International Organization for Standardization  
82 (ISO) [22] and Food and Agriculture Organization (FAO) [23]) to develop guidelines and regulations for the safe

83 use of RW in agriculture. That way, they could ensure a safe practice and prevent risks for public health due  
84 to RW microbiological content, at the same time protecting the environment from the introduction of  
85 hazardous contaminants.

86 However, the main institutions of different countries are still working on the development of legislations for  
87 the direct use of RW for irrigation and aquifer recharge purposes. For instance, the European Parliament has  
88 recently approved a new legislation defining minimum requirements at European level for the safe use of RW  
89 for agricultural purposes, ensuring people and environment protection [24].

90 An appropriate legislation should lead to high quality levels of RW through the application and the combination  
91 of novel or already existing technologies available for the tertiary treatment (Best Available Technologies  
92 (BATs) [25] as defined in the Industrial Emissions Directive (IED)), guaranteeing the fulfilling of high-water  
93 quality standards. With this main aim, the most implemented tertiary methods such as physical, chemical and  
94 biological treatments [26,27] can be exploited to increase the removal efficiencies of total  
95 suspended/dissolved solids, nutrients, microbial pathogens, heavy metals, pharmaceuticals or other  
96 contaminants of emerging concern (i.e. microplastics, hydrocarbons, pesticides, etc.).

97 In this chapter, the effects of climate change and population growth on water resources have been critically  
98 discussed focusing on the Mediterranean area. For each Mediterranean country, a detailed analysis of the  
99 agricultural pressure on renewable water resources and the potential associated with the RW use to cope with  
100 this pressure has been provided. As Mediterranean countries have been chosen all of those that have direct  
101 approach to the Mediterranean Sea. From the total amount of 23, 20 countries have been reviewed in detail.  
102 Less attention has been given to Gibraltar, Monaco, and Montenegro due to their small size, lack of  
103 independent water resources or lack of data on renewable water and wastewater resources. FAO data from  
104 the AQUASTAT database have been exploited to estimate the quantity of freshwaters used for irrigation  
105 purposes, whereas recent SDG data on safely treated, generated and collected wastewater have been used to  
106 investigate the potential use of RW to meet agricultural water needs. Furthermore, a brief overview of  
107 guidelines and regulations on the use of RW in the Mediterranean countries has been provided, highlighting  
108 the barriers and the potential of using RW to cope with the issues related to water scarcity and climate change.

## 109 **2. Effects of climate change and population growth on water resources**

110 The total amount of water available in the Mediterranean area will be reduced as a consequence of three main  
111 factors: (i) temperature increase, (ii) precipitation decrease, and (iii) population growth [28], particularly in the  
112 countries already with limited renewable water resources [29].

### 113 **2.1. Global land surface air temperature anomalies**

114 Land surface air temperature is rising up at an unprecedented pace since the past century [30]. This warming  
115 is not temporally and spatially characterized by uniformity, and its evolution may irreversibly affect the  
116 hydrological cycle and the terrestrial environment in general. The distribution of mean temperature anomalies  
117 for each season has shifted toward higher temperatures and the range of anomalies has raised up (Fig. 1). As

118 it is well known, when solar radiation reaches the Earth's atmosphere, it is partially absorbed by the land and  
119 the oceans, while the rest is reflected back into the space. Some of this energy is trapped by greenhouse gases  
120 in the atmosphere, keeping the Earth warm enough to sustain life. However, recent human activities have  
121 increased the amount of greenhouse gases released into the atmosphere (carbon dioxide, nitrous oxide,  
122 methane, and others), causing a progressive increase in global land surface air temperature. Water resources  
123 are strongly vulnerable to climate change and climate variability. Among the potential climate risks for water  
124 resources are included the reduced groundwater recharge and supplies, the seawater intrusion to coastal  
125 aquifers, the reduction of freshwater availability, and the increased demand from communities and industries.  
126 Moreover, higher global land surface air temperatures may increase the risk, among the others, of bacterial  
127 contamination in water supplies [31], blue-green algal outbreaks [32] and acid-sulphate soil [33] issues.

## 128 2.2. Global precipitation

129 An increase in the average global temperature is very likely to lead to further changes in intensity, duration,  
130 frequency and amount of precipitation events, implying a strong variability in space and time of their  
131 distributions, especially in the Mediterranean area (Fig. 2). Precipitation strongly depends on atmosphere  
132 moisture: the water vapour, which feeds precipitation, originates from two main sources represented by the  
133 evapotranspiration of oceans (about 60% of the total amount) and other water resources in the inland (the  
134 remaining 40%). As the atmosphere gets warmer, it is able to hold more moisture, leading to an increase in  
135 the intensity of downpours and, then, rising up the risk of extreme events such as floods, which depend in part  
136 on how much water can be held by the air at a given time. While a steady moderate precipitation soaks into  
137 the soil and benefits the plants, the same amount of rainfalls in a shorter period of time might cause local  
138 flooding and run-off, leaving the soil much drier at the end of a single day. Floods are therefore associated  
139 with extremes in rainfall, whereas the opposite consequence due to climate change could be identify with a  
140 lack of precipitation and often extremely high temperatures that can contribute to drying the soil. These  
141 drought phenomena are further aggravated by higher values of evapotranspiration that can be detected under  
142 higher air temperatures, thereby increasing the intensity and duration of drought. While flood events are often  
143 in a local scale and are usually characterized by a short duration, droughts are extensive and might last over  
144 months or even years. In order to cope with issues related with droughts, in the field of agriculture, irrigation  
145 has been used as a mitigation approach, resulting however in a further stress for the already limited water  
146 resources. Questioning about the future, different attempts have been made by many researchers worldwide  
147 in order to develop mathematical models to predict the effects due to climate change on precipitation and,  
148 thus, on water scarcity [34,35]. As expected, their findings confirmed a trend towards reduced rainfall in  
149 coming decades, resulting in a worsening of the current situation for water resources.

## 150 2.3. Mediterranean population analysis

151 As shown in Fig. 3, population in the Mediterranean area in the 1950s was around 200 million people, while it  
152 was currently estimated to be about 500 million people [28]. The Mediterranean population continues to

153 grow, and it is expected to reach even higher values by 2100. In this context, the consequent increase of water  
154 demand has to cope with already scarce water resources in the Mediterranean area, resulting in a lack of  
155 water to satisfy the constantly growing demand. The population growth and the progressive movement of  
156 people from rural areas to cities has increased the urbanization phenomena, which on the one hand have led  
157 to an increased pressure on freshwater resources, while on the other hand has strongly modified the  
158 hydrological cycle since natural landscapes were transformed into urban water-impervious lands. The  
159 population growth will lead to an increase in water use and withdrawals for personal (mainly drinking and  
160 hygiene), industrial and agricultural (namely irrigation) purposes. Also, the more the population grows, the  
161 higher is the amount of food required by the population. However, to produce more food, the agricultural  
162 sector needs to increase its production rates, resulting in an increased water use. Therefore, agricultural  
163 productivity and population growth are closely interrelated, and both may cause issues of water scarcity and  
164 hunger. In order to meet this ever-increasing water demand in the Mediterranean area, groundwater is being  
165 extensively used to supplement the available surface water or as a source of drinking water. Also, in situations  
166 of groundwater resources in areas bordering seas such as for the Mediterranean basin, coastal aquifers  
167 became a very important source of freshwater. However, the over abstraction from groundwater and the  
168 consequent lowering of their hydraulic levels, due to an intensive water demand by higher population densities  
169 of coastal zones, will make these water resources particularly susceptible to degradation due to saltwater  
170 intrusion. The population growth, thus, may lead to more restricted access to water in certain regions of the  
171 Mediterranean area. For these reasons, an integrated water resource management approach should give  
172 priority to water supplies that directly affect people's lives and ensure their welfare in an equitable manner,  
173 without compromising the sustainability of the global ecosystems.

### 174 3. Availability of renewable water resources and agricultural water withdrawals in the 175 Mediterranean area

176 In this section, the influence of withdrawals on total renewable water resources (TRWR) will be evaluated in  
177 the Mediterranean area as well as the overall contribution of agriculture on total withdrawals.

#### 178 3.1. Total renewable water resources

179 TRWR represent the maximum theoretical yearly amount of renewable water available per inhabitant of a  
180 country at a given moment [36]. Fig. 4 shows a comprehensive picture of the TRWR per inhabitant ( $\text{m}^3 \text{year}^{-1}$ )  
181 in the Mediterranean area in the 2019 [36]. As shown in Fig. 4, water resources are not equally distributed in  
182 space. The distribution of water resources is mainly conditioned by the distribution of rainfall, which is not  
183 uniform worldwide (Fig. 2). From Fig. 4 and according to the water barrier differentiation proposed by  
184 Falkenmark [37], it can be observed that some of the countries, namely in the southern Mediterranean, fall  
185 into the categories under the threshold value of  $1,700 \text{ m}^3 \text{capita}^{-1} \text{year}^{-1}$ , confirming that those countries are  
186 currently experiencing water stress and absolute water scarcity. Countries such as France, Italy, Spain, and  
187 Turkey are not experiencing a situation of chronic or absolute water scarcity, but the presence of occasional

188 or permanent local water stress is a serious concern that cannot be underestimated. On the contrary, values  
189 higher than 5,000 m<sup>3</sup> capita<sup>-1</sup> year<sup>-1</sup> for countries located in the North-West part of the Mediterranean basin  
190 indicate that there are abundant water resources nationally, and thus for these regions water stress may be  
191 detected only locally. Such countries are for example Albania (10,307 m<sup>3</sup> capita<sup>-1</sup> year<sup>-1</sup>) and Bosnia and  
192 Herzegovina (10,693 m<sup>3</sup> capita<sup>-1</sup> year<sup>-1</sup>), as well as Croatia that is the country with the highest TWRW per capita  
193 in the Mediterranean region (25,185 m<sup>3</sup> capita<sup>-1</sup> year<sup>-1</sup>).

194 In the definition for a country on its state of water scarcity or not, it can be noted that the total amount of  
195 TRWR for each individual country refers to an averaged value. In fact, the distribution of these water resources  
196 is not usually constant in time and space, especially in the case of very large countries, implying that some  
197 regions, even if belonging to the same country, may be more affected by the water scarcity issue than the  
198 others. In this scenario of water scarcity, the mismanagement of the available water resources might  
199 exacerbate the actual situation. Proper management of water resources in the face of changing climate and  
200 population growth requires a reliable knowledge of the relationship between their availability and the effective  
201 demand.

### 202 3.2. Water withdrawals and pressure on total renewable water resources

203 As in the case of TRWR, water withdrawals in the Mediterranean area are not uniform in space and in time.  
204 The difference in water consumption in each country is mostly depending on whether the country is developed  
205 or under a developing phase. However, withdrawals of renewable water resources can take place to meet  
206 people needs or as consequence of their activities in different sectors. Different indicators have been  
207 developed in the last decades in order to investigate on the actual pressure on renewable water resources  
208 and thus on the risk of water shortage in the Mediterranean area. Selected indicators are reported here and  
209 used to assess the Mediterranean countries in more detail.

#### 210 3.2.1. Water Scarcity Indicator

211 The Water Scarcity Indicator (WSI) was developed by Falkenmark [37] to compare water availability to primary,  
212 or even basic, needs (hygiene and domestic uses), estimating that 50 L person<sup>-1</sup> day<sup>-1</sup> are needed to satisfy  
213 them [38,39]. This indicator can be calculated as reported in Eq.1 and identifies the total water resources that  
214 are available to the population of a country or region, measuring scarcity as the amount of renewable  
215 freshwater that is available for each person each year.

$$216 \text{ WSI} = \frac{P \times \text{WS} \times 365}{\text{TRWR}} \times 100 \quad \text{Eq. 1}$$

216 where:

- 217 - P = population of a country (millions of inhabitants).
- 218 - WS = water supply (50 L person<sup>-1</sup> day<sup>-1</sup>).
- 219 - TRWR = total renewable water resources of a country (m<sup>3</sup> year<sup>-1</sup>).

220 Outcomes from calculations related to WSI have been summarized in Table 1. The higher WSI have been  
221 detected for the southern countries of the Mediterranean basin (namely Algeria, Cyprus, Egypt, Israel,  
222 Lebanon, Libya, Malta, Morocco, State of Palestine and Syrian Arab Republic), for which the WSI ranged from  
223 2.1 to 17.5%, denoting that these countries are experiencing chronic or absolute water scarcity. On the  
224 contrary, the lowest WSI values ( $\leq 0.3\%$ ) for countries allocated in the North-West part of the Mediterranean  
225 basin indicate abundant water resources nationally or occasional and local water stress. Intermediate values  
226 of WSI such as for France (0.6%), Italy (0.6%), Spain (0.8%), and Turkey (0.7%) suggest that these countries  
227 are already experiencing water stress, but not at the last stage of absolute water scarcity. Furthermore, as it  
228 can be observed from Table 1, outcomes from WSI calculations were in accordance with data provided by  
229 FAO on water scarcity distribution (Fig. 4) [36].

### 230 3.2.2. Water Exploitation Index and Millennium Development Goal (MDG) Indicator 7.5.

231 As mentioned in the previous Section 3.2.1., WSI refers only to the part of freshwaters that are used to meet  
232 people primary needs. The European Environmental Agency (EEA) has then defined an indicator, commonly  
233 known as Water Exploitation Index (WEI), which instead considers the total freshwater withdrawn each year,  
234 expressed in percentage of the TRWR. This parameter is an indication of the pressure on the renewable water  
235 resources. According to EEA, countries with a WEI lower than 20% are generally identified as non-stressed. On  
236 the contrary, if the threshold value of 20% is exceeded, the country may be considered as water stressed.  
237 Furthermore, for WEI indicators higher than 40%, severe water stress may occur, indicating that the actual  
238 water use is unsustainable. In the past, WEI values could be found on the AQUASTAT database [36], which  
239 today reports this kind of information as an indicator called Millennium Development Goal (MDG) Indicator  
240 7.5. Both the indicators are defined as the percentage of freshwater withdrawn to TRWR, therefore WEI and  
241 MDG are the same, except for their name. It was possible to refer to MDG 7.5. as soon as the Millennium  
242 Declaration was introduced, in which The Millennium Development Goals and targets have been defined [40].  
243 Therefore, in this section only considerations on the MDG 7.5. will be provided. As summarized in Table 1, only  
244 a few Mediterranean countries, namely Albania (3.9%), Bosnia and Herzegovina (1.1%), Croatia (0.6%), France  
245 (12.5%), Greece (16.4 %), Italy (17.9%) and Slovenia (2.9%), have a MDG 7.5. lower than 20%. In contrast, most  
246 of the countries exceed the threshold value of 40%, or even 100% (e.g. Libya; Table 1), highlighting that these  
247 countries are experiencing a chronic water scarcity period and therefore are managing their TRWR in a non-  
248 sustainable way.

### 249 3.2.3. Sustainable Development Goal (SDG) 6.4.2 Water Stress Indicator.

250 Recently, 17 Sustainable Development Goals (SDGs) were proposed by UN Member States within the 2030  
251 Agenda for Sustainable Development framework, and the SDG 6 focuses on clean water and sanitation. Among  
252 the other proposed indicators, the SDG 6.4.2. Water Stress indicator [41] (Table 1) will provide an indication  
253 of the water stress level on TRWR due to the pressure of human and economic activities, considering also  
254 environmental water requirements. In particular, SDG 6.4.2. WS has been then derived from the MDG 7.5.

255 with the introduction of environmental flow requirements, which denote the quantity and timing of  
256 freshwater flows required to sustain freshwater ecosystems and the human livelihoods and well-being that  
257 depend on them. As reported in Table 1, the SDG 6.4.2. WS is in the range of 25-100% for eight of the countries  
258 that have been considered (Cyprus, Italy, Lebanon, Malta, Morocco, Spain, State of Palestine and Turkey),  
259 meaning that they are facing serious water stress, at least during parts of the year. It can be also observed that  
260 a similar number of countries is below that threshold, perhaps due to a more sustainable use of water or  
261 simple because of their high TRWR value. However, there are many countries with an SDG 6.4.2. WS higher  
262 than 100% (e.g. Libya, Algeria, Syria), resulting in an overuse of their available total renewable freshwater  
263 resources. These values indicate that water stress not only is hindering the sustainability of freshwater  
264 resources, but it might also hamper the social and economic development, negatively affecting the population.  
265 Comparing the three indicators together (i.e. WSI, MDG 7.5. and SDG 6.4.2. WS), it can be noted that for each  
266 of the Mediterranean countries  $WSI < MDG\ 7.5. \leq SDG\ 6.4.2.$  That trend and discrepancy among values for the  
267 same country highlight different methodology that was applied for the calculation of these parameters.  
268 Although all three parameters consider the same amount of TRWR, WSI values are the lowest since basic  
269 people needs only represent a small part of total freshwaters resources, whereas MDG 7.5. and SDG 6.4.2  
270 consider also non-basic and environmental requirements and therefore give much higher values.

#### 271 3.2.4. Dependency Ratio

272 Fig. 5 shows a map which reports the percentage of TRWR originating outside the country [36]. In Fig. 5, the  
273 contribution of transboundary water to the TRWR is expressed as percentage, which is commonly known as  
274 Dependency Ratio (DR). DR may theoretically vary in the range from 0 to 100%. A country in which the DR  
275 equals 0% denotes a situation in which all of the country's water resources are generated within its territory  
276 (e.g. an island country), while a DR of 100% indicates that a country receives all the renewable water resources  
277 from the other countries. Most of the Mediterranean countries have a DR lower than 25%, indicating that only  
278 a small percentage of its TRWR is coming from the neighbouring countries (e.g. rivers or groundwater basins  
279 shared by more countries). DR, estimating the part of water resources that a country can effectively control,  
280 can also be viewed as an indicator of a potential or current conflict between countries for water resources,  
281 especially for the ones that already have a low TRWR. For example, it is interesting to compare Croatia and  
282 Israel, the two countries that have a similar DR (64 vs 58%, respectively) but very different TRWR (25,185 vs  
283  $214\ m^3\ capita^{-1}\ year^{-1}$ , respectively). While both receive more than a half of their TRWR from the neighbouring  
284 countries, Croatia would have enough water resources even without that part. Israel, on the other hand, has  
285 a low TRWR, and therefore every further decrease is important to consider. Even more extreme is the example  
286 of Egypt that almost completely ( $DR > 98\%$ ) relies on the neighbouring countries for its renewable water  
287 supply.

288 3.3. Water withdrawals for agricultural purposes  
289 Among others, total water withdrawals (TWW) [36] are intended for industrial, municipal, and agricultural  
290 purposes. As it can be observed from Table 1, many countries bordering the Mediterranean Sea, due to ever  
291 increasing water withdrawals, are increasing the use of their TRWR. In some cases, namely Egypt, Israel, Libya,  
292 and Tunisia, TWW is currently exceeding TRWR, most probably due to the use of non-renewable water  
293 resources, confirming the water scarcity situation that they are currently experiencing. The agricultural sector  
294 is the main water user worldwide, accounting for 70% of total renewable withdrawals on average [42]. Due to  
295 the population growth, it was also estimated that the percentage may rise up to 95% in some developing  
296 countries [11]. In the last decades, agriculture has considerably contributed to the occurrence of water  
297 overuses, the situation when recharge rates of renewable water resources are exceeded by withdrawals,  
298 eventually leading to water scarcity. Focusing on the Mediterranean basin, the situation is not different. As  
299 reported in Table 1, agriculture contributes with a high withdrawal percentage, that is mostly in the range  
300 between 50 and 90% (percentage of Agriculture Water Withdrawal (AWW) [36] to TWW). The highest  
301 percentages of AWW have exceeded the 80% for countries such as Greece (80.0%), Libya (83.2%), Morocco  
302 (87.8%), Syrian Arab Republic (87.5%), and Turkey (85.1%), which are at the same time mostly the countries  
303 with scarce water resources, low TRWR and high water stress.

#### 304 4. Use of RW in the Mediterranean area

305 This section will assess the possibility of employing RW as novel strategy to cope with the increasing water  
306 demand, with particular reference to agriculture needs.

##### 307 4.1. Barriers and potential associated with the use of RW

308 Most of wastewater is re-introduced into the hydrological cycle without being neither collected nor treated  
309 [43], representing *de facto* a source of pollution of the uncontaminated water resources, namely groundwater  
310 and surface water. These polluted waters could then be used as an irrigation source in the field of agriculture,  
311 eventually leading to issues such as deterioration in soil structure (i.e. soil clogging and thus alteration of  
312 infiltration due to high content of suspended solids in the water), soil salinization and phytotoxicity. However,  
313 if all wastewater was properly treated, it could be used in various sectors, including agriculture, as a “non-  
314 conventional” source, helping to cope with the issues of water scarcity and use of water with poor quality. The  
315 use of RW for agricultural purposes is commonly perceived as riskier than using surface water resources,  
316 representing a serious obstacle to accepting a potential novel approach of using them, even though it could  
317 preserve the available freshwaters and safeguard the public and environmental health. The most common  
318 concerns related to the perceived risks to human health and to the possible consumption of food that has  
319 been irrigated by using RW are associated with the potential exposure to pathogens (i.e. viruses, bacteria,  
320 helminths and protozoa), toxic, persistent and emerging contaminants (i.e. microplastics, hydrocarbons,  
321 pesticides, etc.). These concerns are further fuelled by the absence of a univocal regulation for the use of RW  
322 in agriculture. Nonetheless, RW is already being used for irrigational (mostly for green and recreational areas

323 and lesser for crops), municipal (i.e. street washing and technical water) and industrial purposes (i.e.  
324 firefighting, process and cooling water). For this reason, in the last decades there has been a growing interest  
325 by different institutes worldwide on the definition of a regulatory framework, which would allow the use of  
326 RW for the irrigation of edible agricultural products without putting human health to risk. The first attempt  
327 was made by the State of California, which provided the criteria on the use of RW in 1978 [44]. Then, different  
328 water reuse guidelines have been developed by international organisations such as World Health Organization  
329 (WHO) [18], United Nations Environment Programme (UNEP) [19,20], United Nations Water Decade  
330 Programme on Capacity Development (UNW-DPC) [21], International Organization for Standardization (ISO)  
331 [22] and Food and Agriculture Organization (FAO) [23], respectively. However, work is still underway to move  
332 from guidelines to a more structured regulatory framework. At European level, for instance, the use of RW  
333 was identified as a good practice and encouraged by two existing EU directives [45,46] that, on the other hand,  
334 did not provide any condition or requirement for the safe use of RW. Nevertheless, EU has currently proposed  
335 a legislative plan on minimum requirements for the use of RW for irrigation and groundwater recharge [24].  
336 Therefore, despite the fact that use of RW is progressively taking place in the Mediterranean area (i.e. Cyprus,  
337 Egypt, Israel, Libya, Spain, Syrian Arab Republic, Tunisia, etc.), mostly for aquifer recharge and irrigation in  
338 agriculture, this practice is limited by the existence of different principles, regulations and applications in each  
339 Mediterranean country. Israel and Italy may be compared as two extreme examples: despite being the leader  
340 in the use of RW in the Mediterranean basin, Israeli legislation consider only around 10 parameters; on the  
341 contrary, in Italy about fifty restrictions must be respected, and only a small proportion of its treated  
342 wastewater is reused [47]. Table 2 provides a comparative review of guidelines and regulations governing  
343 Mediterranean countries, all of them being different. Hence, the necessity to define a new legislation, which  
344 should eliminate differences as well as prescribe measures for risk management [48,49] in order to the protect  
345 public health and the environment.

346 An additional limiting factor for studying the potential associated with the use of RW is the lack of data on the  
347 total amount of wastewater that is generated, collected, and safely treated. In order to cope with this issue,  
348 the Goal 6 on Water and Sanitation of SDG agenda 2030 [50] will provide countries of the United Nations  
349 Member States with the definition of flexible methods to collect the necessary data, which will be monitored  
350 in line with the existing capacity and resources of the countries and will be used to fill the current data gaps.

351 The use of RW may allow the conservation and better allocation of TRWR, particularly in areas under water  
352 stress, resulting in an increase in the total available water supply and providing a solution to water scarcity  
353 issues. Consequently, the lower energy required by the wastewater treatment and management if compared  
354 with the one currently requested by operations such as pumping groundwater, importing water, desalinating  
355 seawater or exporting wastewater, may represent a climate change mitigation measure through the reduction  
356 of greenhouse gases [51]. The use of RW may also reduce the total amount of discharges and, thus, the level  
357 of nutrients or other contaminants entering waterways and sensitive riverine or marine environments,

358 resulting in a decrease in the phenomenon of eutrophication and its main related problems. Moreover, the  
359 high nutrient content, by which domestic and municipal wastewater are commonly characterized, could be  
360 exploited as valuable source for growing crops, and resulting in a reduction of the supply of chemical fertilizers  
361 in the agriculture field [52].

362 However, in order to use RW in agriculture, produced municipal wastewater needs to be previously treated to  
363 appropriate level to meet specific water quality requirements. It has indeed been observed that if domestic  
364 and urban wastewaters are released to the environment without a proper level of treatment, they may cause  
365 several water-related diseases, including schistosomiasis and cholera [10]. Therefore, in order to increase and  
366 improve the level of treatment, different BATs have been currently applied, considering existing and new  
367 efficient treatment methods [25]. With this purpose, particular attention is paid to the water disinfection  
368 process and thus to the removal of pathogens through the implementation of advanced multi-barrier  
369 treatment schemes, which can include the application of different methods such as micro- or ultra-filtration  
370 [53], reverse osmosis [53], and Advanced Oxidation Processes (AOPs - with chemicals: hydrogen peroxide,  
371 chlorine, ozone and hypochlorite [54] or by means of physical devices: UV light [55] or other mechanical  
372 techniques [56]). Moreover, different nature-based solutions can be used for water reclamation. For example,  
373 constructed wetlands are the systems that mimic processes occurring in natural wetlands in order to treat  
374 wastewater. They have a low environmental impact, low operation costs and can also provide ecosystem  
375 services, which makes them especially suitable for small communities of decentralised treatment [52]. As  
376 advantage, the use of RW may therefore lead to an improvement of the current treatment efficiencies in  
377 wastewater treatment plants (WWTPs), preventing thus the discharge of treated poor-quality wastewater into  
378 receiving water bodies. However, higher efficiencies could be associated with higher treatment costs.  
379 Moreover, transportation costs should be considered as well since the location of WWTPs is not always in the  
380 vicinity of the RW use sites.

#### 381 4.2. Potential of RW use in agriculture for the Mediterranean region

382 In order to evaluate the impact of agriculture on the availability of TRWR, it is necessary to consider the crops  
383 water needs. The AQUASTAT database reports a parameter known as Irrigation Water Requirement (IWR),  
384 which represents the total amount of water exclusive of precipitation and soil moisture that is required for  
385 normal crop production. Values of IWR for each of the Mediterranean countries are summarized in Table 3.  
386 Crops water needs are commonly satisfied by exploiting freshwater resources, limiting their availability. The  
387 AQUASTAT database of FAO has estimated that about 44% of global freshwater withdrawals occur for  
388 agricultural purposes, whereas the remaining 56% is intended for direct consumption and later is released into  
389 the environment as wastewater. However, at least a part of this large amount of wastewater, if properly  
390 treated, may be exploited as “non-conventional” source to reduce the pressure on TRWR. Unfortunately, data  
391 on generation, treatment and use of wastewater are in most of the cases too old or even missing. An example  
392 of the lack of this important information is provided by the ACQUASTAT database, which however is the main

393 information system of water and agriculture worldwide. To fill this gap, the UN-Water Integrated Monitoring  
394 Initiative for the SDG 6 (Clean Water and Sanitation) within the framework of the 2030 Agenda for Sustainable  
395 Development will support countries, including those belonging to the Mediterranean area, in collecting data  
396 through the compilation of periodic data report on generated, collected and safely treated wastewater,  
397 respectively [50]. Even though the final data are not available yet, in this study it was possible to perform an  
398 analysis on the potential use of RW by exploiting preliminary estimated data that have been provided at the  
399 beginning of the same initiative. The analysis started considering the safely treated wastewater (STWW) (Table  
400 3), for which the estimation tracks the percentage of wastewater flows from households, services and  
401 industrial premises that are treated in compliance with national or local standards. It is by no means certain  
402 that the total amount of safely treated wastewater can be directly used for irrigation purposes due to various  
403 reasons (e.g. non-existence of the regulatory framework; different chemical, physical and biological  
404 characteristics of effluents from WWTPs depending on methods that have been used for their treatment;  
405 irrigation areas being too far from the WWTPs). However, considering the data on STWW (Table 3) and  
406 assuming that the total amount of WWTPs effluents was treated according to standards in order to allow their  
407 safe use in agriculture, it was possible to state that STWW could alone meet an average of 19.1% (percentage  
408 of STWW to IWR) of the total irrigation water requirement. The average was calculated considering all the  
409 Mediterranean countries, except for those with a STWW/IWR percentage higher than 100% (namely France,  
410 Malta, and Slovenia). Following the same logic of reasoning as for the STWW, if it were then assumed that the  
411 collected wastewater (CWW) (Table 3) or even the generated wastewater (GWW) (Table 3) could also be  
412 adequately treated in order to be used in agriculture, IWR of the Mediterranean region would be satisfied at  
413 32,1% and 35,6%, respectively. Therefore, the use of RW would certainly represent a significant contribution  
414 to meet water needs, reducing the current pressure on TRWR. However, in Table 3 are listed the individual  
415 percentages of the three parameters (STWW, CWW, and GWW) for each Mediterranean country.

416 Further considerations on the potential RW use could be provided by taking into account the cultivated areas  
417 (CA) in the Mediterranean basin (Table 3), which, according to the AQUASTAT database, are defined as the  
418 sum of arable lands and areas under permanent crops [36]. In order to cope with increasing food demand,  
419 these areas have progressively grown over the last fifty years, mostly at the expense of forest, wetland, and  
420 grassland habitats [57]. However, the cultivated areas can be further categorized as i) area equipped for full  
421 control irrigation: total (AET) and ii) area equipped for full control irrigation: actually irrigated (AEAI), (Table 3).  
422 As mentioned before, some of the Mediterranean countries, have percentages of STWW/IWR higher than  
423 100%, since their STWW were higher than the corresponding IWR (Table 3). This means that these countries  
424 not only could fully meet the irrigation water requirement by using their STWW, but also have a possibility to  
425 use a residual RW volume for different purposes. This surplus in RW could be calculated as difference between  
426 STWW and IWR, and therefore it would be equal to  $4.946 \cdot 10^9 \text{ m}^3 \text{ year}^{-1}$  for France,  $0.006 \cdot 10^9 \text{ m}^3 \text{ year}^{-1}$  for  
427 Malta, and  $0.042 \cdot 10^9 \text{ m}^3 \text{ year}^{-1}$  for Slovenia, respectively. Then, considering for instance the French country,

428 this further quantity of  $4.946 \cdot 10^9 \text{ m}^3 \text{ year}^{-1}$  would lead to an extension of the irrigable area, which could reach  
429  $4,273.9 \cdot 10^3 \text{ ha}$ . This potentially irrigable area would be higher than the AET ( $2,691 \cdot 10^3 \text{ ha}$ ), but lower than CA  
430 ( $19,348 \cdot 10^3 \text{ ha}$ ), indicating that in the case of the French country, the use of SSTW would make it possible to  
431 meet the irrigation needs of the actually irrigated area as well as of the total equipped area for irrigation, and  
432 also of part of the cultivated area that is not equipped for irrigation. The same could be said for Malta, for  
433 which IWR is  $0.012 \cdot 10^9 \text{ m}^3 \text{ year}^{-1}$  and AEAI is  $3 \cdot 10^3 \text{ ha}$ . Then, the potentially irrigable area would be  $4.5 \cdot 10^3 \text{ ha}$ ,  
434 which would be higher than the AET ( $4 \cdot 10^3 \text{ ha}$ ) and lower than CA ( $11 \cdot 10^3 \text{ ha}$ ). Also the same for Slovenia,  
435 which has an IWR of  $0.001 \cdot 10^9 \text{ m}^3 \text{ year}^{-1}$  and an AEAI of  $3 \cdot 10^3 \text{ ha}$ , with a potentially irrigable area of  $129 \cdot 10^3 \text{ ha}$   
436 that would be higher than the AET ( $3 \cdot 10^3 \text{ ha}$ ) and lower than CA ( $238 \cdot 10^3 \text{ ha}$ ). However, contrary to France and  
437 Malta, for Slovenia it can be noted that CWW and GWW are not the same as STWW. Hence, if CWW would be  
438 considered instead of STWW for the calculation of the potentially irrigable area, it would increase from  $129$   
439  $\cdot 10^3 \text{ ha}$  to  $228 \cdot 10^3 \text{ ha}$ , which would be lower than the AET ( $3 \cdot 10^3 \text{ ha}$ ) and still be lower than CA ( $238 \cdot 10^3 \text{ ha}$ ).  
440 However, if GWW would be used for the calculation of the potentially irrigable area, it would further increase  
441 to  $267 \cdot 10^3 \text{ ha}$  and this time would be higher than  $238 \cdot 10^3 \text{ ha}$ , indicating that it could be not only possible to  
442 satisfy the irrigation needs of both the actually irrigated area and the total equipped area for irrigation, but  
443 the cultivated area would be even extended. Hence, the importance of treating all the generated wastewater  
444 (GWW) in order to increase the potential of the RW use, resulting in a potential increase in arable land in use  
445 and consequently in agricultural production.

446 Considering the use of STWW, CWW or GWW to cover at least a part of IWR, gains much more on importance  
447 when water scarce countries are considered. Since Israel collects all of its GWW, and more than 90% of it is  
448 safely treated, it can be used to cover more than 50% of its IWR and thus reduce the pressure on renewable  
449 water resources. However, Israel already reuses a large portion of its wastewater for agriculture [47]. Algeria  
450 could also cover more than 50% of its IWR in the case of CWW or GWW reuse, while that percentage falls  
451 considerably for STWW since most of its CWW or GWW is not safely treated. Table 3 gives also other notable  
452 examples (e.g. Cyprus, Greece or Lebanon), leading to the conclusion that treated wastewater should be given  
453 the importance that it deserves as a resource that can help to mitigate effects of water scarcity.

## 454 5. Current research on the use of non-conventional water resources in the 455 Mediterranean region

456 Partnership for Research and Innovation in the Mediterranean Area (PRIMA) is a joint programme that focuses  
457 on the achievement of integrated and sustainable management of agro-food and water systems in the  
458 Mediterranean region (PRIMA, 2020). Thus, PRIMA will also contribute to United Nations' Agenda 2030  
459 through the achievement of the Sustainable Development Goals (SDGs). PRIMA aims to build research and  
460 innovation capacities and to develop knowledge and common innovative solutions for agro-food systems, to  
461 make them sustainable and more climate resilient, taking into account also environmental, social and other  
462 factors. The Partnership consists of 19 countries in total, including some European Union Member States,

463 Horizon 2020 Associated Countries and Mediterranean Partner Countries. Although still in its beginnings,  
464 PRIMA has already financed projects that deal with overcoming water scarcity in the Mediterranean  
465 agricultural sector. For example, the main objective of the project Safe and sustainable solutions for the  
466 integrated use of non-conventional water resources in the Mediterranean agricultural sector (FIT4REUSE,  
467 <https://fit4reuse.org/>) is to provide safe, locally sustainable and accepted ways of water supply for the  
468 Mediterranean agricultural sector by exploiting non-conventional water resources, namely treated  
469 wastewater and desalted water. In particular, FIT4REUSE will focus on innovative treatment technologies and  
470 on the use of non-conventional water resources in agriculture and for aquifer recharge, including the partners  
471 from 7 Mediterranean countries (Spain, France, Italy, Greece, Turkey, Israel and Tunisia). The project organises  
472 its activities within the three main pillars: i) innovation of wastewater treatment and desalination technologies,  
473 ii) application of non-conventional water resources for irrigation, fertigation and aquifer recharge, as direct  
474 and indirect water reuse schemes, and iii) assessment and regulation of the solutions and schemes proposed,  
475 followed with the engagement of research, governmental and industrial partners from different parts of the  
476 Mediterranean region.

## 477 6. Conclusions

478 Climate change is expected to have a growing impact on water resources worldwide, especially for the  
479 Mediterranean area, which is already experiencing issues related to water scarcity. Higher air temperatures  
480 could lead to increased evapotranspiration rates, radically modifying the soil characteristics and compromising  
481 the natural recharge of groundwater resources. The growing population and the global trend of urbanization  
482 will require higher volumes of available water and ensuring enough supplies in terms of both quantity and  
483 quality is a primary concern, since it might be seriously hindered by the temporal and spatial variability of  
484 water resources and climate change. Agriculture is one of the main sources of pollution of renewable water  
485 resources due to the widespread use of nutrients, pesticides, and other common contaminants. Within this  
486 context, there is an increasing interest in improving the agricultural productivity on a sustainable basis, while  
487 keeping unaltered natural renewable water resources and minimizing the negative impact that agriculture  
488 may have on the environment. Agriculture is not only a cause of contamination for renewable water resources,  
489 but it is also the reason of their increased consumption. The use of non-conventional water resources, and in  
490 particular the use of RW could be an effective solution to the issue of water scarcity. In addition to being a  
491 valuable water source for the mitigation of the impacts of climate change, RW could also lead to a radical  
492 change in the irrigation practice, promoting circular economy and use of nutrients present in wastewater in  
493 order to reduce artificial fertilizers consumption. However, the definition of a new regulatory framework might  
494 be necessary to specify water quality control and monitoring criteria for the safe use of RW, and thus,  
495 overcome the limitations of current legislation. For the Mediterranean area it has been observed that the use  
496 of RW could significantly contribute to meet water needs and, therefore, to decrease the current pressure on  
497 TRWR, providing a novel strategy to face water scarcity and climate change issues. Furthermore, for some of

498 the Mediterranean countries, the use of RW could increase the extension of cultivated areas under irrigation,  
499 favouring a higher food production. However, further studies and monitoring activities for data collection will  
500 be needed on both local and national scales in order to accurately quantify the exact amount of RW that could  
501 be used in the agriculture sector, with the main aim of dealing with the deficit of available freshwaters, which  
502 are currently characterized by lower availability of renewable waters and higher withdrawals.

503

504

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510 industriale” - POR-FESR Emilia Romagna Region 2014-2020 - <https://valuecein.eu/>).

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