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Review

Availability and Feasibility of Water Desalination as a Non-Conventional Resource for Agricultural Irrigation in the MENA Region: A Review

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Abstract: Many countries in the MENA region (Middle East and North Africa) are facing water scarcity, which poses a great challenge to agricultural production. Furthermore, water scarcity is projected to increase due to climate change, particularly in arid and semi-arid regions. The integration of solar power and water desalination systems in greenhouses to overcome water shortages is one of the preferred technologies in crop-growing areas. Crop growth control is done through sufficient management of environmental climatic variables as well as the quantity and quality of water and applied fertilisers with irrigation. Numerous crops such as cucumbers, tomatoes, peppers, lettuces, strawberries, flowers, and herbs can be grown under greenhouse conditions using desalinated water. This paper displays the state of the art in (i) solar-driven saltwater desalination to irrigate crops, (ii) the feasibility of water desalination for agriculture in the MENA region, (iii) the economics and environmental impacts of the desalination process, (iv) the quality of desalinated water compared with other non-conventional water resources and (v) recommendations for the future in the MENA region.

Keywords: solar desalination technology; saltwater; greenhouse; water quality; productivity; crops; climate change

1. Introduction

The MENA region is one of the most responsive regions to climate change and its effects on water resources. Moreover, many countries in the MENA region are facing water scarcity, which impedes agricultural development. It is projected that the annual demand for water in the MENA region will increase almost five-fold from 42 to 200 km^3 by 2050 as a result of population growth and the expected negative effects of climate change. Indeed, the amount of fresh water available to the citizens of MENA decreased by half from 3000 m^3/capita to 1500 m^3/capita from 1975 to 2001, largely due to rapid population growth. At present, a citizen in the MENA countries consumes slightly over 1000 m^3, compared to the average global consumption, which reaches more than 7000 m^3. In fact, most of the world's top twenty water-limited countries are in the MENA region [1].

In Egypt, as in most Mediterranean countries, agricultural production suffers from a water shortage. This is exacerbated by increasing demand and the negative impacts of climate change [2–4]. In this context, Elsaeed [5] showed that it is crucial to obtain new alternative water resources in

Egypt. The water supply in Egypt comes mainly from three sources: the Nile (95%), rainfall (3.5%), and groundwater (1.5%). The Nile gives 55.5 billion m^3 per year, while the other two sources combined provide around 2.2 billion m^3 of fresh water. Egypt's freshwater reserves are around 58 billion m^3 per year, however, the country's annual water requirement is approximately 77 billion m^3. The process of recycling is a way of reducing the gap between supply and demand of water in Egypt. The water shortfall, which is about 19 billion m^3, is met by a mixture of recycled wastewater from agriculture (8 billion m^3) and treated industrial effluent and sewage (4 billion m^3). In addition, a supplementary 4 billion m^3 of shallow aquifers are extracted, and 3 billion m^3 are received from the Al-Salam Canal project [6], (Figure 1).

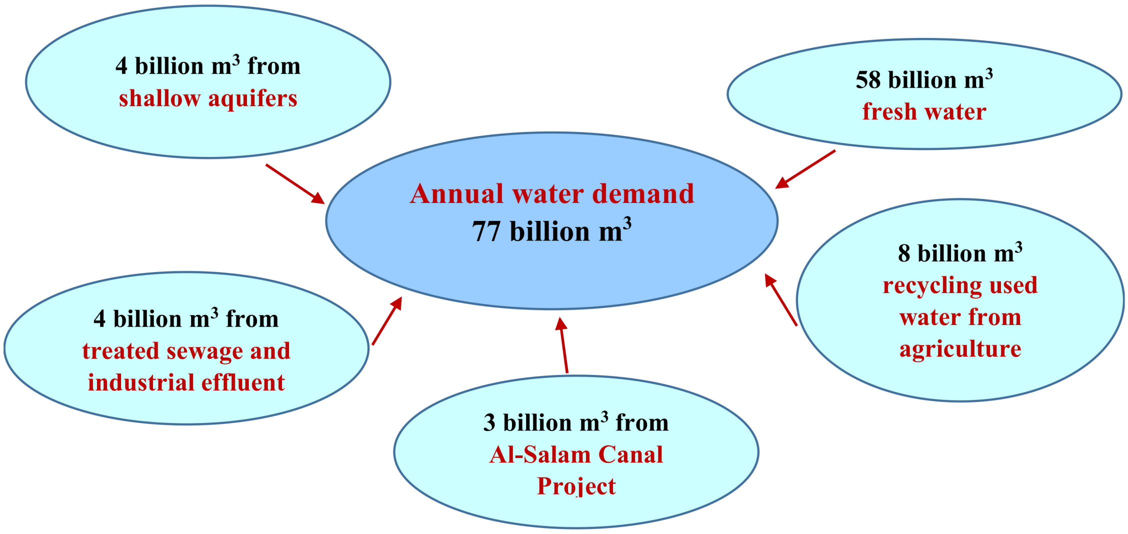

Figure 1. Annual water requirements in Egypt and the sources from where they are obtained.

Similarly, the other countries in the MENA region such as Morocco, Algeria, Tunisia, Libya, Mauritania, Sudan, Lebanon, Jordan, Iraq, Syria, Saudi Arabia, Kuwait, Bahrain, Qatar, the United Arab Emirates, Oman and Yemen suffer from water shortages [7]. Increasing water shortage in these countries requires finding non-conventional water resources such as saltwater, agriculture drainage and wastewater to meet the growing demands for water [8–10]. Solar desalination is a novel approach to produce water with a low salt concentration using solar energy [11]. This paper presents the importance of using solar energy for saltwater desalination to produce economic crops, especially in greenhouse systems, and the possibility of applying that in the MENA region.

2. Expectations of Water Shortage in the Future

It is projected that water availability in the MENA region will decrease due to climate change [2,12,13]. Total renewable water resources will be significantly reduced due to the fluctuations in precipitation and evapotranspiration [14]. When considering the data for the whole MENA region, the total renewable water resources will decrease by about 12% (equal to 47 km^3) a year, as illustrated in Figure 2 [15].

Furthermore, it is expected by 2050 that irrigation water requirements will increase by about 15% over present requirements, if global warming will cause wet weather [2,16,17] (Table 1). Conversely, if the climate becomes drier, irrigation requirements are expected to increase by about 33%. Overall, water requirements are estimated to increase by approximately 24% over the current requirements [16,17].

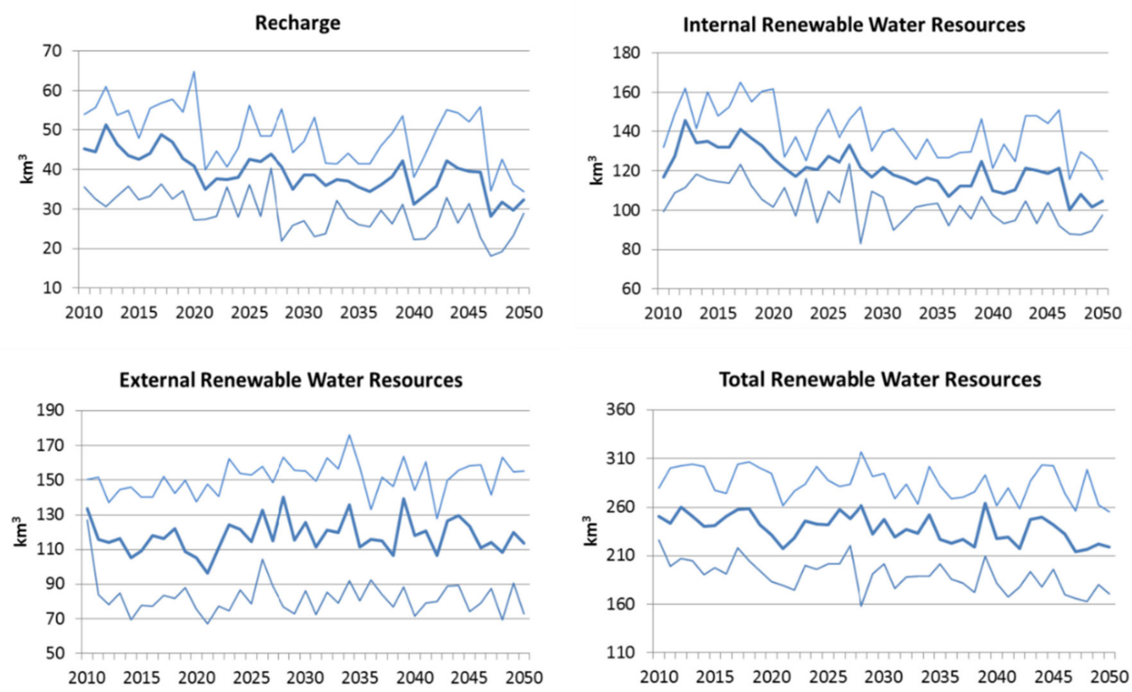

Figure 2. Total gross recharge, internal, external and total renewable water resources in the MENA region from 2010 to 2050 [15].

Table 1. Projected irrigation water requirements in the MENA region (km^3/year) and the percentage increment over the current requirements [16].

Climate Scenario	Average	Dry	Wet
Current 2000–09	213	-	-
2020–30	237 (+11%)	254 (+19%)	222 (+4%)
2040–50	265 (+24%)	283 (+33%)	246 (+15%)

Note: - = not available.

3. Using Solar Energy in Water Desalination to Irrigate Crops

Using water desalination by means of solar energy in agricultural production is crucial as a simple and low-cost technique to cope with water shortages particularly, under current climate change [2,18,19]. Using solar energy in seawater desalination requires solar-energy humidification–dehumidification desalination, thermal diffusion-driven desalination, solar stills, solar membrane distillation, hybrid desalination plant systems that integrate thermal and membrane desalination processes, intense solar energy-based desalination, solar pond distillation and nanomaterials for solar distillation technology [20].

Roca et al. [21] elucidated that water shortages in the Mediterranean region severely affect food production. Accordingly, using thermal desalination processes is needed to avoid the exploitation of aquifers to supply water to the crops. They used a greenhouse at the experimental station of the Cajamar Foundation in Almería, Spain. The cultivation of crops was carried out in two multiple tunnel greenhouses. Crop growth and crop management conditions were adjusted to be analogous to commercial greenhouses. A meteorological station was installed outside the greenhouse in order to record rainfall, relative humidity, temperature, light radiation, wind direction and velocity. Also, the climate variables inside the greenhouse such as air temperature, soil temperature, leaf temperature, photosynthetic active radiation (PAR), solar radiation, relative humidity, CO_2 levels, and leaf wetness were measured, as well as the electrical conductivity and the pH in both irrigation and drainage water. They attempted to reduce the cost of producing fresh water from the solar desalination technique by using a hierarchical controller; using an appropriate control system with solar desalination reduces the electricity costs. Moreover, an external source of energy could be involved to confirm continuous freshwater production. Davies and Paton [22] modelled a greenhouse with humidification–dehumidification that combined a solar desalination scheme by utilising a computational fluid dynamics model, and calibrated the model with data from a preliminary greenhouse model in the United Arab Emirates. Their results indicated that this technique increased freshwater production, and simultaneously decreased the air temperature in the greenhouse.

Salem [23] indicated that solar-powered desalination is extremely appropriate under sunny environments such as those in the MENA region. Both efficiency and economy should be taken into consideration before using solar-powered water desalination. A novel scheme of humidification–dehumidification for desalination reduces the temperature inside greenhouses. Accordingly, this system produces fresh water from seawater as well as supplying a perfect environment for cultivating temperate crops. This approach produces required fresh water for crop production in a greenhouse system. It acts as a thermal still while giving a suitable environment for growth and crop production.

Furthermore, nanoparticles such as metal oxides could be used to increase the energy efficiency of the solar stills, which is a novel approach in this respect. These particles increase the absorption surface area to solar radiation ratio. In this context Sain and Kumawat [24] utilised nanoparticles of aluminum oxide (Al_2O_3) combined with black paint to enhance the efficiency of the solar still. They demonstrated that mixing nanoparticles with black paint increased the temperature of the solar stills. Accordingly, this led to a 38.1% increment in productivity of the solar still and a 12.2% increase of thermal efficiency compared to black paint without nanoparticles.

4. Feasibility of Saltwater Desalination in Greenhouse Systems

In the deserts, plants are exposed to harsh conditions due to environmental stress, low soil fertility, low precipitation and shortage of fresh water for irrigation. The deserts adjacent to sea water could be exploited by performing saltwater desalination in the greenhouse systems. Simple transparent solar stills could be used in new solar-powered agriculture greenhouses for water desalination [25]. The stills are fixed on the greenhouse roof surface. A certain amount of solar radiation is intercepted by the plants for the photosynthesis process and the main part is collected by the solar still units for desalination [25]. Under tropical and temperate conditions, a humidification–dehumidification (HDH) water desalination system can produce 11.6 and 20.4 m^3/year-ha fresh water, with power consumption of 1.6 and 1.9 kWh/m^3, respectively [22]. The HDH system was prepared to provide a cool and bright environment in desert climates in the vicinity of saline water, with several benefits compared to traditional greenhouses [11,26]. There are many types of greenhouses, including lean-to, even-span, uneven-span, Quonset/hoop-house, Gothic arch, elliptical, spherical dome, conventional and smart [27]. It is interesting to note that the spherical dome-type greenhouse represents the best geometrical shape that allows for a greater penetration of solar radiation to the crop plants (Figure 3a). A smart greenhouse system gives complete control of environmental conditions and agricultural processes through remote control (Figure 3b). It is extremely important to control the temperature in a greenhouse environment [28]. Remote monitoring and control systems protect the plants from precarious temperatures. This is performed through sensors to measure environmental variables (humidity, soil temperature, and air temperature, both outdoors and indoors) and actuators (such as shade screens and LED lights) are connected to automation software. Integrated climate systems, which include irrigation and dosing systems are also connected to automation software [29].

In this context, Kim et al. [30] investigated the impacts of irrigation with desalinated water on the growth of lettuce (*Lactuca sativa* L.) in South Korea, compared with saline under controlled greenhouse conditions. Their results showed that using saline irrigation water increased the salinity level in the soil and, consequently, adversely affected lettuce growth and yield, while desalinated water did not have these negative effects. Similarly, Martínez-Alvarez et al. [31] reported that irrigation using seawater desalination has been greatly applied in southeastern Spain in the last decade due to rising pressure and competition for water resources.

Irrigation and fertilisation are essential for agricultural production [2,32]. Kafkafi and Tarchitzky [33] demonstrated that fertigation has numerous benefits compared to applying fertilisers and water separately. These benefits comprise reducing the loss of irrigation water due to leaching, maintaining an optimal balance of nutrients by directly applying nutrients to the root zone, controlling the concentration of mineral elements in the soil solution, reducing energy costs, timing the fertilisation based on the plants' requirements, and mixing the fertilisers with other micronutrients [34]. Therefore, fertigation is a flexible technology that can be simply combined with the greenhouse system. In this context, Martínez-Alvarez et al. [31] recommended using fertigation with desalinated seawater because the fertilizer and irrigation costs are reduced.

(a) **(b)**

Figure 3. Certain types of greenhouses: (**a**) a spherical dome greenhouse and (**b**) a smart greenhouse [27,35].

5. Possibility of Water Desalination for Agricultural Production in the MENA Region

Recently, desalination technologies have been developed and utilised with improved technology and lower costs. Moreover, their application has been extended to the agriculture sector worldwide [36,37]. The determination of desalinated water costs must consider three factors: (i) energy requirements, (ii) feed water quality, and (iii) water quality of the product. Kabeel and El-Said [26] reported that most countries have high solar energy potential for rural water supply and irrigation. HDH systems were developed, with technical and economic considerations, for agricultural use and drinking water requirements in arid regions. These systems contain a humidifier and a dehumidifier, energy sources for heating and electrical energy generation as well as accessories for the fluid transfer and control devices [38–40]. The main crop requirements inside greenhouses in an HDH system are given in Table 2 [41,42]. Presently there are about 200,000 ha of classical greenhouses in Mediterranean countries, used to produce fresh water from saltwater, and used to provide water for irrigation, which reduces groundwater depletion [26].

Table 2. Requirements of certain crops in greenhouses in a humidification–dehumidification (HDH) system [26,41].

Crop	Temperature (°C)	Relative Humidity (%)	Water (L m^{-2} day^{-1})
Cucumber	20	60–65	3
Tomato	15–25	60–65	3
Pepper	20	60	3
Flower	15–25	70–90	8
Lettuce	20–25	60	3

The countries of the MENA region suffer from some of the greatest water shortages in the world. Simultaneously, this region is considered the largest importer of agricultural products. Consequently, solar desalination could be used to provide fresh water for agricultural production in that area.

Recently, Egypt started a major national project in 2019 to establish 100,000 greenhouses, including 5000 greenhouses over an area of 8500 ha in the areas of El-Hammam, Abu Sultan, the Tenth of Ramadan and Al-Amal village east of Ismailia. The use of high-tech greenhouses for some crops has led to a 90% saving in irrigation water with a six-fold increase in productivity compared with open agriculture, as well as increasing the supply of different vegetable varieties in the market for citizens, at economic prices throughout the year [43].

It is worth mentioning here that Saudi Arabia is one of the most specialized countries in desalination in the Arab world, with 18% of its global freshwater production coming from desalination. In this country, more than 1.6 billion m^3 of water are annually produced by desalination, followed by the United Arab Emirates and the United States of America, with each desalinating up to 13% of water for fresh water. Worldwide, there are more than 15,000 water plants dedicated to seawater desalination, producing 60 million m^3 of water per day. Furthermore, Qatar uses about 1.2 million m^3/day from desalinated water. However, agricultural production could be increased if the farmers apply the most efficient systems such as drip or sprinkler irrigation and hydroponics [44].

During the summer season, Tunisians face problems with their drinking water supply. Therefore, 200 desalination plants were established in 2018 on the island of Djerba (one of the most popular tourist destinations in Tunisia), where the treated water is directed mainly to the cities of Djerba on the island and Zarzis on the nearby mainland. The desalination plant produces 50,000 m^3 of drinking water per day, which can be expanded to 75,000 m^3 per day. The operation of the desalination plant contributes greatly to the economic, social and environmental progress of the island. It is the largest seawater desalination plant, in terms of total area, of the entire Maghreb region [43].

Hirich et al. [45] showed that a greenhouse-cropping system is used frequently in the region of Souss-Massa in Morocco; it covers an area of more than 15,000 ha. Nevertheless, the region has a great problem of water scarcity as the annual precipitation does not surpass 200 mm, and the water shortage is more than 260 million cubic metres. Moreover, agricultural production in this region uses about 90% of the available water. Furthermore, the increased costs of over-pumping due to the low-level of groundwater, especially in coastal areas, exacerbates environmental problems. The use of desalinated seawater to irrigate crops such as tomatoes, berries, and various vegetables can be an economic alternative to ensure the continued production of horticultural products. Table 3 shows the production of certain crops in the Souss-Massa region of Morocco in 2010 and 2013, as well as the expected yields for 2020 [45]. The highest production comes from vegetables, followed by citrus fruit. This region produces about 77% of Morocco's vegetables, 40% of the production of citrus fruit, and only 2% of the production of olives. Moreover, the expected increase in agricultural production by 2020 will necessitate more water requirements. Consequently, progress in desalination technologies is needed to provide the required amount of water in these regions, at economical costs.

Table 3. Production of some crops in the Souss-Massa region of Morocco [45].

Product	2010 (ton)	2013 (ton)	2020 (ton)
Vegetables	1480 (77%)	1778	2140
Cereals	385 (5%)	283	287
Citrus	646 (39%)	893	1070
Olive	27 (2%)	28	43
Other fruits	562 (18%)	571	677

Vegetable crops such as those in the solanaceous family (i.e., tomato, potato, eggplant and pepper) and the cucurbits family (i.e., watermelon, melon, cucumber and summer squash) are suitable for greenhouse conditions. Success of these crops under controlled cultivation is due to their good adaptation and growth across several cultivation cycles, as well as their economic convenience. These crops represent about 80% of the controlled cultivation in most countries in the MENA region [46]. Furthermore, these crops are produced in large quantities in the MENA region, as illustrated in Table 4, [47]. Subsequently, it is efficacious to use desalinated water for producing these crops under greenhouse conditions.

Table 4. Total production of some vegetable crops in the MENA countries during 2018 (in tonnes) [47].

Country	Cauliflower and Broccoli	Melon and Cantaloupe	Potato	Tomato	Watermelon	Cucumber and Gherkin
Algeria	207,697	-	4,653,322	1,309,745	2,095,757	193,647
Bahrain	461	575	68	4114	194	546
Egypt	127,273	701,071	4,896,476	6,624,733	1,483,255	457,795
Iraq	11,285	113,538	294,778	266,294	222,595	114,828
Jordan	66,034	40,673	177,431	839,052	110,417	209,362
Kuwait	13,252	2811	36,212	97,991	749	58,590
Lebanon	20,549	13,091	387,791	300,157	65,384	151,558
Libya	7457	26,351	348,361	215,584	236,012	9269
Mauritania	-	-	2260	-	2980	-
Morocco	59,056	500,823	1,869,149	1,409,437	742,375	47,787
Oman	28,031	33,463	15,613	199,232	56,047	12,545
Qatar	1455	2463	17	25,105	426	1761
Saudi Arabia	-	39,360	482,305	312,343	634,491	115,617
Sudan	776	35,259	442,988	674,378	172,867	240,405
Syrian Arab Republic	23,841	54,000	540,000	669,000	230,900	104,397
Tunisia	14,332	102,546	423,800	1,357,621	548,649	76,425
United Arab Emirates	6500	3686	451	78,607	2205	71,350
Yemen	-	27,029	248,889	114,297	146,507	14,715

6. Economics of the Desalination Process

The process of assessing the cost of water depends on many factors, including: benefits of the produced water in the long run, the greenhouse cost, the type of water desalination process, the plant production capacity, the water quality, the options available for waste disposal, the annual market value of production, the costs of labour, maintenance marketing, transportation and the cost of employees during the life of the plant [45,48,49].

Chaibi and Bourouni [50] evaluated the impact of the water cost on crop productivity. They disclosed that the water desalination process could be economically advantageous for farmers to produce great commercial value if they followed the technical recommendations for a high crop yield production.

Hirich et al. [45] showed that the process of water desalination would support agricultural development in the Souss-Massa region with respect to production and export of agricultural products such as vegetables and fruit. They reported that although the pumping cost in the Souss-Massa region (cost US\$0.3/m^3) is cheaper than the desalination process (US\$0.5/m^3), most farmers are motivated to use desalinated water for irrigation. This indicated that the farmers are aware of the scale and implications of the water shortage problem in the region.

The current shortage of water resources in Egypt is about 20 billion m^3, and the economic cost of desalinated water is still high [51]. The production of the existing desalination plants contributes to about one billion m^3 of water, at a cost of 20 Egyptian pounds per m^3 of desalinated water. Therefore, it is not economically efficient to irrigate extensive crops such as wheat, corn or rice using desalinated water. Table 5 shows the installation and water production costs for some types of desalination plant [16]. These details reveal that using desalinated water is not economical for growing field crops, but is economical for producing high price vegetable and fruits crops.

Table 5. Installation and water production costs of several types of desalination plant [16].

Desalination Plant	Installation Costs (US $/m^3)	Water Production Cost (US $/m^3)
Multistage flash distillation	1200–1500	1.10–1.25
Multiple-effect distillation	900–1000	0.75–0.85
Multistage flash distillation (Singapore)	2300	1.50
Multiple-effect distillation (Metropolitan Water District, California, USA)	660	0.46
Vapour compression distillation	950–1000	0.87–0.95

7. Environmental Impacts of the Desalination Process

Throughout the establishment of seawater desalination plants and the installation of desalination equipment and technologies, water pollution caused by turbidity might lead to the death of marine organisms. In addition, water withdrawals and drainage could lead to some modifications to the seabed as a result of the withdrawal of marine organisms with water, which may also cause blockages in the pipes. Desalination may also have an impact on fisheries and coral reefs, and lead to the spread of chemicals. Additionally, the residuals (high temperature and high-salinity water) of the desalination processes could lead to the death of marine organisms, particularly coral reefs and the residuals could reflect negatively on the seabed as they lead to pollution when they enter the sea [52,53].

Additionally, the desalination process results in atmospheric and marine pollution, caused by brine disposal. There are some difficulties associated with desalination technologies with regard to the success of wide implementation, especially because they need highly skilled and/or highly educated farmers or users and it might not be profitable unless farmers use the technologies for high-value products. It is not feasible for mass production or accessibility to local consumers. Moreover, the severely polluted source of saltwater might limit the availability of accessible saltwater for desalination [52,54]. These negative environmental impacts must be investigated and overcome to maintain a sustainable use of desalination technology.

8. Quality of Desalinated Water Compared with Other Non-Conventional Resources

In light of water scarcity, many countries in the MENA region use non-conventional water resources such as desalinated saltwater, reused agriculture drainage and wastewater [28,55,56]. Desalinated saltwater is a potential non-conventional water resource that provides water with high quality [30,31]. Additionally, desalination is completely climate-independent and produces acceptable amounts of good-quality water for use in different sectors. Accordingly, desalination is expected to increase around the world over the next years [7,10,57]. In this context, almost all countries are showing much interest in minimising the pollution of fresh water to reduce the cost of treatment and prevent an adverse impact on public health [58].

On the other hand, the rapid progress of human activities, especially industrial and agricultural activities, and the release of large quantities of nutrients and other pollutants into coastal seawater, have led to high eutrophication in some parts of the countries of the Mediterranean Coast [59,60]. Certain studies reported several heavy metals in the water, and sediment and/or animals in the coastal sea areas [61]; other studies were concerned with the total amount of pesticides and petroleum hydrocarbons [62] and chemical oxygen demand (COD) [63,64]. Therefore, water quality and reduction of pollution sources at different levels is essential to reduce negative effects on crop production. Moreover, it is not only crop production that is affected by water pollution, but also soil quality, aquaculture, lake biodiversity, and, most importantly, human health. Furthermore, it has been documented that drainage water contains high quantities of untreated wastewater, municipal waste and fertilisers that are a hazard to the quality of potable and irrigation water [65–67]. Additionally, salinity of drainage water is considered a major concern for water quality used in agriculture, particularly in arid regions. Reutilising drainage water with high levels of salinity adversely affects irrigation sustainability and crop production [68]. El-Bouraie et al. [69] analyzed the quality of river water in the Rosetta branch at the outlet of the El-Rahawy drain of the Nile Delta. Seasonally, they collected water samples from El-Rahawy and the Rosetta branch and determined their physicochemical parameters. The results indicated that the water presented a high concentration of ammonia, total dissolved solids (TDS) with low COD, dissolved oxygen (DO) and biochemical oxygen demand (BOD) values along the El-Rahawy drain; these negative impacts were deteriorating the water quality downstream of the Rosetta branch, particularly through periods of low flow in the winter. In this respect, El-Agha et al. [68] studied the drainage system of the approximately 82,740 ha Meet Yazid area located in the upper part of the Nile Delta. They reported that the quality and salinity of drainage water have great variability, both in time and space, in the Nile Delta. The secondary drains showed uppermost variability of salinity compared to the subsurface drainage and the main drain collectors. In the secondary drains, the salinity increased about 4 times more than that of the drainage water coming from the collectors. Furthermore, Dorgham et al. [70] indicated that the discharged wastewater caused pronounced quality changes in the coastal waters of the Nile Delta. The nutrient salts showed excessive variation through the studied area and over the studied time scale. Nitrate showed a range from 3 to 1682 μg/L, nitrite's concentration ranged from 0.42 to 1106.2 μg/L, ammonia displayed a high concentration (1646.6 μg/L), the total phosphorus fell within the range from 10 to 8260 μg/L and silicate ranged from 40 to 40800 μg/L. High phytoplankton biomass was registered over the whole area (Chlorophyll-a from 0.4 to 197.4 μg/L). The results of this study revealed a great degradation and unhealthy consequences on public health.

Treated wastewater is another non-conventional water resource to cope with water shortages [71]. Wastewater has poor quality, therefore, it should be treated efficiently to diminish adverse health risk. In this context El-Bana et al. [67] assessed wastewater quality during 2015 in the winter crop season in the Bahr El-Baqar Drain in Sharqia, Egypt. This drain is one of the main ones in the Nile Delta that receive diverse types of wastewater. The chemical and microbial analyses revealed oxygen depletion for all collected samples. Furthermore, the microbial analysis showed contamination by fecal coliform (>1000 per 100 mL) in winter and summer samples. Moreover, concentrations of NO_3, MoO_4 and NH_4 levels were more than the recommended standards for reusing the water of Bahr El-Baqar in irrigation. According to the results of soil analysis, cadmium contamination was detected, with levels higher than the standard values [67]. Likewise, El-Rawy et al. [72] studied the quality of water in the Ismailia Canal, in the Nile Delta in Egypt. The investigated drains were extremely polluted from the discharge of industrial waste and wastewater treatment. El-Osta et al. [73] investigated the geochemical evolution of groundwater quality for the Nubian Sandstone Aquifer. The water quality index (WQI) showed that most of the sample points (approximately 89%) were inappropriate for drinking due to hazardous iron levels.

In Morocco, due to the noticeable water shortage, using treated wastewater in irrigation is required for the preservation of water resources. Consequently, the feasibility of the reuse procedure was studied [74]. In addition, farmers were forced to adopt the use of raw wastewater in areas where it is available close to their agricultural lands due to the increasing demand for food. According to Choukr-Allah [75], around 700 million m^3 of raw wastewater is released, and about 60% of this amount is discharged into the sea; the remaining quantity is divided between draining-off of surface waters that represent the major part, and a reuse operation concerning more than 7000 ha. However, the continuation of these discharges may lead to a deep degradation in the water resources and dangerous consequences for the drinking water supply for many regions of the country. Similarly, continuing to reuse raw wastewater may have serious negative effects on public health [74].

The government of Algeria is well aware of the need for additional water resources since the country is characterised by an arid and semi-arid climate. Significant investment has been provided for the construction of treatment plants for wastewater reuse. With additional treatment, the wastewater can be used for several purposes, and in particular, for agriculture. However, beyond the clear advantages of reuse, there are many constraints, in terms of legislation and above all of the water quality itself. While it is obvious that the reuse of wastewater has a great future in Algeria, it is also imperative to create the necessary conditions for its development. The treated water could be reutilised for irrigation of some salt-tolerant crops. The sewage sludge, with a relatively low quantity of organic matter, could be used as a fertiliser [76].

Tunisia is facing increasingly serious water shortage problems. For that reason, Tunisia reused about 24% of the total collected wastewater. Half of this amount is used directly for irrigation in agriculture, parks, and on golf courses and the rest flows indirectly into the water reserves [77]. Several authors, such as Bahri [78], have reported on the status of the reuse of wastewater in Tunisia. According to forecasts, increased domestic and industrial water consumption by the year 2020 may cause a reduction in the volume of fresh water available for Tunisian agriculture. Bahri [78] claimed that the annual required water is expected to reach 290 mm^3 in the year 2020. Consequently, the government will increase the amount of reused wastewater.

9. Conclusions and Recommendations

Water shortage is projected to increase in the MENA region due to climate change, particularly in arid regions. Accordingly, it is crucial to find non-conventional water resources such as desalinated saltwater, agriculture drainage and wastewater. Desalinated seawater is a potential non-conventional water resource that provides very reliable amounts of good-quality water for use in different sectors. Otherwise, agriculture drainage and wastewater contain heavy metals, pesticides and petroleum hydrocarbons. Accordingly, these two types of water have dangerous consequences and serious negative effects on public health. Subsequently, it is essential to be treated efficiently for diminishing its adverse health risk. Furthermore, the treated wastewater can be used for landscaping and agriculture instead of valuable non-renewable groundwater. Using water desalination by means of solar energy in agricultural production to address water shortages is crucial as a simple and low-cost technique. Solar desalination could be economically advantageous for farmers to produce great commercial value if they followed the technical recommendations to produce a high crop yield. However, the desalination process has certain negative impacts on the environment that must be investigated and overcome.

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