Water **2014**, *6*, 1134-1150; doi:10.3390/w6041134

OPEN ACCESS

water

ISSN 2073-4441

www.mdpi.com/journal/water

Review

Desalination Technologies: Hellenic Experience

Konstantinos Zotalis [1,*], Emmanuel G. Dialynas [2], Nikolaos Mamassis [1] and Andreas N. Angelakis [3,4]

[1] Department of Water Resources and Environmental Engineering, National Technical University of Athens (NTUA), Heroon Polytechniou 9, Zografou, Athens 15780, Greece; E-Mail: nikos@itia.ntua.gr

[2] Dialynas SA Environmental Technology, P.O. BOX 4 Alikarnasos, Iraklion, Crete 71601, Greece; E-Mail: md@dialynas.com

[3] National Agricultural Research Foundation (NAGREF), Iraklion Institute, Iraklion, Crete 71203, Greece; E-Mail: info@a-angelakis.gr

[4] Hellenic Union of Municipal Enterprises for Water Supply and Sewerage (EDEYA), 37-43 Papakuriazi, Larissa 41222, Greece

* Author to whom correspondence should be addressed; E-Mail: kzotalis@gmail.com; Tel.: +30-69-3706-5768.

Received: 18 February 2014; in revised form: 6 April 2014 / Accepted: 17 April 2014 / Published: 30 April 2014

Abstract: Beyond doubt, desalination is growing rapidly worldwide. However, there are still obstacles to its wider implementation and acceptance such as: (a) high costs and energy use for fresh water production; (b) environmental impacts from concentrate disposal; (c) a complex, convoluted and time-consuming project permitting process; and (d) limited public understanding of the role, importance, benefits and environmental challenges of desalination. In this paper, a short review of desalination in Greece is being made. Data on the cost of desalination shows a decrease in the future and the potential of water desalination in Greece. The paper summarizes the current status in southeastern Greece (e.g., Aegean islands and Crete), and investigates the possibility of production of desalinated water from brackish water.

Keywords: brackish water; cost of desalination; desalination worldwide; desalination plants in Greece

---

1. Introduction

Ever since desalination was originally invented in antiquity, different technologies have been developed. Back in the 4th century BC, Aristotle, the Hellenic philosopher, described a desalination technique by which non-potable water evaporated and finally condensed into potable liquid. Likewise, Alexander of Aphrodisias in the 200 AD described a technique used by sailors, as follows: seawater was boiled to produce steam, and that steam was then absorbed by sponges, thereby resulting in potable water [1]. Since then, the technology of seawater desalination for the production of potable water evolved rapidly and has become quite popular [2].

The most reliable desalination processes that can currently be exploited at the commercial scale can be divided in two main categories:

(a) thermal (or distillation) processes like multi-stage flash distillation (MSF), multi-effect distillation (MED), thermal vapor compression (TVC), and mechanical vapor compression (MVC) processes; and
(b) membrane processes: reverse osmosis (RO) and electrodialysis (ED) processes. ED is mostly used for brackish water installations, while RO can be used for both, brackish and seawater [3].

Over the last few years, a large number of desalination plants began to operate globally. Moreover, the production cost of desalinated water has been considerably decreased and is expected to decrease even further [4,5]. This is mostly due to the recent improvements in membrane technology, but also due to the increase of the energy conversion coefficiency for desalination processes [6].

In this paper, a short review of water desalination is provided before cost data are examined and processed. This paper focuses on water desalination processes and projects in Greece.

2. Desalination is Growing around the World

Desalination is growing so fast globally that it is more than certain that it will play a significant role in water supply in the years to come. Desalination is growing particularly in parts of the world where water availability is low. Annual desalination capacity seems to increase rapidly as years go by.

A sharp increase in the number of desalination projects to supply water is indicated. This rose from 326 m^3/d in 1945 to over 5,000,000 m^3/d in 1980 and to more than 35,000,000 m^3/d in 2004 [7]. In 2008, the total daily capacity was 52,333,950 m^3/d, from some 14,000 plants in operation globally [8]. In 2011, the total capacity was about 67,000,000 m^3/d, while in 2012 it was estimated at about 79,000,000 m^3/d from some 16,000 plants worldwide [9].

The Gulf Region (Middle East) has the biggest number of desalination plants in the world, followed by the Mediterranean, the Americas, and Asia [10]. The percentages of desalination plants for each geographical area are shown in Figure 1.

The global capacity of desalination plants, including renewable desalination, is expected to grow at an annual rate of more than 9% between 2010 and 2016. The market is set to grow in both developed and emerging countries such as the United States, China, Saudi Arabia (SA) and the United Arab Emirates (UAE), as shown in Figure 2. A very significant potential also exists in rural and remote areas, as well as in islands (Figure 2, rest of world (ROW)), where grid electricity or fossil fuels to generate energy may not be available at affordable costs. About 54% of the global growth is expected to occur in the Middle East and North Africa (MENA) region [11], where the 21 million m^3/d of desalinated water in 2007 is expected to reach 110 million m^3/d by 2030, of which 70% is in SA, the UAE, Kuwait, Algeria and Libya [11].

Figure 1. World desalination plants per geographical area (%). Adapted from [10].

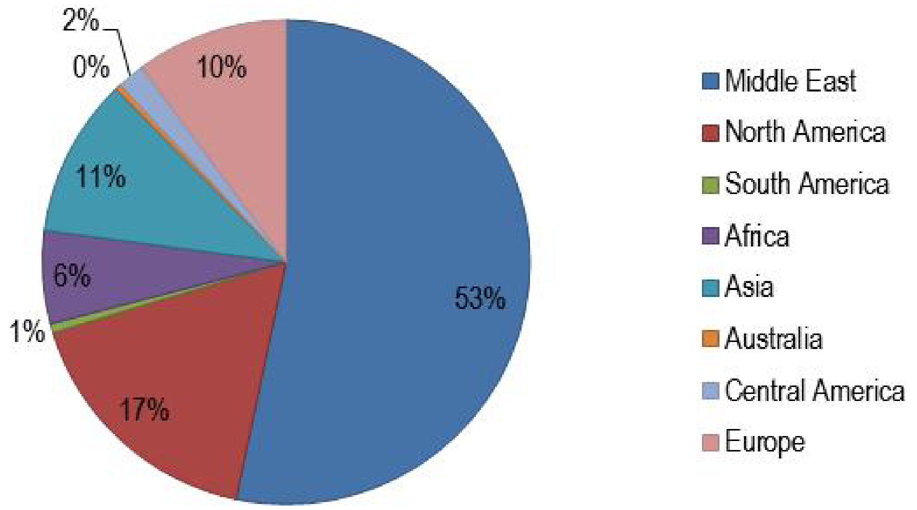
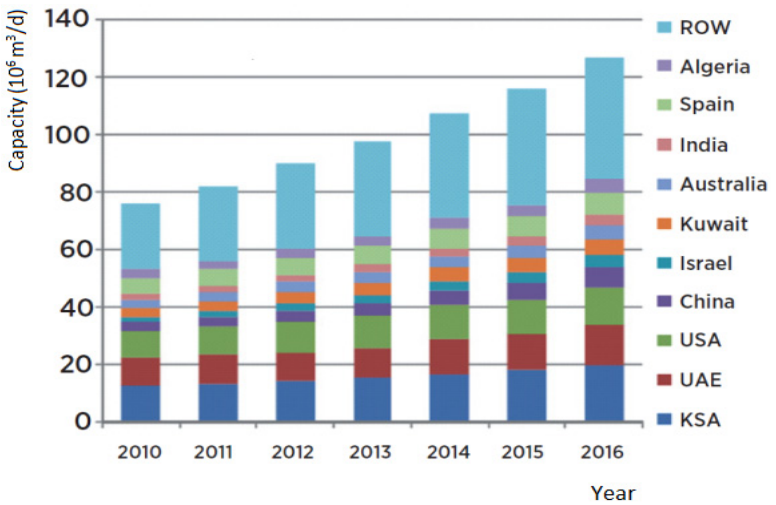


Figure 2. Global installed desalination capacity, 2010–2016. Adapted from [11].



The majority of the largest desalination plants (in operation or under construction) use seawater and are located in the Middle East. The biggest desalination plant is the Ras Al-Khair in the city of Ras Al-Khair (also called Ras Al-Zour or Ras Azzour) SA, which uses both membrane and thermal technology with a capacity over 1,000,000 m^3/d, in operation since 2013. The Ras Al-Khair plant supplies Maaden factories with 25,000 m^3 of desalinated water and 1350 MW of electricity. It also supplies with water the capital city of Riyadh and several central cities with a total need of 900,000 m^3/d [12,13]. Another example is the 880,000 m^3/d MSF Shuaiba 3 desalination plant that is located along the east coast of SA and supplies with potable water the cities of Jeddah, Makkah, and Taif. SA also hosts the Ras Al-Zour unit, producing 800,000 m^3/d of water [14]. Table 1 shows some of the biggest desalination plants in the world.

Table 1. The biggest desalination plants around the world. SA: Saudi Arabia; and UAE: United Arab Emirates. Adapted from [12,13,15].

Location	Capacity (m^3/d)	Feedwater	Operation year
Ras Al-Khair, SA	1,025,000	N/A	2013
Shuaiba, SA	880,000	Seawater	2007
Ras Al-Khair, SA	800,000	Seawater	2007
Al Jubail, SA	730,000	Seawater	2007
Jebel Ali, United Arabic Emirates	600,000	Seawater	2011
Al-Zour North, Kuwait	567,000	Seawater	2007

As far as the membrane technologies are concerned, especially the RO desalination technology (one of the most renowned), there are big plants around the world with great potential in energy saving and reasonable production cost (Table 2) [16]. The largest membrane desalination plant in the world is the Victoria Desalination Plant in Melbourne, Australia with a capacity 444,000 m^3/d, in operation since 2012. However, larger units will soon operate, like the Magtaa plant in Algeria and the Soreq plant in Israel, with capacities of 500,000 m^3/d and 510,000 m^3/d, respectively [13].

Table 2. Major reverse osmosis (RO) desalination plants in the world. Adapted from [13,16].

Location	City, Country	Capacity (m^3/d)
Soreq desalination plant	Rishon Letzion, Israel	510,000
Magtaa desalination plant	Oran, Algeria	500,000
Victoria desalination plant	Melbourne, Australia	444,000
Point Lisas desalination plant	Point Lisas, Trinidad	109,019
Tampa Bay desalination plant	Tampa, FL, USA	94,635

3. Production Cost of Desalinated Water

The overall cost of desalination can be divided into investment cost and maintenance-operation cost. Investment cost involves land, edifices and equipment, as well as transportation cost, insurance, construction, legal fees and unforeseen costs. Maintenance and operation cost is divided in energy cost, maintenance, repairs, personnel/staff, spare parts, and reconstruction when required. Energy cost is the higher contributor to operation cost and thus to the overall cost. In many cases, energy cost can reach almost the 60% of the operation and maintenance cost. A comparison of the total cost of the RO and MSF technologies is given in Table 3 [17].

Table 3. Cost percentage in conventional RO and multi-stage flash distillation (MSF) of the same capacity in Lybia. Adapted from [17].

Desalination technology	Investment cost (%)	Energy cost (%)	Maintenance & repair cost (%)	Membrane replacement cost (%)	Personnel cost (%)	Chemicals cost (%)
RO (membrane)	31	26	14	13	9	7
MSF (thermal)	42	41	8	0	7	2

Cost evaluation for desalination is a difficult process as data are influenced by different factors such as energy cost, materials and labor. Those factors differ significantly from place to place.

Moreover, cost is influenced by elements like desalination technology, total dissolved solids (TDS) concentration of the raw water used to feed the plant, and other economic parameters that related to local conditions [18]. In conclusion, desalination cost is significantly decreasing when brackish water is used instead of seawater and when the capacity of the plant is increased (Table 4).

Table 4. Desalinated water production cost from seawater and brackish water.

Capacity (m^3/d)	**Cost (€/m^3)**	
	Sea water	**Brackish water**
3,800	0.97	0.50
7,600	0.70	0.27
19,000	0.54	0.21
38,000	0.50	0.17
57,000	0.49	0.15

Membrane desalination technologies such as RO are known for their lower energy demands compared to thermal technologies which can be further reduced using energy recovery systems. Such limited energy demands have direct effect on the cost of the produced desalinated water, which in most cases is lower than the cost of water produced by thermal technologies. The RO cost per feeding water and capacity is shown in Table 5, compared to the cost related to the most common thermal desalination technologies.

Table 5. RO desalination production cost compared to thermal desalination technologies cost, per feeding water and production capacity. MED: multi-effect distillation; and VC: vapor compression. Adapted from [19].

Feedwater	**Plant capacity (m^3/d)**	**Cost (€/m^3)**
Brackish water RO	<20	4.50–10.32
	20–1,200	0.62–1.06
	40,000–46,000	0.21–0.43
Seawater RO	<100	1.20–15.00
	250–1,000	1.00–3.14
	1,000–4,800	0.56–1.38
	15,000–60,000	0.38–1.30
	100,000–320,000	0.36–0.53
MSF	<100	2.00–8.00
	12,000–55,000	0.76–1.20
	>91,000	0.42–0.81
MED	23,000–528,000	0.42–1.40
VC	1,000–1,200	1.61–2.13

Hybrid desalination systems, which are used to combine desalination technologies, are suitable for big installations in order to accomplish scale economies that reduce the production cost. In such plants, membrane technologies can be combined with thermal technologies and *vice versa*. To give an example, in a plant where the brine flow of RO is the feed flow of membrane distillation, the cost is 0.94 €/m^3. Had the system used only RO, the respective cost would be 0.94 €/m^3, whereas the same system operating under membrane distillation would have a production cost of 0.99 €/m^3. In other words, when technologies are combined the double quantity of water is produced at the same cost or less compared with the alternatives. To give another example, a MSF used in a desalination plant of 528,000 m^3/d, produces water at a 0.32 €/m^3, whereas when it is combined with RO, its cost is reduced by 15% [18]. It should be noted that the water production cost of a desalination plant that uses renewable energy is estimated to be higher than one that uses conventional energy [20]. An example of the cost per feeding water and energy source used is shown in Table 6.

Table 6. Cost of desalinated water production per feeding water and energy source used. Adapted from [19].

Feedwater source	Energy source	Cost (€/m^3)
Brackish water	Conventional energy	0.21–1.06
	Photovoltaic panels energy	4.50–10.32
	Geothermal energy	2.00
Seawater	Conventional energy	0.35–2.70
	Wind power	1.00–5.00
	Photovoltaic panels energy	3.14–9.00

A decreasing attitude is observed to the cost of desalination for production of potable water, compared with other technologies. Improvement on membrane technology will be a catalyst in cost reduction [21]. In Greece and other Mediterranean areas there have been several comparisons between desalinated water production and conventionally extracted water (e.g., dams and groundwater wells). However, in such comparisons, the rapid improvement of the RO membrane technology should be considered. In the near future it is expected that desalinated water cost (especially coming from brackish water) will be less than any other conventional technologies. It is estimated that desalination cost will be lowered 4% to 5% per year due to the continuous improvement of membrane technology.

Some examples of desalinated water production cost in different regions worldwide are presented:

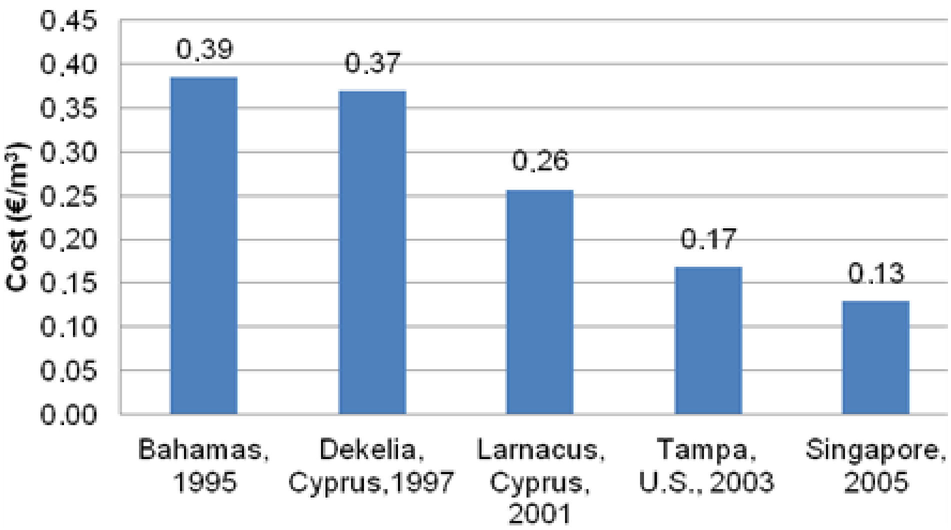
(a) In Malta, where 70% of the total water consumption comes from desalination, cost varies between 0.30 €/m^3 and 0.45 €/m^3.
(b) In Cyprus, the country with a high density of dams worldwide, the last decade potable water supply was reinforced by three desalination plants. The total cost at the two plants at Larnaca varies today from 0.45 €/m^3 to 0.54 €/m^3.
(c) In Israel, the cost of water production in the Ashkelon plant is around 0.50 €/m^3. This quantity consists of desalinated seawater (48%), desalinated brackish (45%), and recycled wastewater (7%). The total cost for desalination at the five plants ranged from 0.61 €/m^3 to 0.94 €/m^3. Increased cost is due to: (i) the technology chosen (multiple stage evaporation) for the energy consumed; and (ii) very high *TDS* concentrations (47,000–50,000 mg/L) of seawater in the Gulf.
(d) In East Australia, in areas with very low water availability (Perth), water supply was based on desalination for the past 10 years. Total cost was as low 0.33–0.42 €/m^3.
(e) In Greece, and especially in touristic areas, there are numerous RO installations. Today, the average water production cost from seawater for such technology is 0.60–0.70 €/m^3. The production cost in case brackish water is used ranges from 0.3 €/m^3 to 0.4 €/m^3, depending on the feed

water *TDS* concentration and the condition of operation and management. On the other hand, for the RO desalination plant on the island of Milos (with capacity 3360 m^3/d and energy produced from wind turbines), the cost is 1.80 €/m^3 [22], whereas in the geothermal MED plant on the same island, the cost is less than 1 €/m^3 [23].

(f) In California, USA, there are over 20 desalination plants operating or under construction that by 2015 will reach 2,600,000 m^3/d, a quantity that covers 15% of the total water needs [9]. One of these plants (Carlsbad), with a capacity of 190,000 m^3/d, is called a "Green desalination plant" as it has environmentally friendly installations, total energy reclamation as well as the respective minimization of greenhouse gasses. The plant was constructed as a build-own-transfer (BOT) project and is the biggest in the US, producing 8% of the water needs in the region of San Diego. Water production cost is estimated at 0.50 €/m^3.

(g) In general, the cost of recently constructed RO plants (e.g., in Tampa Bay USA in 2003 and in Singapore in 2005) has been reduced up to 1/3 in comparison with that of the plants constructed 13–18 years ago (e.g., in Bahamas in 1995, in Dekelia, Cyprus in 1997, and in Limassol, Cyprus in 2001) (Figure 3). Such a decrease is not only attributed to the rapid evolution of desalination technology during recent years but also to the cost reduction due to the increased size of those plants. It is difficult to quantify the effect that these parameters have, since they seem to act simultaneously [24].

Figure 3. Cost of desalination plants that were installed between 1995 and 2005. Adapted from [24].



4. Desalination Environmental Impacts

The desalination process has relatively low environmental impact. However, it is reported that the discharge of brine into the sea may erode the seashore [25] or harm the aquatic life [26]. Moreover, to avoid unregulated development of coastal areas, desalination activity should be included in the regional development projects [27].

The main environmental impact concerns are land use, brine disposal, and energy consumption. Land use issues emerge from the fact that seawater desalination plants are situated close to sites with particularly sensitive environmental habitats and many social, economic, ecological, and recreational functions. The search for an appropriate plant location has to be carried out with great caution in order to minimize adverse impacts [28]. Furthermore, desalination processes produce a particularly high salinity flow (brine) and its disposal directly to the sea may also harm the environment. Potential environmental impacts should be minimized by refraining from discharging brine directly into the sea. Finally, as far as energy consumption is concerned, despite the great achievements in this field, desalination processes like RO are still quite energy-intensive. Since most of the energy is taken from fossil sources, the CO_2 emissions are an issue that cannot be ignored. However, the use of modern processes and alternative energy sources can reduce the emissions of CO_2 and other air pollutants [29].

5. Water Scarcity in Greece

In Greece, and particularly in several southeastern regions, there is a very low water availability, which is exacerbated by the high water demand for tourism and irrigation in summertime. Therefore, the integration of desalinated water, treated wastewater and other marginal waters into water resources and the management of master plants are of paramount importance to meet future water demands [30].

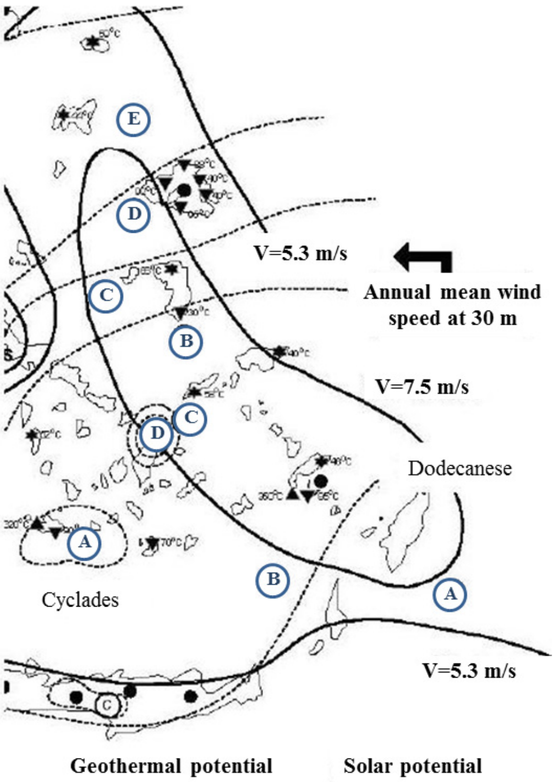
The problem seems to be more evident in the Aegean Islands (particularly the Dodecanese and Cyclades), Thessaly in Central Greece, eastern Continental Greece (Sterea Greece), eastern Crete and the southeastern Peloponnese (Figure 4). More specifically, in central Greece (Thessaly and Sterea Greece), there is a high water demand for agricultural irrigation [31], while on the islands the problem is mainly attributed to the increased demand in potable water during the summertime [32]. Both the population density of the Region of Crete (Prefectures of Chania, Rethymno, Iraklio and Lasithi) and the Regions of North and South Aegean (Prefectures of Lesvos, Chios, Samos, Dodecanese and Cyclades) are below the population density of Greece. Both regions receive large numbers of visitors during the summer [33]. Nonetheless, that high water demand is also attributed to over-exploitation of groundwater aquifers, as well as to groundwater contamination, including seawater intrusion in coastal areas. In addition, the small size of the islands and their geography does not allow other possible cost-effective technologies to increase water availability [31].

The aforementioned regions are located in the southeastern part of Europe. Their climate is typically Mediterranean: hot and dry. Their relatively long distance from the mainland adds to their economic woes compared to similar parts of Europe [34]. Due to their geographical isolation, these areas are equipped with autonomous, yet limited conventional power grids. However, there is an abundance in renewable energy sources such as aeolic and solar power, as well as geothermal and wave power (Figure 5) [35].

Currently, the main way for meeting deficient water balance of the "semi-arid" islands is water transportation whose cost varies from 4.91 €/m^3 to 8.32 €/m^3 [36], and has a great environmental burden in terms of ship emissions. Moreover, the water transported is in most cases not potable, therefore, an economic and environmental analysis should also take into consideration the impacts of increased use of bottled water. Other ways of meeting the water deficiency needs are the exploitation of ground water, dams, and rainwater collection.

Figure 4. Deficit and/or surplus of potable water per water district in Greece [31]. With permission of Stefopoulou *et al*. (2008) [31].

Figure 5. Renewable energy sources in Cyclades and Dodecanese. With permission of Manolakos (2012) [35].



Zone	kWh/m²
A	>1650
B	1600-1650
C	1550-1600
D	1500-1550
E	1450-1500
F	1400-1450
G	<1400

Last but not least, there are also a few desalination plants, especially in southeastern water supply and sewage municipalities or where big hotels are located. Many of these desalination plants use the RO technology. Apart from the state-owned desalination plants, there are many private plants in operation owned by hotels. A significant number of desalination plants is currently under construction or under planning.

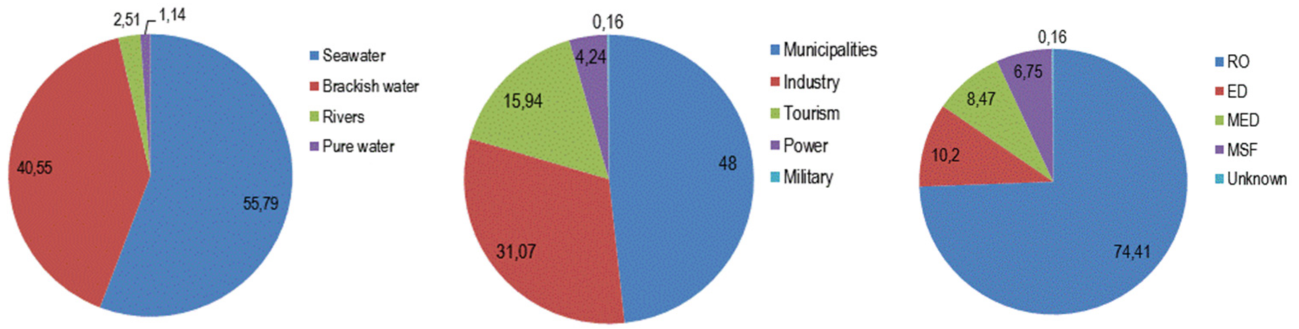
6. Desalination Status in Greece

According to the 2011 IDA Worldwide Desalting Plants Inventory in Greece, there are currently 157 operating desalination plants, with a total capacity of 109,115 m^3/d, while another 35 are expected to soon be operational, with a total capacity of 40,135 m^3/d. Moreover, in 2011, five more desalination plants were under construction, with a capacity reaching 32,800 m^3/d [37].

As for the feed water, 56% is seawater, while 41% is brackish water (Figure 6a). Regarding the use of the produced desalinated water, 48.08% is to supply the municipalities, 31.07% goes to the industry, 15.94% covers touristic demands, and 4.24% and 0.16% are directed to power production and water supply of military camps, respectively (Figure 6b).

RO is the most popular desalinating technology in Greece, as it produces 74.41% of the desalinated water. ED is used for the desalination of 10.20% of the total desalinated water produced, whereas MED is used for 8.47% of the produced water and MSF is used for the 6.75% (Figure 6c) [37].

Figure 6. Desalinated water production according to: (**a**) feed water; (**b**) its uses; and (**c**) the used technology, in Greece. Adapted from [37].



(**a**) (**b**) (**c**)

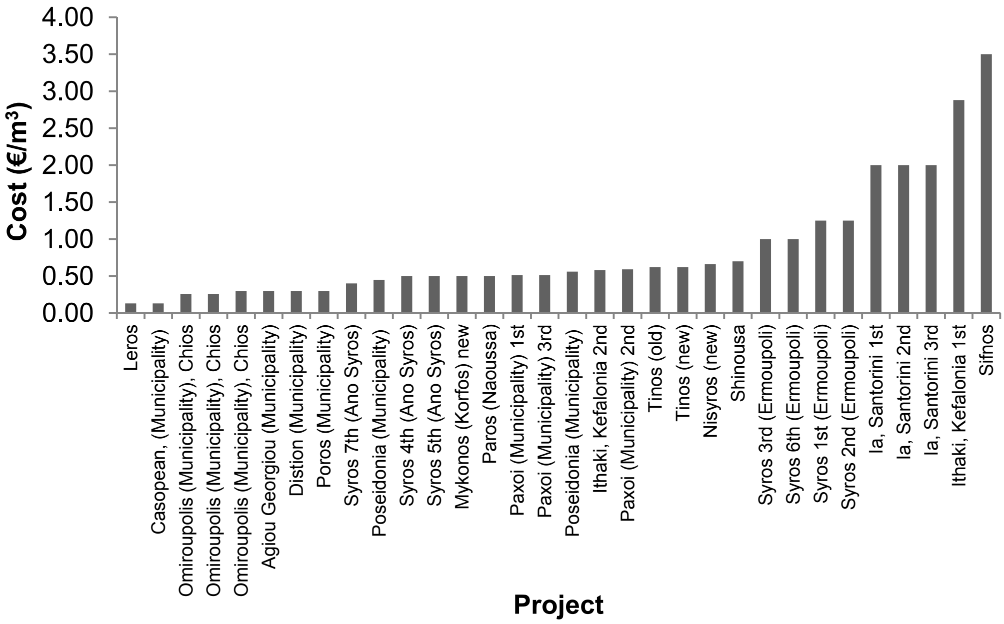
There are 35 RO plants operating in the Hellenic island municipalities with a total capacity of 22,860 m^3/d and operating costs ranging from 0.13 €/m^3 to 2.70 €/m^3 (Table 7). The newest desalination plant in Almyros (Iraklion, Crete), with a capacity of 2,400 m^3/d, has been in operation since January 2014. This project is the first one whereby the produced water will be sold by the contractor to the Municipality of Iraklion, at a guaranteed price of 0.27 €/m^3 for five years [38]. Also, a future upgrading of its capacity up to 20,000 m^3/d is planned. Note that the Almyros brackish spring, from where the plant will be fed, has a capacity more than 620,000 m^3/d.

The average operating costs of 30 RO plants of seawater desalination (Table 7) in the Hellenic islands has been estimated at 0.85 €/m^3. More precisely, the 4800 m^3/d capacity plant in Leros has a minimum operational cost of 0.13 €/m^3, while the 500 m^3/d capacity in Sifnos reaches the highest registered value of 3.5 €/m^3. The range of this cost is depicted in Figure 7 [36].

Table 7. RO desalination plants in Hellenic islands' municipalities. Adapted from [38].

Project	Year	Type	Capacity (m^3/d)	Initial cost (M €)	Operation cost (€)	Contractor	Acceptance
Almyros Iraklion	2014	RO & UF	2,400	0.850	0.25	Sychem S.A., GR	Good
Syros 1st Ermoupoli	1992	RO	800	0.589	2.70	Christ, CH	Good
Syros 2nd Ermoupoli	1997	RO	800	1.482	2.70	Christ, CH	Good
Syros 3rd Ermoupoli	2001	RO (SW)	40	0.346	2.00	Culligan Greece	Good
Syros 4th (Ano Syros)	2000	RO	250	0.215	0.50	Temak, GR	Good
Syros 5th (Ano Syros)	2002	RO	500	0.400	0.50	Temak, GR	Good
Syros 6th (Ermoupolis)	2002	RO (SW)	2,000	0.313	0.40	Temak, GR	Good
Syros 7th (Ano Syros)	2005	RO	1,000	1.000	0.40	Temak, GR	Under construction
Shinousa	2004	RO	100	0.120	0.70	Temak, GR	Under construction
Mykonos (Korfou) old	1981	RO	500	N/A	2.00	Metek, IT	Good
Mykonos (Korfou) new	2001	RO	2,000	1.276	0.50	Culligan Greece	Good
Paros (Naousa)	2001	RO	1,200	0.415	0.50	Ionics Itaba	Good
Tinos (old)	2001	RO	500	0.434	0.62	Culligan Greece	Good
Tinos (new)	2005	RO	500	0.376	0.62	Culligan Greece	Good
Ia, Santorini 1st	1994	RO	220	N/A	2.00	Matrix, USA	Good
Ia, Santorini 2nd	2000	RO	320	0.210	2.00	Culligan Greece	Good
Ia, Santorini 3rd	2002	RO	160	N/A	2.00	Matrix, USA	Good
Sifnos	2002	RO (BW)	500	0.224	3.50	Hoh, DM	Good
Omiroupolis, Chios, Municipality, 1st	2000	RO (BW)	600	0.205	0.30	Culligan Greece	Good
Omiroupolis, Chios, Municipality, 2nd	2005	RO	3,000	0.710	0.26	Culligan Greece	Under construction
Omiroupolis, Chios, Municipality, 3rd	2005	RO	500	0.200	0.26	Culligan Greece	Under construction
Nisiros (old)	1991	RO	300	0.572	N/A	Metek, IT	Out of operation
Nisiros (new)	2002	RO	350	0.295	0.66	Temak, GR	Good
Ithaki, Kefalonia 1st	1981	RO	620	0.264	2.88	Christ, CH	Good
Ithaki, Kefalonia 2nd	2003	RO	520	0.587	0.58	Judo, DE	Good
Lerou (Municipal Enterpr.)	2001	RO	200	0.074	0.13	Culligan Greece	Good
Kassopeon (Municipality)	2001	RO	500	0.170	0.13	Culligan Greece	Good
Posseidonia (Municipality), 1st	2002	RO	500	0.464	0.56	Culligan Greece	Good
Posseidonia (Municipality), 2nd	2005	RO	1,000	0.574	0.45	Culligan Greece	Under construction
Agios Georgios (Municipality)	2002	RO	500	0.102	0.30	Culligan Greece	Good
Paksoi (Municipality) 1st	2005	RO	330	0.260	0.51	Culligan Greece	Good
Paksoi (Municipality) 2nd	2005	RO	150	0.162	0.59	Culligan Greece	Good
Total: 32	-	-	22,860	-	-	-	-

Figure 7. Operating cost (€/m^3) of seawater RO desalination plants in the Hellenic islands. Adapted from [36].



The cost of desalinated water in Greece is between 0.5 €/m^3 and 3.5 €/m^3 [38,39]; however, in most cases, the cost is above 1.2 €/m^3. The cost is relatively higher compared to the cost of large desalinations plants, like those operating in Israel, Malta, and Cyprus, where the cost is usually below 0.7 €/m^3 due to the size of the Hellenic plants and their age [38]. However, as a consequence of the critical importance of desalinated water, it is expected that the Hellenic Government will subsidize the electric energy consumed for this purpose. In southeastern Greece, water supply in the future is expected to be mainly based on desalination. Modern desalination processes of utilizing solar [40,41], wind [42], or wave [43] energy, instead of fossil fuels, are under development. Desalination plants utilizing renewable energy sources have also been operating in Greece. Such plants are:

(a) A vapor compression plant charged with a 750 kW wind turbine is located on the island of Symi, producing 450 m^3/d, has been operating since 2009.
(b) A MED plant using geothermal energy was built on the island of Kimolos in 2000. This unit has a 188 m well and is considered to be a low enthalpy one (61 °C), capable of producing 80 m^3/d.
(c) A hybrid RO was constructed on Keratea in 2002, combining wind turbines with photovoltaic panels. The capacity of this hybrid plant reaches 3 m^3/d, while the wind turbines and photovoltaic cells are of 900 W and 4 kWp nominal power, respectively [23].
(d) Another plant of today's capacity 3,360 m^3/d is on the island of Milos. It is a RO plant which used the electrical energy needed from an 850 kW wind turbine operating at 600 kW [44].
(e) Finally, on Irakleia island, there is a removable RO desalination plant, which uses both wind and solar energy through a 30 kW wind turbine and a backup photovoltaic panel system.

7. The Potential of Using Brackish Waters for Desalination in Greece

Several studies indicate that throughout Greece, especially in island areas, millions m^3/year of brackish water are available. Currently the use of brackish water is next to zero. For instance, Crete has an over 1000 hm^3/year brackish water potential, while a considerable amount of brackish water also exists on the Aegean islands.

Only discharges of the well-known source of brackish springs (known as *Almyroi*) on Crete (Iraklion) reach more than 1000 million m^3/year: one almyros in the west of Iraklion city has an average discharge of 235 million m^3/year, quantities that correspond to 50% of the total annual water used in Crete [45]. Today, the brackish water is not exploited. Water from the Almyros of Iraklion could be used even as potable for 45–50 d/year when the TDS < 200 mg/L, which means about 5 million m^3/year of fresh water could be saved [46]. One could draw similar examples from other islands.

The desalination of brackish water is of considerably lower cost, compared to the desalination of seawater. This cost reduction may be over 50%, mostly because the cost for the removal of dissolved salt is lower at power salt concentrations [47].

8. Discussion and Conclusions

The global population boom, urbanization and climate change have severely reduced water supplies. Furthermore, tapping fresh water for metropolitan areas has become more difficult, if not impossible. Without any doubt, the future relies on the implementation of "NEWater" technologies such as desalination and direct potable reuse of treated wastewater [27]. Desalination, especially in coastal areas, is the most cost-effective approach to long-term water supply sustainability, compared with other options.

Desalination of sea and brackish water for both water supply and irrigation in arid and semi-arid coastal regions of the world seems to be a very promising technology. In fact, desalination is already a competitive alternative in regards to other options; as the water produced is low-priced in most cases, energy requirements have been significantly reduced and last but not least, it is friendly to the environment, especially when the process powered by renewable energy sources. Also it should be noted that the combination between desalination and renewable energy sources in autonomous independently operating desalination systems, is a unique solution for water in coastal, relatively isolated areas with weak and limited possibilities of local energy supply networks.

As far as Greece is concerned, desalination could be a sustainable option to face water scarcity in the "waterless" islands, especially during the summer months, when there is an increase in water demand. Given adequate public support, desalination plants could become highly competitive in regards to alternatives such as water transfer from the mainland. Transfer cost varies from 4.91 €/m^3 to 8.32 €/m^3 and is currently the main way of meeting deficient water balance of the semi-arid islands [36]. Finally, desalination plants could be used as storage of redundant renewable energy in RES installations.

Today, RO desalination technologies have turned out to be the most appropriate in Greece, especially for water supply of the semi-arid islands in the southeastern regions of the country. These technologies have the lowest energy requirements, which can be covered by air turbines or solar panels, e.g., renewable energy sources are abundant in those areas (such as wind and sun), and thus burden only to a minimum the rather sensitive local networks and the environment. Also, RO technologies have limited spatial requirements and are adaptable to changes in productivity. Their manufacture process is simple, a feature absolutely necessary for installations in limited areas, where water demands change continuously. Finally, the cost of water, also an important criterion, is kept low, although it remains somewhat higher than in other desalination processes. However, it remains lower than the cost of transporting water, while in the case of the hybrid RO system, costs are kept at the lowest possible level.

Conclusively, the main points that emerge from this study are the following:

(a) The RO desalination costs over the last 15 years have been significantly reduced. The use of alternative energy sources will further reduce the cost.
(b) Research and technology on the desalination membrane processes will continue to develop in the years to come to the direction of becoming friendly to the environment and cost effective.
(c) Water demand will continue to increase and desalination and water reuse will be sustainable options in increasing the low water availability.
(d) Greece has all the potential to move forward in terms of research and technology on water management internationally and especially in the Mediterranean region, provided there is investment in relative sectors. Emphasis should be put on the green aspect of the desalination technology.
(e) The use of desalination technologies to solve the problem of water shortage in the "waterless" Hellenic islands may lead, under certain circumstances, to the best economic, environmental, and social results, for both the island environment and the local communities, contributing substantially to a comprehensive and worth-living growth.

Acknowledgments

Thanks are due to Veolia Environment, Paris, France and Sychem S.A., Iraklion, Greece for the information provided.

Author Contributions

Konstantinos Zotalis prepared the manuscript and made the data collection; Emmanuel G. Dialynas made the bibliographical review and contributed to manuscript preparation; Nikolaos Mamassis analyzed the data and codified the methodology; and Andreas N. Angelakis had the original idea and supervised the research.

Conflicts of Interest

The authors declare no conflict of interest.

References

1. Kalogirou, S. Seawater desalination using renewable energy sources. *Desalination* **2005**, *31*, 242–281.
2. Garcia-Rodriquez, L. Seawater desalination driven by renewable energies: A review. *Desalination* **2002**, *143*, 103–113.
3. Koroneos, C.; Dompros, A.; Roumbas, G. Renewable energy driven desalination systems modelling. *J. Clean. Prod.* **2007**, *15*, 449–464.
4. Shannon, M.A.; Bohn, P.W.; Elimelech, M.; Georgiadis, J.G.; Marinas, B.J.; Mayes, A.M. Science and technology for water purification in the coming decades. *Nature* **2008**, *452*, 301–310.

5. Khawaji, A.D.; Kutubkhanah, I.K.; Wie, J.M. Advances in seawater desalination technologies. *Desalination* **2008**, *221*, 47–69.
6. Fritzmann, C.; Löwenberg, J.; Wintgens, T.; Melin, T. State-of-the-art of reverse osmosis desalination. *Desalination* **2007**, *216*, 1–76.
7. Jiménez, B.; Kim, I.S.; Ng, H.Y.; Gray, S. Editorial. *J. Water Reuse Desalin.* **2011**, *1*, 1.
8. Seamonds, A. *Desalination in 2008: Global Market Snapshot*; International Desalination Association (IDA): Topsfield, MA, USA, 2008. Available online: http://idadesal.org/wp-content/uploads/2008/10/2008ida-desalination-snapshot_october-2008.pdf (accessed on 20 May 2012).
9. Voutchkov, N. Overview of Desalination Status and Future Trends. In Proceedings of the Water and Energy Exchange (WEX) 2012, Lisbon, Portugal, 31 January–2 February 2012.
10. Clayton, R.A. *Review of Current Knowledge, Desalination for Water Supply*; Foundation for Water Research: Marlow, UK, 2011.
11. Isaka, M. *Water Desalination Using Renewable Energy*; Technology Brief I12; International Energy Agency (IEA)-Energy Technology Systems Analysis Program (ETSAP): Paris, France; International Renewable Energy Agency (IRENA): Abu Dhabi, United Arab Emirates, 2012.
12. ConstructionWeekOnline. Largest Desalination Plant in World 75% Complete, 2013. Available online: http://www.constructionweekonline.com/article-22824-largest-desalination-plant-in-world-75-complete/#.UgjrLtJM_7E (accessed on 14 July 2013).
13. The International Desalination & Water Reuse Quarterly Industry Website. Installed Desalination Growth Slowed in 2011–2012, 2013. Available online: http://www.desalination.biz/news/news_story.asp?id=6746&title=Installed+desalination+growth+slowed+in+2011%26%238209%3B2012 (accessed on 30 September 2013).
14. Henthorne, L. The Current State of Desalination. In Proceedings of the International Desalination Association (IDA) World Congress, Dubai, United Arab Emirates, 7–12 November 2009.
15. Gleick, P.H.; David Katz, H.C.; Lee, E. *The World's Water 2006–2007: The Biennial Report on Freshwater Resources (World's Water Quality)*; Island Press: Washington, DC, USA; Pacific Institute for Studies in Development, Environment and Security: Oakland, CA, USA, 2006; Volume 5.
16. Huntington Beach Facility. Desalination Worldwide: Worldwide Seawater Desalination Capabilities, 2010. Available online: http://hbfreshwater.com/desalination-101/desalination-worldwide (accesed on 12 December 2013).
17. Al-Karaghouli, A.A.; Kazmerski, L.L. Renewable Energy Opportunities in Water Desalination. In *Desalination, Trends and Technologies*; Schorr, M., Ed.; InTech: Rijeka, Croatia, 2011; pp. 149–184.
18. Gude, V.G.; Nirmalakhandan, N.; Deng, S. Renewable and sustainable approaches for desalination. *Renew. Sustain. Energy Rev.* **2010**, *14*, 2641–2654.
19. Karagiannis, I.C.; Soldatros, P.G. Water desalination cost literature: Review and assessment. *Desalination* **2008**, *223*, 448–456.
20. Mathioulakis, E.; Belessiotis, V.; Delyannis, E. Desalination by using alternative energy: Review and state-of-the-art. *Desalination* **2007**, *203*, 346–365.
21. Karamoutzis, D.; Alexopoulos, A.; Angelakis, A.N. *Desalination Technologies for Water Supply*; Union of Municipal Enterprises for Water Supply and Sewerage Systems: Larissa, Greece, 2008. (In Greek)

22. Gerasimou, A. *Desalination Using Wind Power in Milos, An Integrated Solution for the Water Availability Problem*; Ios-Aegean Energy Agency: Cyclades, Greece, 2010. (In Greek)
23. Tzen, E. Water Desalination Using Renewable Energy Sources. In Proceedings of the Promotion of Renewable Energies for Water Production through Desalination (ProDes) Project, Agricultural University of Athens (AUA) Workshop: Athens, Greece, 29 May 2010. (In Greek)
24. Ebensperger, U.; Isley, P. *Review of the Current State of Desalination*; Working Paper 2005–2008; Environmental Policy Group at the Andrew Young School of Policy Studies: New York, NY, USA, 2005.
25. Al-Barwani, H.H.; Purnama, A. Re-assessing the impact of desalination plants brine discharges on eroding beaches. *Desalination* **2006**, *204*, 94–101.
26. Latorre, M. Environmental impact of brine disposal on posidonia seagrasses. *Desalination* **2005**, *182*, 517–524.
27. Leverenz, H.L.; Tchobanoglous, G.; Asano, T. Direct potable reuse: A future imperative. *J. Water Reuse Desalin.* **2011**, *1*, 2–10.
28. *Sea Water Desalination in the Mediterranean: Assessment and Guidelines*; MAP Technical Report Series No. 139; United Nations Environmental Programme (UNEP)/Mediterranean Action Plan (MAP)/Programme for the Assessment and Control of Pollution in the Mediterranean Region (MED POL): Athens, Greece, 2003.
29. Bleninger, T.; Jirka, G.H. *Environmental Planning, Prediction and Management of Brine Discharges from Desalination Plants*; Middle East Desalination Research Center (MEDRC): Muscat, Sultanate of Oman, 2010.
30. Angelakis, A.N.; Bontoux, L.; Lazarova, V. Main challenges and prospectives for water recycling and reuse in EU countries. *Water Supply* **2003**, *3*, 59–68.
31. Stefopoulou, A.; Soulis, K.; Papapetrou, M.; Kyritsis, S.; Epp, C. Institutional and policy framework analysis in relation to the application of autonomous desalination systems—Greece. *Desalination* **2008**, *220*, 455–467.
32. Spyrou, I.D.; Anagnostopoulos, J.S. Design study of a stand-alone desalination system powered by renewable energy sources and a pumped storage unit. *Desalination* **2010**, *257*, 137–149.
33. Dedian, V.; Katochianou, D.; Labropoulou, A. *The Social-Economic Identity of the Water Compartments*; Centre of Planning and Economic Research (KEPE): Athens, Greece, 2000. (in Greek)
34. Kaldellis, J.K.; Kavadias, K.A.; Kondili, E. Renewable energy desalination plants for the Greek islands—Technical and economic considerations. *Desalination* **2004**, *170*, 187–203.
35. Manolakos, D. *Desalination Systems in the Islands*; Agricultural University of Athens (AUA): Athens, Greece, 2012. (In Greek)
36. Zotalis, K. Energy and Cost Evaluation of Desalination Systems and their practice in Greece. Master's Thesis, School of Rural and Surveing Engineering, National Technical University of Athens (NTUA), Athens, Greece, 2012. (In Greek)
37. Cuenca, J.C. *Report on Water Desalination Status in the Mediterranean Countries*; Natural Resources Department, Instituto Murciano de Investigación y Desarrollo Agrario y Alimentario (IMIDA): Murcia, Spain, 2012.

38. Angelakis, A.N. Water Reuse Technologies. In *Desalination Technologies for Water Supply*; Karamoutzis, D., Alexopoulos, A., Angelakis, A.N., Eds.; Union of Municipal Enterprises for Water Supply and Sewerage Systems: Larissa, Greece, 2008; pp. 17–28. (In Greek)
39. Gikas, P.; Angelakis, A.N. Water resources management in the Greek river basin districts of Crete and Aegean islands, with emphasis on the utilization of non-conventional water sources. *Desalination* **2008**, *248*, 1049–1064.
40. Qiblawey, H.M.; Banat, F. Solar thermal desalination technologies. *Desalination* **2008**, *220*, 633–644.
41. Khaydarov, R.A.; Khaydarov, R.R. Solar powered direct osmosis desalination. *Desalination* **2007**, *217*, 225–232.
42. McBride, R.; Morris, R.; Hanbury, W. Wind power: A reliable source for desalination. *Desalination* **1987**, *67*, 559–564.
43. Davies, P.A. Wave-powered desalination: Resource assessment and review of technology. *Desalination* **2005**, *186*, 97–109.
44. Gerasimou, A. *Proposal for Water Deficiency Coverage in the Arid Islands of Cyclades and Dodecanese*; International Technological Application (ITA) S.A.: Athens, Greece, 2008. (In Greek)
45. Knithakis, M.; Kaloumenos, K. The Risk for Bracketing of Surface and Underground Water Resources. In *Water Resources Management in Crete*; Greek Geotechnical Chamber, Department of Crete: Chania, Greece, 1993; pp. 37–56. (In Greek)
46. Vergis, G. Study of the Possibility Construction of Water Reservoir in the Area of Almyros Brackish Spring in Iraklion, Greece. Master's Thesis, School of Mining and Metallurgical Engineering, National Technical University of Athens, Athens, Greece, 2006; p.148. (In Greek)
47. Jaber, I.S.; Ahmed, M.R. Technical and economic evaluation of brackish groundwater desalination by reverse osmosis (RO) process. *Desalination* **2004**, *165*, 209–213.