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Water scarcity in North Cyprus and solar desalination research: a review

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ABSTRACT

The shortage of water for domestic and agricultural purposes in North Cyprus (N. Cyprus) is obvious. Various measures have been planned and implemented to increase the supply of water and ensure it is used more efficiently. The backbone of the local economy is agriculture, where the exportation of citrus fruits and potatoes was a significant source of revenue for the government back in the 1960s. The present water crisis on the island however has affected the agricultural sector as this has ceased to be functioning. The water crises implies that there is a shortage of water for irrigation purposes, which has affected the yearly quantity of agricultural produce as vast quantities of arable land suffer from a low yield. Furthermore, seawater has seeped into the aquifers, which have also negatively affected citrus fruit cultivation as most produce die naturally due to the high salt content of the water resources available to them. This paper reviews the sources of water in N. Cyprus and discusses the water scarcity problem in the region. The work also presents solar desalination applications in N. Cyprus to relieve the edible water scarcity.

Keywords: North Cyprus; Solar desalination; Water scarcity; Capacity building; Edible water

1. Introduction

Approximately 71% of the earth's surface is covered by water. However, a tiny fraction (0.014%) of the world's total water supply is readily available freshwater [1,2]. The hydrologic cycle collects, purifies, and distributes this fixed supply of available freshwater on a continuous basis. This purification process provides enough freshwater as long as it is neither overloaded with persistent pollutants and non-degradable wastes nor withdrawn from underground supplies faster than it is replenished. The physical shortage of water resources to meet the basic requirements of society is called scarcity.

Water scarcity is currently an issue attracting attention worldwide especially in regions where renewable water is limited (Table 1). The United Nations has suggested that without a significant reversal of economic and social trends, it will become more acute over time. Water is a renewable resource, but in many parts of the world, water resources have become so depleted or contaminated that they are unable to meet an ever-increasing demand. The challenges are more acutely felt in developing countries where 95% of the world's new population is born each year [3]. The scarcity of water in many areas has led to a host of problems like socio-economic, environmental, and political conflicts/issues.

Water scarcity is a phenomenon brought about by imbalances found between the demand and

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Table 1
Population size and growth and renewable freshwater availability in water-scarce countries, 1995 and 2025

Country	Population 1995 (million)	Water per capital 1995 m^3/year	Population 2025(million)	Water per capital 2025 (million)	Total fertility rate 1998	% Growth rate of population 1998
Algeria	28.1	527	47.3	313	4.4	2.4
Bahrain	0.6	161	0.9	104	3.2	2.0
Barbados	0.3	192	0.3	169	1.7	0.5
Burundi	6.1	594	12.3	292	6.6	2.5
Cape Verde	0.4	777	0.7	442	5.3	2.9
Comoros	0.6	1,667	1.3	760	5.1	2.7
Cyprus	0.7	1,208	1.0	947	2.1	0.7
Egypt	62.1	936	65.8	607	3.6	2.2
Ethiopia	56.4	1,950	136.3	807	7.0	2.5
Haiti	7.1	1,544	12.5	879	4.8	2.1
Iran	68.4	1,719	128.3	916	3.0	1.8
Israel	5.5	389	8.0	270	2.9	1.5
Jordan	5.4	318	11.9	144	4.4	2.5
Kenya	27.2	1,112	50.2	602	4.5	2.0
Kuwait	1.7	95	2.9	55	3.2	2.3
Libya	5.4	111	12.9	47	6.3	3.7
Malawi	9.7	1,933	20.4	917	5.9	1.7
Malta	0.4	82	0.4	71	2.1	0.6

Sources: Gardner-Outlaw & Engelman.

supply of water in a society, where the demand far outweighs the supply. The "population-water" resources equation strains society and has an adverse impact on domestic hygiene, public health, and the cost of domestic water; and could impart political problems [4]. Water scarcity is strongly linked with low annual rainfalls and low per capita volume of renewable water resources. Any area with less than an annual 500 m^3 of water per person has reached the "water barrier"—a critical line below which it becomes difficult to survive [5]. The increase in population growth rates, increased rural—urban migration, the growing tourism industry, uncontrolled irrigation for agricultural use, late adoption of modern irrigation techniques, poor maintenance/efficiency of municipality pipelines, poor water network systems, and increase in the number of industries and recent huge investment in real estate in North Cyprus (N. Cyprus) are the main reasons for the water problem in N. Cyprus. This escalating demand for water in the area has led to extraction of water from groundwater resources, which resulted into salinization (up to 5,000 parts per million of the total dissolved solid) and a high volume of salt contamination due to salt-water intrusion along the coastal aquifers located in N. Cyprus. It is possible to get potable water from salinated water (seawater or brackish water) using desalination techniques. Water desalination has become a major source of freshwater supply in many countries, especially in the Middle East and North Africa (MENA) regions where freshwater supplies are very limited. The huge numbers of running projects of sea/brackish water desalination in the MENA region have proved that water desalination can provide unlimited and constant supply of high-quality drinking water, and reduce pressure on freshwater ecosystems and groundwater resources [6–12]. The provision of potable water by sea/brackish water desalination in the arid/semi-arid areas is considered a scientific breakthrough, especially where the conventional sources of freshwater are not available or have been contaminated. Desalination (the process of separating water from its contaminant), an essential technology in water scarce regions, can be used to prevent the current overexploitation of conventional water resources in N. Cyprus. Desalination processes are energy intensive, a shortcoming that led to solar desalination innovation. It is observed that the intensity of solar energy is usually high in regions with water scarcity problem, specifically in summer, when the demand for water is at its peak. Currently, utilizing solar energy to convert saline underground or river water to edible water is being considered around the world.

2. Water resources in N. Cyprus

N. Cyprus is at the hub of three continents (Africa, Asia, and Europe) where the trade routes intersect, located at 35°N 33°E of Greenwich meridian. The country is surrounded by the Mediterranean Sea and characterized with Mediterranean climate of hot and dry summer and mild winter. The de facto population of N. Cyprus is 285,365 according to a recent report by the Statistics and Research Department of the State Planning Organization 2009 [11]. The land distribution of N. Cyprus constitutes 56.7% agricultural (of about 1,870 km^2), 19.5% of forestry (about 643 km^2), 5.0% of grassing area (163 km^2), 10.7% is covered by towns, villages, rivers, and reservoirs (386 km^2) and nearly 8.2% is a bare land (269 km^2) with 87 km^2 of irrigable land [13]. There are no ever-flowing or perennial streams in N. Cyprus. There are 38 streams in N. Cyprus, of which 10 originated from the southern part of the island, around the Trodos Mountains and are relatively rich in water when they flow, but the construction of dams by the southern administration prevented the flow of the streams to the Northern part. Eight of these streams namely Yesilirmak, Kamburdere, Madendere, Lefke deres, Gamlidere, Taslidere, Dogance, and Guzelyurt deres carry about 43 million m^3 of water per year. Kanlidere and Ganlidere are quite large streams which start from the south and flow to the North but do not bring water because the water flows into dams built in the Southern part of Cyprus. The remaining 30 streams get their water from Besparmak Mountains and carry about 27 million m^3 of water on the average per year [14]. A total of 70 million m^3 of water flows in streams in N. Cyprus. Approximately 38 million m^3 of this water feed the aquifers in the western part of the country. The remaining water is used for irrigation and some of it flows uncontrolled. There are about 40 dams and ponds built in N. Cyprus. The storing capacity of these dams and ponds varies between 2,000 m^3 and 4.5 million m^3 and these dams have a total storage capacity of 21 million m^3 per year. Table 2 shows some selected dams in N. Cyprus with their capacity and year of construction. The most important water resources in N. Cyprus are the groundwater sources. The aquifers are characterized into 13 groups within eight hydrological regions, which have various capacities of water storage (Table 3). The Guzelyurt aquifer is the most important and the largest of the aquifers in N. Cyprus. It is located in the Guzelyurt region with an area of 280 km^2 of which only 180 km^2 is in the northern part, while the rest 100 km^2 extends to the South of the island. It is estimated that the water-holding capacity of the aquifers is about 920 million m^3. Annual water inflow is about 37 million m^3 and annual water outflow is about 57 million m^3. About 92% of this water from the Guzelyurt aquifer is used for irrigation and 8% is used for domestic purposes. Because of the excess water withdrawal from this aquifer, the water level has fallen sharply and the salt content of the water about 1 km from the shore is around 2,000 ppm NaCl. Akdeniz aquifer, not far from the Akdeniz village, has an area of 20 km^2. Its average thickness is about 30 m with annual water feed of about 2 million m^3 of which the same amount of water is drawn annually from it. Lefke—Gemikonagu aquifer annual feeding is about 14 million m^3 with an annual withdrawal of about 6 million m^3 and its remaining water directed to the Guzelyurt aquifer.

Table 2
Dams in N. Cyprus constructed after 1987

District	Dams	Years of construction	Capacity (10^3)	Irrigation area (ha)
Gazimagusa				
	Gonendere	1987	940	150
	Gecitkale	1989	1,360	240
	Mersinlik	1989	1,140	170
	Tatlisu	1989	156	50
	Ergazi	1989	400	84
Guzelyurt				
	Akdeniz	1988	1,470	–
	Gemikonagi	1988	4,120	–
Girne				
	Gecitkoy	1989	1,800	161
	Zeytinlik	1989	50	–
	Karsiyaka	1989	25	–
	Arapkoy 1	1990	440	40
	Arapkoy 2	1990	600	65
	Besparmak	1992	775	67
	Dagyolu	1994	392	82
Lefkosa				
	Degirmenlik	1990	297	30
	Hamitkoy	1992	529	95
	Serdarli	1992	391	56
	Lefkosa	1994	517	40

The Girne Coastal aquifer surface area is about 40 km^2 consisting of two small aquifers of 7 km^2 each. Annual replenishment of the aquifer on the average is about 10.5 million m^3, which is also the amount withdrawn on a yearly basis. Gazimagusa Aquifer is no longer in active use due to the aquifer contamination by the seawater. It occupies 45 km^3 of which 16 km^3 is only the Northern part of the island, while the rest extends to the southern part of the island. The other aquifers are smaller in storage as seen in Table 3. The

Table 3
The aquifers' capacities in N. Cyprus [DSI 2003]

Aquifers	Recharge (10^6 m^3)	Sustainable yield (10^6 m^3)	Withdrawals (10^6 m^3)
Guzelyurt	37	37	57
Akdeniz	15	1.5	1.5
Lefke-G. Konagi			
Y. dalga	15.5	6	6
Yesilirmak	7	1.5	1.5
Girne Mountains	11.5	11.5	11.5
Gazimagusa	2	2	8.5
Beyarmudu	0.5	0.5	0.5
Cayonu-Guvercinlik-			
Turkmenkoy	2	2	2
Lefkosa-Serdarli	0.5	0.5	0.5
Yesilkoy	1.6	1.6	3
Girne Coast	5	5	5
Yedikonuk-			
Buyukkonuk	0.3	0.3	0.3
Dipkarpaz	1.5	1.5	1.5
Korucam	1.2	1.2	1.2
Others	2	2	2
Total	89.1	74.1	103

water withdrawal is much more than the water inflow to the aquifers and the quality of the water is growing worse. Theoretical water demand in N. Cyprus is about 123 of which 93 million m^3/year is used for agriculture and 30 million m^3 for domestic use. Actual water consumption in N. Cyprus is about 94 and 78 million m^3 for agriculture, while 16 million m^3 is used for domestic purposes annually [15].

3. Water scarcity in N. Cyprus

Cyprus is among those countries that are water stressed, particularly the Northern part of Cyprus where freshwater shortage is evident. Some of the identified factors responsible for the water scarcity in N. Cyprus are increase in population due to possibility of reconciliation with the southern part, the growing tourism industry, poor water management, and drought. Drought is the most deadly of these factors causing water scarcity in this part of the world. Most of the streams are dry due to consistent dry winter over the past two decades. The country witnessed a climate change with reduction in precipitation per year, high evaporation rate of about 2,000 mm/year, and the temperature has increased by 0.45°C yearly from 2006 [16,17]. The reduction in precipitation and the raise in temperature have had an adverse impact on the availability of the natural water resources. Extreme climatic phenomena especially droughts are more frequent than before, with droughts causing water shortage and scarcity, and adverse effects on the economy, on the social life, and on the environment. There is strong evidence of seasonal disparity in rainfall, which varies between 200 and 600 mm. The available data, according to Biyikoglu [18], show average rainfall of 440–450 mm at the beginning of the century which declined to a stable figure of about 402 mm between the years 1941–1972 [18]. The years 1975–1993 witnessed a lower average rainfall of about 382.4 mm per year.

The precipitation figures have since worsened, with November having the highest precipitation of 104 mm, June, and July with no precipitation at all. As at 1997, 1.2 billion m^3 of rainfall has fallen on Cyprus, in which part of the water infiltrates into the aquifers and some water was harvested using the dams and ponds in different parts of the country [19]. A considerable portion of the water was lost to high evaporation rate, an average of 2,200 kg/m^2 was lost per year while 13 million m^3 of water was lost from the dams and ponds each year [19]. The probability that the climate parameters will continue is substantial. The effect of global warming on sea levels around the island will continue to rise with severe impacts on the coastal aquifers and on the coastal lands used either for agriculture or for other uses. Unless capacity-building strategies are in place to mitigate global warming effect, the water problem in N. Cyprus will be more severe in coming years. One way to solve the problem of drought on the island is to concentrate the effort on new water sources like desalination. The effects of the drought are more pronounced with the disappearance of surface water sources like rivers and dams in the northern part of Cyprus. The demand and supply of renewable water in N. Cyprus is not balanced; the demand for freshwater supply is increasing exponentially yearly, while efforts to meet the demand are not sufficient, making the demand far outstrip the supply. Table 4 shows the water use in N. Cyprus based on a sector wise annual water withdrawal. Table 5 shows the available water resources, while Table 6 shows the quality of water in selected areas of the Island. Poor water management is also seen as a major reason for water scarcity in N. Cyprus; losses in agricultural and domestic use accounted for about 35% of available water. Evidence of poor management was seen in the agricultural sec-

Table 4
Sector wise annual water withdrawals (m^3)

	Irrigation	Agricultural use losses	Subtotal	Live stock	Hotels	Domestic use universities	Residents	Losses	Subtotal	Total
LMR										
C. Lefkosa	82,022	70,215	152,237	75,387	18,834	226,555	4,513,408	1,450,255	6,284,438	6,436,675
Degirmenlik	575,349	513,982	1,089,331	165,500	0	0	1,732,564	569,419	2,467,483	3,556,814
Ercan	550,961	522,686	1,073,647	192,050	0	0	143,354	100,621	436,025	1,509,672
Guzelyurt	37,812,296	21,863,489	59,675,785	248,173	2,774	0	6,930,926	2,154,562	9,336,434	69,012,219
Lefke	3,170,069	2490,606	5,660,675	30,746	5,256	40,184	682,185	227,511	985,882	6,646,557
Total	42,190,697	25,460,978	67,651,675	711,856	26,864	266,738	14,002,437	4,502,368	19,510,262	87,161,937
MMR										
Magosa A	1,824,077	1,673,518	3,497,595	118,877	125,414	359,211	2,705,380	992,664	4,301,546	7,799,141
Magosa B	348,666	344,259	692,924	70,089	0	0	256,869	98,087	425,045	1,117,969
Akdogan	1,335,133	1,103,063	2,438,196	177,768	0	0	659,920	251,306	1,088,994	3,527,190
Y. Erenkoy	1,228,282	1,078,670	2,306,952	187,094	4,672	0	834,390	307,847	1,334,002	3,640,954
Mehmetcik	686,154	673,919	1,360,073	92,392	0	0	453,330	163,717	709,439	2,069,512
Y. Iskele	485,257	463,085	948,342	123,857	39,420	0	844,793	302,421	1,310,491	2,258,833
Gonendere	212,983	212,984	425,967	72,330	0	0	487,275	167,882	727,487	1,153,454
Gecitkale	373,223	360,357	33,579	136,433	0	0	131,856	80,487	348,776	1,082,355
Total	6,493,774	5,909,854	12,403,628	978,841	169,506	359,211	6,373,813	2,364,411	10,245,781	22,649,409
GMR										
Girne East	669,566	642,904	1,312,470	62,118	315,506	47,897	1,966,620	717,642	3,109,783	4,422,253
Girne West	2,826,507	2,729,797	5,556,304	10,001	248,127	0	1,017,620	382,724	1,658,472	7,214,776
Bogaz	374,485	369,072	743,557	139,131	0	0	1,032,494	351,487	1,523,112	2,266,669
Camlibel	926,917	834,605	1,761,521	131,732	0	0	258,694	117,128	507,554	2,269,075
Total	4,797,475	4,576,377	9,373,852	342,981	563,633	47,897	4,275,428	1,568,982	6,798,920	16,172,772
N. Cyprus	53,481,946	35,947,209	89,429,155	2,033,678	760,003	673,846	24,651,678	8,435,761	36,554,963	125,984,118

Table 5
Water resources based on annual water extractions (m^3)

	Available resources					
	Springs	Sanitary	Dams	Transport	Desalinization	Groundwater
LMR						
C. Lefkosa	0	3,445,840	152,237	0	0	0
Degirmenlik	19,751	0	318,009	0	0	3,219,054
Ercan	0	0	0	0	0	1,509,672
Guzelyurt	0	0	0	1,661,901	0	73,634,756
Lefke	0	0	1,490,806	0	0	5,155,751
Total	19,751	3,445,840	1,961,052	1,661,901	0	83,519,233
MMR						
Magosa A	0	36,870	0	0	0	7,762,272
Magosa B	0	0	0	0	0	1,117,969
Akdogan	0	0	0	0	0	3,527,190
Y.Erenkoy	0	0	0	0	0	3,640,954
Mehmetcik	4,179	0	0	0	0	2,065,333
Y. Iskele	40,898	5,422	97,737	0	0	2,114,776
Gonendere	12,665	0	425,967	0	0	714,822
Gecitkale	25,266	0	0	0	0	1,057,089
Total	83,008	42,292	523,704	0	0	22,000,405
GMR						
Girne East	11,654	41,026	474,620	0	109,500	3,785,453
Girne West	111,527	7321	0	0	0	7,095,928
Bogaz	1962	0	43,174	0	0	2,221,533
Camlibel	137,390	0	80,253	0	0	2,051,432
Total	262,533	48,347	598,047	0	109,500	15,154,346
N. Cyprus	365,292	3,536,478	3,082,803	1,661,901	109,500	120,673,984

Table 6
Quality of underground water sample from selected

Source of water	Total dissolved solids (ppm)	Conductivity (μS/cm at 25°C)
E.M.U campus	3,175	1,820
Gunesoglu	5,941	3,530
Lastikgi	6,679	4,570
Guvercinlik forth well	10,657	6,030
Buyukonuk	2,668	1,720
Iskele	5,862	3,201

Sources [20].

tor with uncontrolled irrigation, poor water piping network, and obsolete irrigation equipment. The losses in water will require water management on the part of the government and water conservation orientation on the part of consumers. The boost in the tourism industry is also putting stress on the available water; the island hosts over 2 million tourists yearly. The tourist facilities available require a huge amount of water to meet the recreational needs of their customers. Water rationing exists in most parts of the island, where most parts do not have water for more than 24 h in a week. The water that runs from the pipe/tap is not potable; it is only used for domestic purposes outside cooking and drinking. Every home has had to provide potable water by themselves by buying from water vendors. The issue of potable water can easily be addressed by desalination systems, of which solar desalination systems can be mounted on a house roof.

4. Efforts to solve N. Cyprus water problem

Currently in N. Cyprus, nearly all the water sources contain a high content of salt. This condition makes the water not useful directly except when treated. The embargo imposed on N. Cyprus worsens the situation more and make freshwater a valued commodity. Projects have been proposed as to import freshwater from Turkey by tankers, or through the use of large water bags and/or by pipelines. The first load of water was transported by water bags on 25 July 1998 [21]. Water bags of 10,000 m^3 capacity with the potential of bringing 3 million m^3 of water in one year from Soguksu River of Anamur in Turkey were introduced. An increase in the capacity of the water bags to 30,000 m^3 would enable 7 million m^3 of water to be imported annually. This amount is the maximum the system can permit to be pumped from Kumkoy to Serhatkoy and then to Dikmen where the main reservoirs are situated and from where water is sent to Nicosia and Gazimagusa. According to Biçak and Jenkins [14], the cost of the water transportation was \$5.6/m^3 as at the prevailing cost then. This project was later abandoned due to water loss when the bags burst on transit by sharp materials in the Mediterranean Sea. Another important project was the water conservation by converting traditional irrigation systems to modern irrigation methods in areas such as Guzelyurt. The new irrigation equipment conserved water used for irrigation in the area by 30%. The percentage of water saved relieved the overextraction of the Guzelyurt aquifer and thus salination was prevented, thus the productivity and quality of the agricultural output increased in the area. The government cannot continue with the replacement of the traditional irrigation systems due to non-availability of funds, as the embargo on the island prevented exportation of citrus fruits to the EU. One other project to ease the water shortage in N. Cyprus for all uses is through importing water by pipeline either from Anamur or from Manavgat in Turkey. Through this project 75 million m^3 of water could be brought to Kumkoy of N. Cyprus. The Council of Ministers of Turkey has taken the decision to implement the project with the Turkish firm ALARKO. This project appears to be financially not feasible if one considers only the revenues from the water sold for use in N. Cyprus. The project might be feasible if some quantity of water could be sold to South Cyprus [14]. This project is now postponed due to some conflicting views between the government and the local villagers that would be affected by this project. Another important project is the Rehabilitation of the Haspolat Sewage Treatment Plant sponsored by the EU in a bid to unite the two communities on the Island; the project will cost 25 million Euro. This project will provide 3.5 million m^3 of water to be used in agriculture. The cost of the water will be at \$7.14/m^3 which is high for agricultural purpose, except for government subsidy.

Another project was the establishment of a 150 m^3/day capacity small reverse osmosis (RO) desalination plant in Eastern Mediterranean University to supply potable water for campus use, but due to ill management of the plant, the plant is no longer functional. There are other small RO rooftop units available in some homes in Famagusta and some few places in Lefkosa and Grine. Efforts are onto establish another RO plant in the hostel centre area on the Island. The government is working on improving its water management practices that will enhance efficient water use. These efforts will only take years to realize it goal. There are already water supply cuts; some towns only have water supply for 6 h in a week, while some others have it for 48 h a week. The re-use of household waste water in irrigation is difficult due to traditional belief. But the waste water recycle plant is being funded by the EU; hoping when it is completed, it will help in efforts to relieve water shortages in N. Cyprus.

The aforementioned efforts carried out to relieve the water situation have not been successful, which necessitate the use of solar desalination. The island is surrounded with the Mediterranean Sea and abundant sunshine throughout the year especially in the summer season when the temperature on a clear day reaches up to 45°C with maximum solar radiation around 1,200 W/m^2. Desalination of the seawater/brackish water can be a major source of freshwater to households. Today there are a number of environmental issues on the use of conventional desalination, these issues include uncontrolled discharge of concentrated brine into water bodies, which can contaminate underground water sources and damage aquatic ecosystems. Also the constituent of the brine discharge include chemicals and other agents used in the water purification. Desalination plants require thermal and electrical energy that are often derived from power plants; these power plants produce carbon dioxide emission, which results in environmental pollution. In addition to the carbon emission, the plant constitutes sources of noise pollution, especially to the immediate environment. All these effects necessitate the use of renewable energy in desalination.

The government is not supplying freshwater (in this case edible water) to households in N. Cyprus; it is the responsibility of each household to get freshwater for drinking and cooking. The provision of edible water for household motivated the proposed solar desalination systems that can be roof mounted and provide daily edible water. RO is also part of the consideration only that the cost of electricity in N. Cyprus is very high. However, the current financial situation on the island cannot sustain desalination using fossil fuel and a huge solar desalination plant will be an expensive project for now. Since the government depends on aids from the EU and Turkey to run its economy, the need for a small-scale solar desalination is proposed for solving the freshwater scarcity (edible water) problem in N. Cyprus. Currently, each household buys its own edible water from water hawkers. These water hawkers are not readily available in remote areas, even in major cities you may have to wait several hours before delivery. The need for solar desalination units for household edible water is feasible and economically viable in Northern Cyprus. The feed water for the solar desalination units will be brackish water (contains around 1,000–2,500 ppm) as supplied by the municipalities to various homes; the municipality water is used for other need in the house except for drinking and cooking.

5. Desalination research in N. Cyprus

Solving water scarcity problems with water conservation, water-pricing mechanism, improved water resources management, wastewater recycling, and desalination is very common. Water conservation is a preventive method of avoiding scarcity of water. The truth is that water demand far outstrips its supply in most cases. Increase in population and rapidly industrialization are stressing the available freshwater. Water conservation is one way to slow down the gap between water demand and supply. Water sources in Northern Cyprus are not edible. Therefore, water conservation is not an immediate solution to provide edible water for households. Water pricing mechanism cannot apply also, since edible water needed in household is not available in order to use pricing to curb the use of water. Improved water resources management is vital to water sustainability, especially in the agricultural sector. Poor water resource management led to the seawater intrusion into the underground water in the 1980s. The excessive withdrawal of the underground water for agricultural use increased the vulnerability of water shortages especially to households. The farmers had no incentives for efficient water usage and the water systems lacked institutional systems that could control and monitor underground water withdrawals. Until recently, the country lacked water policies that could account for water use. A structured farmer's water right under water resources management and efficient irrigation system could help improve water use for agriculture. The water for farm irrigation is brackish water as supplied by the municipalities; farmers still have difficulties in using brackish water for irrigation due to high saline content (1,000–2,500 ppm). Wastewater recycling is another viable option for agricultural water use on the island, which currently has a wastewater recycling plant in rehabilitation. The EU is funding the plant and the water from this plant will be used to relieve water shortages in the agricultural sector. For edible water, one solution will be new water through desalination technology. As mentioned earlier, there are no edible water sources on the island. One major potential for inexhaustible sources of edible water is the seawater, only that it contains a high content of salt and other contaminations. Desalination is a technology that can produce edible water from seawater or brackish water. World Health Organization (WHO) had set the permissible salinity in water to 500 ppm, while most oceans have salinity up to 10,000 ppm, and seawater normally has salinity in the range of 35,000–45,000 ppm in the form of total dissolved salts. This technology can provide new source of edible water to household in Northern Cyprus.

The oil-rich countries of the MENA region have constantly satisfied their water needs through desalination of seawater, a process that requires significant quantities of energy to achieve separation of salts from seawater. Using thermodynamics, it is possible to calculate the minimum energy to separate pure water from seawater. The agreed figure ranges from 0.7 to 0.9 kWh/m^3. The energy consumption and environmental pollution caused by the use of fossil fuels to power these plants are of great concern. Majority of these plants across the Middle East region also produce electricity. For instance, Saudi Arabia has 27 desalination plants in the Kingdom, supplying over 70% of the country's drinking water (edible water) as well as more than 2.8 GW of electricity. The most recent of the desalination plants produced about 800,000 m^3 as well as 2,750 megawatts of electricity at an investment cost of US$ 3.8 billion. The UAE is another oil-rich country in the MENA region with a daily production of about 8,885,366 m^3/d of contracted desalination capacity. The country spent about $682.3 million in 2010 as the cost of operating existing plants and adding new plants. Algeria in the Northern part of Africa has a desalination plant with a daily production of 200,000 m^3 of potable water with an investment cost of US$ 250 million. The El-Hamma Seawater Desalination Plant in Algeria provides sufficient water for the country's capital and supplies excess water to some neighborhoods around the capital. Other desalination plants include Jordan's 2400 m^3

per day plant that eases the water problem in DeirAlla in the Jordan Valley. Turkey has desalination plants that produce more than 500,000 m^3 of freshwater daily to support its surface and underground water. All of the mentioned desalination plants use fossil fuel and given current understanding of the greenhouse effect and the importance of CO_2 levels, burning of fossil fuels (oil) on this large scale negatively affects the environment. The Southern part of Cyprus produce over 30 million m^3 per year of potable water from desalination plants that represent about 12% of the total water consumption on that part of the island. The water produced is not shared with the Northern part (Northern Cyprus) because it can barely meet water demand in the south.

The demand of edible water for households supply in Northern Cyprus can be satisfied with desalination plants. One major obstacle is the finances, involvement in the construction and maintenance of such desalination plants since the Northern Cyprus government operates under economic isolation. In Northern Cyprus, most of the notable projects are either sponsored by Turkey or the European Union since the government on its own cannot trade or be traded with due to the economic embargo. The European Union is financing the wastewater recycle project, while Turkey is considering water transportation to the island through pipeline. The economic embargo had crippled the wish of the government to provide edible water to every home. Currently each household provides or sorts for its own edible water from water hawkers/vendors. The water hawkers produce water from reserve osmosis and some of them import water from Turkey. The price of edible water from the water vendor costs between $0.15 and $0.25 per liter. In addition, availability of the edible water depends on close proximity to the major cities. The distributed water is only good for household use, except for drinking and cooking. Since the government is not currently thinking of desalination plants due to cost and other social environmental issues associated to it, household simple solar desalination system can be a cheap, immediate, and viable solution to the edible water scarcity. An inclined solar water desalination system is proposed for the production of edible water for household use in Northern Cyprus. The components of the system are cheap and available in the local market, the feed water for the system will be the brackish water supply by the municipalities and the region's high solar radiation (up to 1,000 W/m^2) will be used as the energy for water separation. The yearly weather condition in Northern Cyprus favors the use of solar desalination systems, for instance there is sunshine for about 300 days out of 365 days in the year in Northern part of Cyprus. The ambient temperature ranges from 20 to 40°C in winter to summer times. Already Cyprus is one of the leaders in the use of rooftop solar air heater technology, a system used for heating water. The advances in solar desalination are still ongoing and renewable energy-powered desalination systems(small or large scale) cannot compete with conventional systems in terms of the cost of water produced for now, but will be better off if the environment is seen as a major factor for consideration. The cost of distilled water from inclined solar water desalination system is around $0.0885 based on the construction of a single unit for experimental purposes; commercial production of the unit will reduce the cost of the system and make the distilled water cheaper. As it is now, the distilled water from the solar desalination system is cheaper when compared to water procured from water vendors. It is more economical providing edible water from inclined solar water desalination (ISWD) than procuring it from a water vendor. In addition, the quality of water from the ISWD (70–100 ppm) is better than that from the vendors (120–350 ppm). The ISWD system uses maximum of 20 l per day to distil 6.41 l of edible water. The schematic diagram of the system is shown in Fig. 2. The research on how to improve the efficiency and daily production of the system is still ongoing in the Mechanical Engineering Department of Eastern Mediterranean University. The works of renowned author(s) like Tiwari et al. and Delyannis have provided detailed historical reviews on desalination and solar desalination units [22]. A number of other author(s) have also performed experimental and analytical investigations on different solar desalinating units to increase efficiency, daily production, and to optimize the use of alternative energy [23–29].

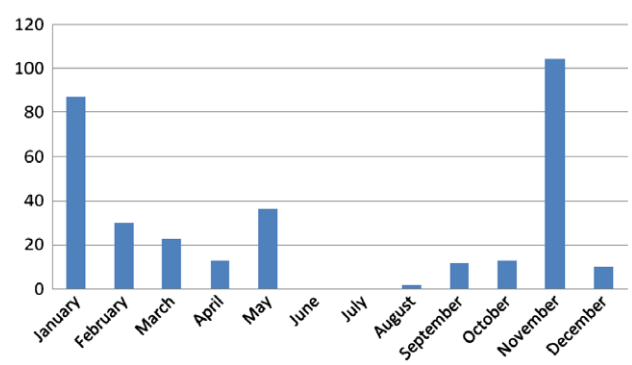

Fig. 1. 2005 average precipitations in mm [SPO 2005].

There are many researches ongoing on solar desalination in N. Cyprus. The department of Mechanical Engineering of Eastern Mediterranean University in

Table 7
Some selected desalination research in N. Cyprus

No.	Name of the system	Average solar intensity (w/m2)	Ambient mean temperature (°C)	Productivity (kg/m^{2}day)	Reference
1.	IBSS with bare plate	450	30	1.29	[30]
2.	IBSS with black fleece	450	30	2.995	[30]
3.	IBSS with bare plate and Glass base without mirror	620	34	3.41	[31]
4.	IBSS with black wick and Glass base without mirror	620	34	4.21	[31]
5.	IBSS with bare plate and Glass base with mirror	710	34	5.13	[31]
6.	IBSS with black wick and Glass base with mirror	710	34	6.41	[31]
7.	IBSS with metal sheet plate	620	34	2.80	[31]
8.	IBSS with blue wick	620	34	3.61	[31]
9.	Single basin solar still	540	34	2.20	[31]

NB: IBSS-Incline basin solar system.

Famagusta has continued to provide innovative research on solar desalination. Table 7 shows some selected research on solar desalination in the last five years. The effect of solar radiation, in feed flow rate, nozzles jets, bare plate, and wick clothes on daily production was studied. Other research works are going onto advance the use of solar desalination in the region to ease the scarcity of edible water. There are other desalination systems across the region like the RO. Eastern Mediterranean University used to have a functional unit of 150 m^3 per day that no longer functions due to membrane problems. There are RO plants in construction stages in the Bafra region of the country to serve the consortia of five star hotels. The cost of the RO's plant and its maintenance are to be shared by the member of the consortia. The feed water of the RO is the seawater and the Mechanical Engineering Department of Eastern Mediterranean University is working on ways to improve membrane life span.

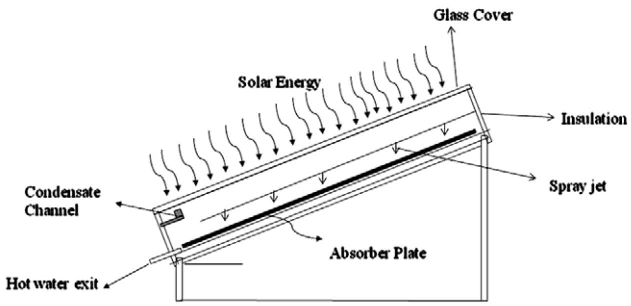

Fig. 2. Schematic diagram of the inclined solar water distillation system.

The system as shown in Fig. 2 was tested under the climatic weather condition of Famagusta and the results of the experiments are shown in Table 7. The results show improvement on the system since 2005 when the research was initiated. Economic analysis of the system distilled water is as presented in Table 9. The technical and economic feasibility of this projects shows that the system is suitable for edible water provision in N. Cyprus. The system will be more affordable (even more cheaper) if it is commercialized.

Table 8 shows the cost of conventional desalination water. It is obvious that large desalination plants produce cheap distilled water as compared to small plants. The cost of distilled water from the proposed inclined solar water desalination is high compared to cost of water given in Table 8, yet the ISWD is economical when compared to the current cost of water from the water vendors in northern Cyprus. This solution will remain the cheapest source of edible water for households until large fossil fuel desalination

Table 8
Desalination unit size and cost of water produced

Feed water Type	Size of plant (m^3/day)	Cost (per m^3)	Source
Brackish	<1,000	0.78–$1.33	[32]
	>5,000	$0.26–$0.54	[33–34]
Seawater	<1,000	$2.21–$8.51	[35–36]
	>5,000	$0.69–$3.9	[35–36]
	>60,000	$0.50–$1.00	[37–39]

Table 9
4 Cost analysis of distilled water from 2 of the systems in TL (1TL = $0.67)

ISWD types	*P*	CRF	FAC	*S*	SFF	ASV	AMC	AC	*M*	CPL
IBSS with bare plate and glass base with mirror	485	0.18	85.85	97	0.057	5.53	12.88	93.20	1,328.60	0.070
IBSS with black wick and glass base with mirror	491	0.18	86.91	98	0.057	5.60	13.04	94.35	1,600.00	0.059

plants exist. In addition, costwise, it is better to desalinate water than to import water from Turkey or to re-use the sewage and household water

The following are main parameters in the cost analysis of solar desalination systems: P is the capital cost of desalination system, capital recovery factor (CRF), fixed annual cost (FAC), and sinking fund factor (SSF), annual salvage value (ASV), average annual productivity (M),. and annual cost (AC), and salvage value (S) is taken as 20% of capital cost of desalination system. Other parameters are annual maintenance operational cost (AMC) and finally CPL (cost per litter). AMC is used for calculation of maintenance cost for removing salt deposits, maintenance of pump [40]. In this work, 15% of the present cost has been considered as maintenance cost.

$$\mathrm{CFR} = \frac{i(1+i)^n}{[(1+i)^n - 1]} \tag{1}$$

$$\mathrm{FAC} = P(\mathrm{CRF}) \tag{2}$$

$$\mathrm{SFF} = \frac{i}{[(1+i)^n - 1]} \tag{3}$$

$$S = 0.2P \tag{4}$$

$$\mathrm{ASV} = (\mathrm{SFF})\mathrm{S} \tag{5}$$

$$\mathrm{AMC} = 5\%\mathrm{FAC} \tag{6}$$

$$\mathrm{AC} = \mathrm{FAC} + \mathrm{AMC} - \mathrm{ASV} \tag{7}$$

$$\frac{\mathrm{AC}}{L} = \frac{\mathrm{AC}}{M} = \mathrm{CPL} \tag{8}$$

6. Capacity building in desalination

One major obstacle in developing desalination technology is the lack of professional capacity to deal with desalination projects. For the case of N. Cyprus, there have been no publications to address capacity building in desalination particularly due to:

(1) Economic isolation imposed on the area (N. Cyprus).
(2) Lack of data and information on water resources of N. Cyprus.
(3) Lack of technical expertise and limited technical capabilities.
(4) Lack of financial resources for research and infrastructure.
(5) Lack of viable national water policies regarding use of water, desalination technology, and water conservation schemes.

The need to provide a lasting solution to water scarcity in the Northern part of Cyprus requires urgent investments, training, and capacity building in desalination technology. The need for desalination technology has not gained enough attention from politicians and policy-makers in this region. The monetary investments and projects by Turkey to ease the water scarcity have failed because such funds/projects are grossly misplaced. The money intended for the construction of a water pipe from Turkey to Grine in N. Cyprus can be invested in desalination technology. The manpower to successfully run the desalination technology is not available yet, but training and research in desalination can be mandated in the six universities located within the region. The trainings and research work in the area of desalination should be an essential prerequisite for a well-established desalination industry, especially in Cyprus where it is evident that qualified manpower in desalination is lacking. Eastern Mediterranean University (EMU), owned by the government, installed small-scale desalination plants years ago, which is presently out of operation due to the unavailability of skilled labor. The most important recommendation in this respect is to establish a training scheme in the universities to train the workers in the sector. The training scheme programs should include all renewable energy sources and technologies especially solar desalination due to the climatic condition of N. Cyprus.

6.1. Capacity building in education

Currently there are six universities in N. Cyprus namely; Eastern Mediterranean University, Near East University, European University of Lefke, Middle East Technical University (N. Cyprus Campus), Girne America University, and Cyprus International University. There are training at both undergraduate and graduate studies in renewable energy, but is not specific to desalination. Recently, the Middle East Technical University, N. Cyprus campus, introduced an MSc program in Sustainable Energy to focus more on energy sustainability. The other universities except Grine America University, have engineering faculties that foster the development of energy and energy conservation at the undergraduate level. Eastern Mediterranean University, the leading University on the entire Island (North and South), has wide-ranging graduate level programs (MSc and PhD) in Engineering. In 2007, the Energy research centre of Mechanical Engineering department in conjunction with Association of Mechanical Engineers in N. Cyprus organized some short courses in the areas of energy and energy management. At the undergraduate level, none of the six universities offers programs covering key elements of desalination like membrane technology, desalination, or water resources. There are courses in civil engineering and mechanical engineering of EMU that discuss water and energy, but they are grossly inadequate for the needed education in desalination. The desalination courses need to cover fundamentals of membrane technology and seawater and brackish water RO applications. The need to review the Engineering curricula of most of the universities to provide for desalination and water resources is urgently needed. The universities engineering faculties are weak in providing expertise knowledge in the field of desalination and there is a need to strategically develop a teaching module that will stress desalination technology. If desalination technology, especially RO, is to be employed in solving N. Cyprus water scarcity, there will be need for an average of 1,000 staff to be trained yearly due to the complexity involved in RO desalination technology. Such an example is seen in Saudi Arabia where more than 3,500 staff are trained yearly to maintain the huge RO system in the country. So far, there have not been national and/or international conferences on this issue in the last 10 years. Conferences on this subject matter will help bring experts together to brainstorm on the desalination process that will be best for the nation. The southern part of the Island (the recognized Republic of Cyprus) is currently planning to build a solar-powered RO desalination plant to complement the existing RO system in Larnaca. The main aim for desalination capacity building in Education is to comprehensively cater for theoretical and practical knowledge required by desalination manpower at all levels. The advantage of desalination capacity building in the Universities will include:

(1) Elimination or reduction of time and costs for training hired staff in desalination plants.
(2) Positioning manpower in the desalination industry to work efficiently having understood necessary theoretical basis needed for their job description.
(3) Opportunities of widening their scope on related industries like wastewater treatment, power plants, and air pollution.
(4) Learning trends, developments, and research in desalination.
(5) Bridging the gap between the industry, research centers, and universities.

6.2. Capacity building in research

There are many research ideas on desalination, solar desalination technology, and renewable energy. The issue of funds is a major limitation due to the non-industrialization of the area coupled with the international isolation. The government is also not helping matters as they favor projects that bring political credits instead of research that can advance the course of the people in the end. Considering the number of researchers in the area of desalination in the Universities, there should be a local research center well funded by the government to advance the desalination technology. Small-scale research in the fields of desalination (and not membrane technology) is widespread in universities within N. Cyprus. Mechanical Engineering of EMU is well involved in research projects on solar energy, solar air heater, and solar energy application in general. Research areas such as reuse of waste effluent, membrane systems, and nano-filtration systems are lacking. The situation in N. Cyprus is such that aside research in the Universities, there are no other bodies that carry out research due to non-industrialization of the area. The contribution of Research and Development (R & D) arms of Companies, or private-owned research Laboratories, is not available to consolidate the Universities' efforts. There are few workshops/conferences on Energy but they do not focus on the major areas of desalination technology like membrane technology and desalination plant materials. Moreover, many of the research projects carried out by N. Cyprus universities and research institutes are done without any major co-operation with the industries. Another setback in research witness is the lack of fund to carry out research activities. Often the researchers are limited in carrying out a research due to the use of personal money that is grossly inadequate for a research that can birth industrial application. Many of EMU PhD research projects carried out involve numerical modeling in order to ease the burden of sourcing for funds. The need for the Universities in N. Cyprus to collaborate with Universities in Europe in the area of PhD studies is inevitable due to non-availability of research fund. The poor research in desalination in North Cyprus Universities is due to a combination of commonly observed factors:

(1) Limited financial resources for research facilities
(2) Economic isolation of the area that affects technology transfer from developed countries
(3) A shortage of faculty staff in most of the Universities
(4) Lack of cooperation between the Universities and the industries

7. Conclusion

The water scarcity in N. Cyprus is evident and severe. There are various projects planned and/or implemented but with no lasting solutions to the problem. The efforts to bring water from Turkey either by pipelines or through water tankers have proved abortive. There is need for more attention on using the abundant sun in the region to separate the seawater to get freshwater. The research on solar desalination on the island is a small scale process that when fully funded can generate a big solar desalination plant that will produce water for both domestic and agricultural use and part of it can also be sold to the southern part for some income earning. N. Cyprus has potential to be free from water scarcity and can make some fortune from selling water. This work has contributed to research on water scarcity in Cyprus, especially in the northern part, where there is limited information and documentation on the issue.

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