DESALINATION FOR FACING THE DEFICIT IN FRESH WATER RESOURCES IN THE ARAB WORLD (EGYPT CASE)

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Abstract

The water question goes beyond the local and the Arab level to the regional and the international one. It is believed that the next conflict between the Arab states and Israel will take place for one of them to control the limited natural water resources in the region.

Water scarcity leads to a big pressure on food production, economic growth and natural systems protection.

Fresh water represents about 1% of the total amount of water available in the whole world, while saline water represents more than 97%.

Desalination is a part of the natural water cycle and thus it may gradually become not only the best but also the most promising way for producing fresh water to face the deficit of its resources in the Arab world. The study shows that the use of solar energy for desalination in Egypt and in the Arab countries will contribute to the national income by savings in fossil fuel, in minimizing environmental pollution and with almost zero running costs.

1. Introduction

All the fresh water in the world's lakes, streams and rivers represents about 0.01 % of all the earth's water. Figure (1) gives a clearer picture of thus reality. Renewable fresh water resources (RFWR) is a term which refers to water that humanity can count on for use year after year and for a long time to come. The Hydrologic cycle, which is responsible for replenishing water, which is used or lost, can be concluded from Fig. (1). Using the sun as its sole energy source, this cycle acts as a natural desalination process by evaporating 425 km^3 per year of the water in the seas and oceans, of this amount 385 km^3 falls back to where it came from as precipitation. The rest (40 km^3) combines with water similarly evaporated from lakes and other water bodies on land or transpired by surface vegetation to form clouds. These clouds drop their load of fresh water (111 km^3 per year) in the form of rain or snow on land. The balance after evaporation percolation through the ground, return to sea as flood run off, flow into sea in un-inhabited areas leaving about 9000 km^3 of water per year available for human use worldwide [1]. Had this amount been equally divided among world's population (presently estimated to be 6 billion) the result would have been more than 4000 liters per day per capita. However, neither the population nor usable water is evenly distributed all over the world. Hence, local availability of water varies widely giving rise to countries extremely rich in water, others water-poor with a great number scarcely find their needs of fresh water.

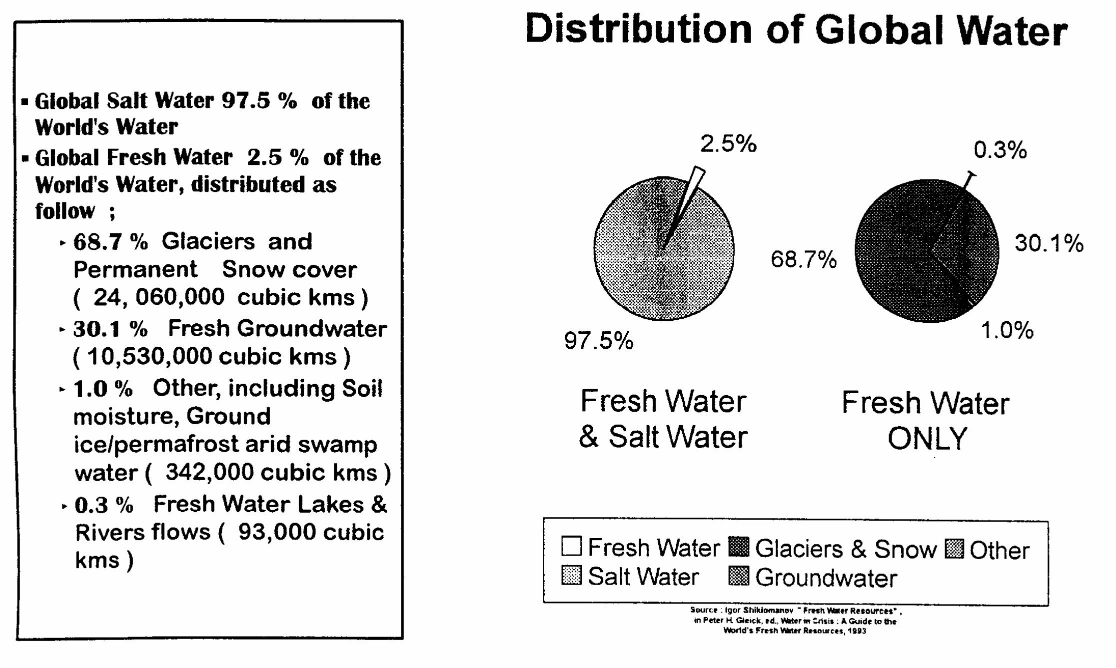


Fig. 1. Distribution of global water

The Arab world is mostly arid and semi-arid land which suffers from water shortage, (cultivated land 0.7 million km^2 from the total area of 14 million km^2, i.e. less than 0.05 %). Arab world composed of 22 countries; it covers an area of about 14 million km^2. Its population is estimated in 1996 to be 250 millions capita with an average annual growth rate of about 2.6 %. Population is expected to reach 350 millions capita by the year 2010. Average rainfall ranges between 100 and 300 mm, and most of the Arab countries have neither rivers nor fresh lakes. Also, ground water in most places lies at a considerable depth which ranges between 1000 to 2000 m. In Table (1) some selected data about the Arab world are given.

Table (1): Arab World (Selected Data)

Country	Area 10^3 km^2	Population (10^6) / % incre.	Population Density Per km^2	GDP Per Capita US $	Annual Rainfall mm	Amount of Rainfall 10^9 m^3	Total Water Resources 10^9 m^3
Algeria	2381.7	25.260 / 3.0	11	1924	20 – 1000	185	17,275
Bahrain	0.7	0.497 / 3.1	710	7198	75 – 100	0	0,188
Comor Island	n/a	n/a / n/a	n/a	n/a	n/a	n/a	n/a
Djibouti	22.0	0.424 / 2.9	19	9002	25 – 300	5	0.010
Egypt	1001.4	52.886 / 3.0	53	498	20 – 200	15	58,901
Iraq	435.0	7.902 / 3.1	41	3390	50 – 1200	70	109,126
Jordan	90.0	3.435 / 3.4	38	1133	50 – 650	9	1,314
Kuwait	17.8	2.063 / 4.2	116	16,316	30 – 140	2	0,634
Lebanon	10.0	2.655 / 2.5	255	1390	200 – 1500	9	4,983
Libya	1759.5	4.546 / 3.7	3	5648	5 – 500	50	4,832
Mauritania	1030.7	2.001 / 2.5	2	506	n/a	157	8,881
Morocco	710.9	25.128 / 2.5	35	967	50 – 600	150	28,055
Oman	300.0	1.500 / 3.5	5	5797	80 – 400	15	1,988
Palestine	27.0	1.628 / 3.6	n/a	n/a	100 – 1000	8	n/a
Qatar	11.4	0.389 / 3.6	34	17,244	75 – 100	1	0,224
Saudi Arabia	2240.0	14.870 / 3.9	7	5220	35 – 400	127	6,107
Somalia	637.7	6.285 / 2.9	10	199	50 – 600	191	8,505
Sudan	2505.8	25.095 / 2.8	10	414	20 – 1800	1094	120,774
Syria	185.2	12.558 / 3.7	68	1480	100 – 1000	46	25,788
Tunisia	164.0	8.084 / 2.2	49	1260	60 – 1500	35	4,370
UAE	77.7	1.844 / 3.3	24	15,283	80 – 160	2	1,136
Yemen	550.0	12.186 / 3.1	22	539	110 – 1400	67	5,214
TOTAL	141,589	221.236 / 3.0	16	1801		2237	408,305

Sources:

1. CAMRE (League of Arab States), UNEP, and ACSAD: "State of Desertification in the Arab Region and the Ways and Means to Deal with it", Cairo, March 1996.

2. ACED: "Arab Economic Report", 1998.
3. n/a : not available

The Arab countries may be divided waterwise into three groups: rich countries, countries suffering soon from water resources deficit then countries suffering for so many years from a scarcity in this resource; thus due to so many reasons the most important one is that the Arab territory is located in a semi dry region of the planet and the Israeli occupation, add to this the unfair distribution of common international waters, a non optimal utilization of water resources, increasing of water pollution proportion and the growth of population, [2].

It has been reported [3] in the begging of nineties, that the Arab world is on brink of a major natural water resources crisis. In Fig. (2) the annual renewable fresh water availability with population growth in the Arab world is illustrated. Figure (3) gives the percentages of usable water resources and end-user in the Arab world.

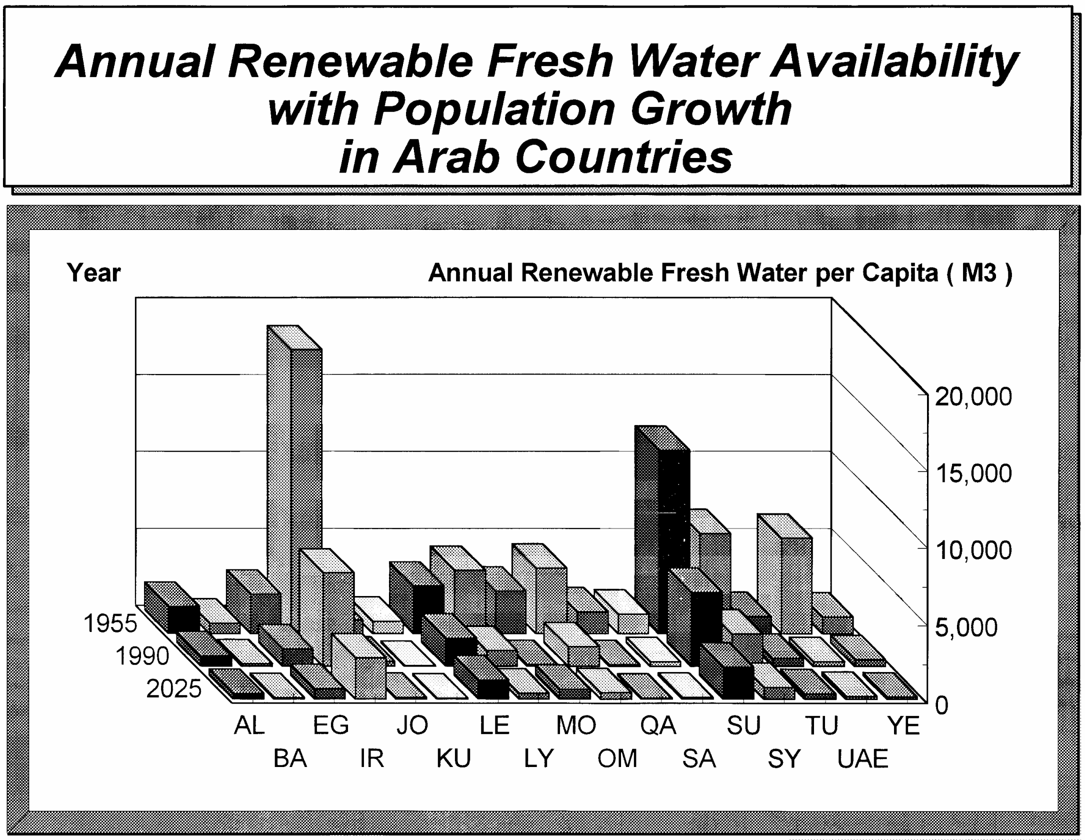


Fig. 2. Annual renewable fresh water availability

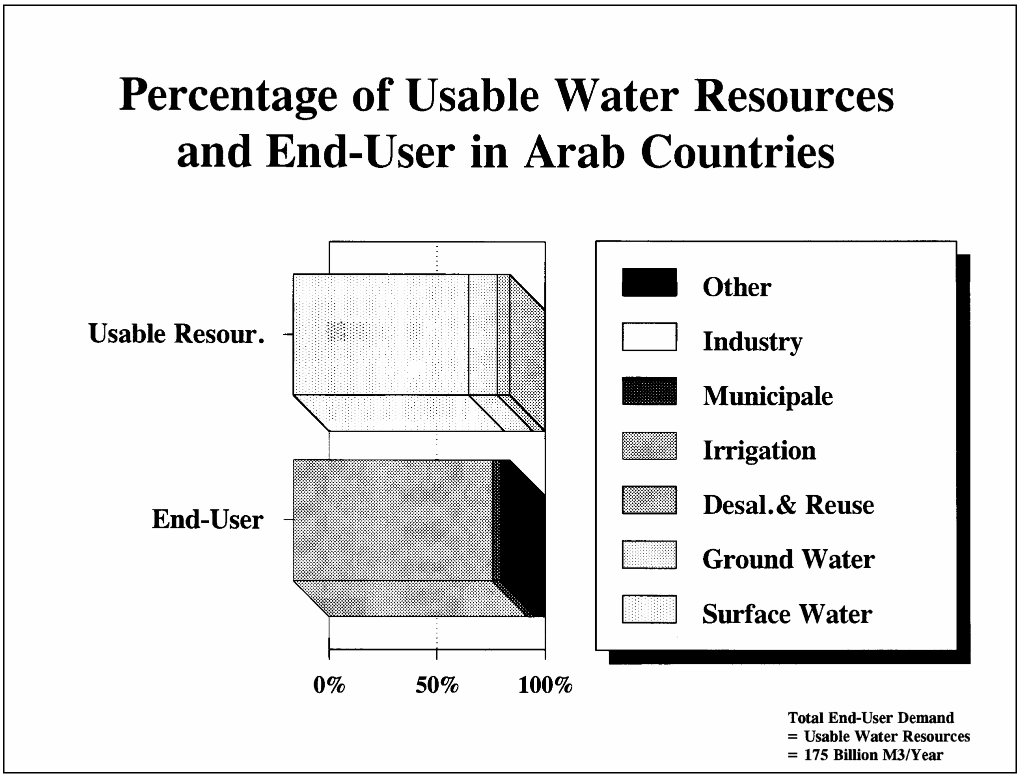


Fig. 3. Percentage of usable water resources and end-user in Arab countries

2. Desalination Technologies

Worldwide availability of potable water exceeds substantially the amounts of water being used. However, water resources are not evenly distributed. It is estimated that about three-quarters of the world's population lack safe drinking water. Populations' growth, increased pollution and reduction of existing ground and surface water resources are expected to increase water supply problems, in particular in arid regions. In addition to potable water, which is essential to sustain life, water is required by households to ensure an adequate quality of life, by industry as an essential input to industrial production, and by agriculture, where irrigation may be needed to complement precipitation. Figure (4) shows the water supply and demand in Arab countries. From this figure it is clear that the Arab countries are facing an increasing deficit in water.

Arid areas have in general few untapped potential water resources and costly investments will be needed for the development of new potable water supply options such as improvements to water distribution infrastructure, water transport from surplus to shortage areas, brackish water desalination, new dams, water treatment and reuse facilities. As less expensive supply alternatives are exhausted, sea water desalination becomes the option to be chosen for locations within a reasonable transport distance from the sea. Sea water is indeed the largest water source available and accounts for 97.5% of the world's water resources. Compared with existing fresh water natural resources, its availability are essential unlimited, and it is still reasonably unpolluted except in specific areas. All other options involve a limited water potential.

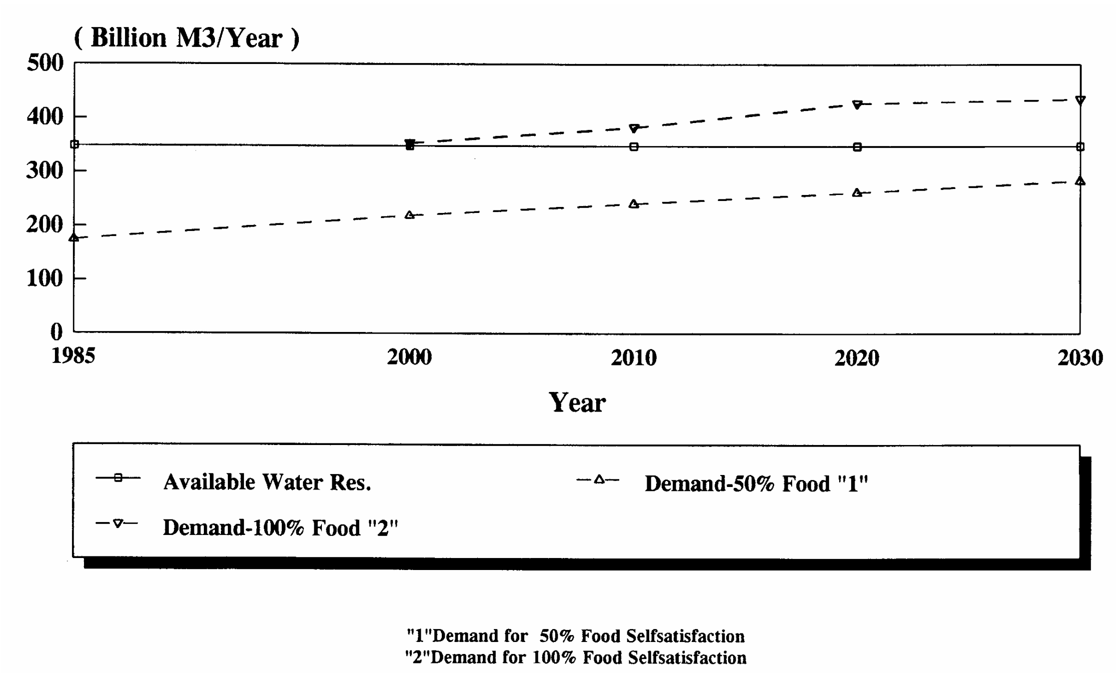


Fig. 4. Water supply and demand in Arab countries

Desalination is certainly one way of bridging the gap between supply and demand for water. However, high capital investments and high running costs make desalination the choice of those who can afford it and have no other alternatives.

Although seawater desalination started on board ships, followed by small land-based units, it started emerging as commercial process only in the early sixties. From there on its growth continued steadily as shown in Fig. (5). With an all time record of units added in 1993 capable of producing about 1.9 million cubic meters per day, world total capacity reaching 18,678,000 m^3/d by the end of December 1993, [4].

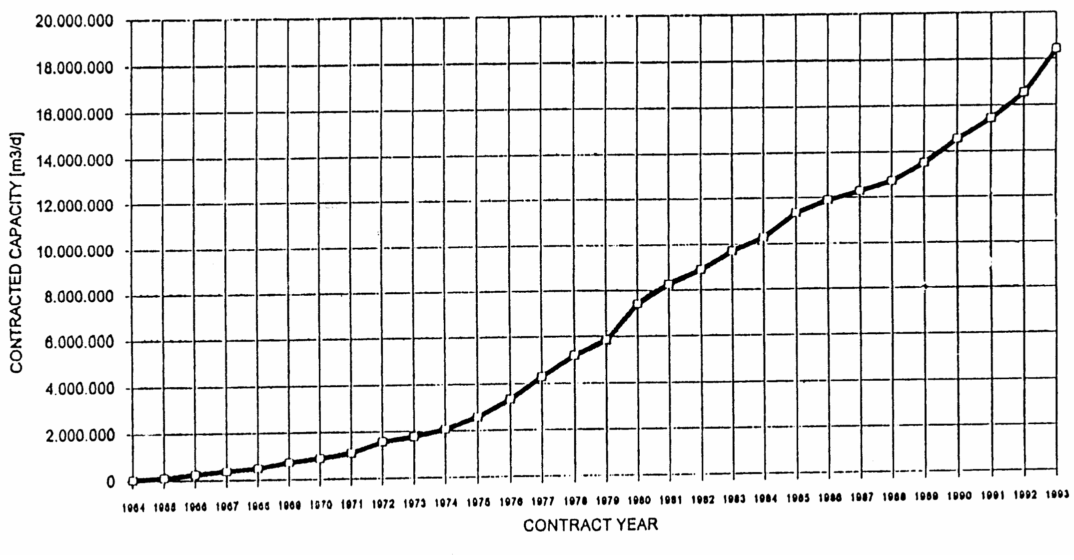


Fig. 5. Cumulative capacity of all land-based desalting plants capable of producing 100 (m^3/d)/UNIT or more fresh water vs. contract year

The available commercial desalination processes which currently appear as the most interesting large scale water production are given in Table (2), [5].

Table (2): Commercial Desalination Processes

SOURCE	TYPICAL TDS (ppm)	BWRO	EDR	MED	MSF	MVC	SWRO
Potable	1000	Yes	Yes	Yes	Yes	Yes	Yes
Brackish	7500	Yes	Yes	Yes	Yes	Yes	Yes
Seawater	35000	No	Yes	Yes	Yes	Yes	Yes
Brine	60000	No	No	Yes	Yes	Yes	No

The historical development of desalination in terms of the worldwide cumulative desalination capacities is shown in Fig. (5).

Since all desalination processes can use some combinations of energy sources and can be designed for different levels of energy efficiency, simple comparisons are difficult to make. In Table (3) such comparison is given.

Table (3): Energy Comparisons for Desalination Processes

PROCESS	Min Power	Max Power	Min Steam	Max Steam	Min GOR	Max GOR
	kWh/ tonne	kWh/ tonne	kgs/kgd	kgs/kgd		
BWRO	0.26	1.85	n/a	n/a	n/a	n/a
EDR	n/a	n/a	n/a	n/a	n/a	n/a
MED	0.75	1.75	0.10	1.00	1	10
MED-TC	0.75	1.50	0.07	0.33	3	15
MSF-BR	2.64	3.96	0.08	0.25	4	12
MSF-OT	2.38	3.17	0.13	0.50	2	8
MIVC (all elec)	8.50	12.00	0.03	0.05	30	40
SWRO	3.96	7.93	n/a	n/a	n/a	n/a

- Gained Output Ratio (**GOR**) = lb of distillate / lb of steam or = kg of distillate / kg of steam.
- The units for steam consumption are shown as kilograms of steam per kilogram of distillate produced.

The historical label of desalination as an expensive option is no longer valid. Both unit cost of desalted water and unit cost of plant capacity have been decreasing over the last three decades. The unit cost of desalting seawater today can be in the range of US $ 0.75 per cubic meter for large well designed plants. The unit cost can be as low as 0.50 $\$/m^3$ for large dual purpose plants if the primary product is electrical power. This cost is about 4% of the unit cost of desalted water produced by the best plant in the 1960's, after normalizing for inflation. The reduction in unit cost of plant capacity is more difficult to quantify, however it is still significant.

The typical ranges of unit cost of desalination today are given in Table (4). The large range of unit cost of construction reflects large variations in project requirements as well as variations in capital cost of various commercial processes.

Table (4): Typical Cost of Desalination

▪ <u>Sea Water</u>	
1. **Capital Cost**	**1 – 3** $ / liter / day
2. **Water Cost** :	
a)- **Large Plants**	**0.75 – 1.5** $ / 1000 liter
b)- **Small Plants**	**2.0 – 3.0** $ / 1000 liter
▪ <u>Brackish Water</u>	(As % of Sea Water Cost)
1. **Capital Cost**	**25 – 75 %**
2. **Water Cost**	**25 – 50 %**

Water cost is mainly a function of quality of feed water and size of plant and fuel monetary value. The definition of large or small plants as used in Table (5) depends on type of process used. The benefits of economy of scale of large plant can be realized at 10,000 m^3/day for seawater RO plant while MSF process will require plants larger than 10,000 m^3/day to achieve the same unit cost. The cost of desalting brackish water depends to great extent on the quality of feed water. Capital cost of desalting high salinity brackish water can be more than three times the cost of desalting good quality low salinity water. Energy cost is a major factor for most applications specially for desalting seawater, [6].

Table (5): Desalination Cost Major Factors

- **Plant Size**
- **Feed Water Salinity & Quality**
- **Energy Cost**
- **Plant Location & Infrastructure**
- **Process Type**
- **Optimal design**
- **Material of Construction**
- **Plant Reliability & Flexibility**
- **Cost Allocation** (for Dual-Purpose Plants)

The types of desalination technology used in integrated power and water schemes in the Arab region have been Multistage Flash (MSF), Multi Effect Distillation (MED), and Reverse Osmosis (RO), [7, 8].

MSF was developed in the Gulf States as early as 1970s and has been used successfully on the Arabian Peninsula in large scale applications. The capital costs of MSF vary from $4 to $12 /gpd, equivalent to $1050 to $3150 /$m^3$ per day of installed capacity.

MED is older than MSF and is more energy efficient. However, the technique has suffered some operational problems and its maximum unit capacity is limited compared with MSF.

MSF has been the mainstay for large scale water production in the Arab world, but its position is now being challenged by the latest developments in MED. Analysts believe that this type of process offers significant potential for water cost reduction. Specific investment costs for main desalination processes are shown in Table (6).

Table (6): Investment Costs for Main Desalination Processes

Process	MSF	MED	RO
Specific Investment Cost ($/ m^3 /day)	**1100-1600**	**900 - 1250**	**700 - 1000**

Specific investment costs for a MED plant are 10 – 20 % lower than for an MSF plant. Two recently contracted desalination plants, with comparable local conditions and identical capacities are shown in Table (7). The MED plant investment cost is 11 % lower than the MSF investment cost, [7, 8].

Table (7): Investment Cost Comparisons

Plant Type	MSF Jebel Ali K	MED Sharjah Layyah
Specific Investment Cost ($/ m^3 / day)	**1100**	**980**

3. Nuclear Desalination, [9]

The reasons behind nuclear power's use for electricity generation also apply to its potential use for seawater desalination. These reasons are, for example, economic competitiveness in areas which lack cheap hydropower or fossil fuel resources, energy supply diversification, conservation of fossil fuel resources, the promotion of technological development, and environmental protection by avoiding emissions of air pollutants and greenhouse gases.

About 500 reactor years of operational experience from nuclear co-generation and heat-only reactors are now available in twelve countries. Nuclear energy has been used for seawater desalination at location in Japan, China, and Kazakhstan. While in Japan the desalination plants are mostly for on-site water supply, the Aktau Desalination Complex in Kazakhstan supplies water to nearby population center.

While most industrialized countries are favoring large nuclear power stations for domestic application, there is a growing interest in smaller reactors (SMR's) in several states.

Energy has been found to be a significant contributor, about 35 to 55% in recent plants and 25 to 40% in future modern plants to the total cost of desalination. Nuclear energy has the potential to reduce that cost. Nuclear desalination is technically and economically feasible (Table (8)) based on currently available technology and the Kazakhstan experience at Shevchenko bears it out. Currently available technology includes various thermal distillation processes using low temperature heat and electrically-coupled processes using Reverse Osmosis techniques. Also, using of nuclear energy for large-scale desalination would have less environmental impact than fossil-fired thermal energy resources.

Table (8) : Summary of Water Cost (\$ / m^3)

Source	**Size**	**MED**	Stand Alone **RO** (EC)	Stand Alone **RO** (WHO)	Conti-guous **RO** (EC)	Conti-guous **RO** (WHO)
Nuclear Power Plant (MW(e)) (A)						
	50	1.06	1.16	0.99	1.11	0.94
	300	0.94	0.97	0.84	0.94	0.79
	600	0.83	0.89	0.75	086	0.73
	900	0.79	0.85	0.72	0.83	0.70
Nuclear Heating Plant (MW(th)) (B)						
	50	2.02	n/a	n/a	n/a	n/a
	100	1.66	n/a	n/a	n/a	n/a
	200	1.47	n/a	n/a	n/a	n/a
	500	1.27	n/a	n/a	n/a	n/a
Fossil Power Plant (MW(e)) (A)						
▪ **Diesel**	50	n/a	0.98	0.84	0.95	0.80
▪ **Gas Turbine**	100	0.94	1.10	0.94	1.06	0.89
▪ **Oil / Gas**	150	0.98	1.07	0.91	1.01	0.86
▪ **Oil / Gas**	400	0.93	0.96	0.82	0.92	0.78
▪ **Coal**	500	0.94	0.91	0.77	0.88	0.74
▪ **Coal**	600	0.89	0.87	0.74	0.85	0.71
Fossil Heating Plant (MW(th)) (B)						
▪ **Oil / Gas**	100	1.56	n/a	n/a	n/a	n/a
▪ **Coal**	500	1.21	n/a	n/a	n/a	n/a

- Calculations based on 8% real interest rate
- n/a = not available

I) Dual Purpose or Electricity Generation Plants
II) Single Purpose Plants

4. The use of Solar and Wind Energy in Desalination

Desalination is an energy intensive separation process. The energy requirements for seawater desalination range between 6 – 15 kWh/m^3 of product water. The cost of energy represents around 30 – 40 % of the total production cost of fresh water. The economic viability of desalination process can thus be significantly improved by minimizing the energy cost factor. Large scale MSF are frequently part of a dual purpose plant which produced power for a distribution network as well as distilled water. The MSF is thus an add-on to the steam generation power plant, economically justified on the basis of low-pressure steam remaining at the end of the power cycle.

For small-scale desalination plant, renewable energies have been used as viable alternatives to fossil fuels. The original source of renewable energies is the solar energy and owing to its diffuse nature there is less advantage to be gained by scaling up to large systems as in the case for fossil fuel, and small scale desalination stills are likely to be used for providing water for families or small communities. And, for places with solar isolation of at least 1400 kWh/m^2 year, the combination of a solar pond and MED desalination plant is a sound solution which results in a competitive water cost, [10, 11].

The renewable energies, which have been under developments for water desalination, can include direct solar energy, which incorporates both thermal and photovoltaic, and direct solar energy, which covers the wind energy.

So, the use of solar stills for providing water requirement of small isolated communities, are attractive and economically feasible compared to conventional means. Their output can be relatively increased with the use of efficient solar collectors such as solar ponds, evacuated tubes or concentrators. And, small scale applications of photovoltaic cells are commercially spread all over the world, but their application for large scale is questionable unless a break through in R&D will be achieved.

5. Desalination in Arab World, [12]

The Arab World assumes a leading role in the desalination industry contributing according to the latest inventory 60% of the total world production (Table (9)).

Table (9) : Desalination Inventory in the Arab World

Country	CAPACITY (M^3 / day) Process						No. of Units
	MSF	MED	VC	RO	ED	Total	
Algeria	125,222	955	33,525	83,964	19,976	263,624	174
Bahrain	581,420	1,135	47,264	140,526	13,914	784,259	156
Egypt	33,652	2,577	12,350	139,133	33,385	221,624	230
Iraq	10,824	1,175	Nil	232,051	88,563	332,613	207
Jordan	Nil	Nil	1,100	7,726	1,537	10,363	n/a
Kuwait	1,468,750	11,672	150	166,472	5,093	1,652,137	178
Lebanon	520	Nil	14,670	3,200	Nil	18,390	n/a
Libya	462,575	6,456	71,489	138,430	69,264	748,214	431
Mauritania	3,000	Nil	1,654	Nil	Nil	4,654	n/a
Morocco	7,002	Nil	8,064	Nil	1,404	16,470	n/a
Oman	329,927	4,200	14,019	28,837	896	377,879	102
Palestine	Nil	Nil	Nil	2,246	Nil	2,246	n/a
Qatar	782,901	3,642	21,334	13,811	Nil	821,688	94
Saudi Arab	3,486,985	17,870	75,512	1,751,191	97,776	5,429,334	2074
Somalia	Nil	Nil	120	288	Nil	408	n/a
Sudan	226	750	900	Nil	Nil	1,876	n/a
Syria	Nil	Nil	Nil	6,983	1,983Nil	8,966	n/a
Tunisia	336	240	4,820	58,615	Nil	64,011	64
UAE	4,468,769	9,346	474,505	174,553	5,102	5,132,275	382
Yemen	2,400	61,506	250	7,411	3,330	74,897	66
TOTAL						14,965,401	

<u>Source</u>: "2000 IDA Worldwide Desalting Plants Inventory CD-PAM200", prepared and published by Wangnick Consulting.

Out of the 11 million m^3/d produced by the Arab world the GCC countries contribute 87%. The Arab countries can arbitrarily be grouped into 3 groups:

Group A: Countries producing more than 1% of world capacity including Saudi Arabia, United Arab Emirates, Kuwait, Libya, Qatar, Iraq, Bahrain, and Algeria.

Group B: Countries producing between 0.1 and 1% of world production including Oman, Egypt, Tunisia, and Yemen.

Group C: Countries producing less than 0.1% of world production such as Morocco, Jordan, Syria, and Lebanon.

Leading processes used in desalination seawater are multistage Flash Distillation (MSF), Reverse Osmosis (RO), Multieffect Distillation (ME) and Vapor Compression (VC), Electrodialysis being mainly used for desalting brackish water. MSF and RO contribute together 74.3 % of desalination water worldwide. Within the Arab World their contribution is 94.4 % while other processes being responsible for only 5.6 %.

6. Desalination in Egypt, [13, 14]

Egypt is characterized by a warm dry climate and low rain fall, the greater area therefore are mainly of barren desert. Traditionally water has been supplied to the water-short area by low yield wells, rainwater collection and Nile water delivered by trains, trucks, and pipelines of limited capacities. Limitation of current water supply schemes for new developing areas on the Red Sea, Sinai, and the Mediterranean Sea make desalting of both ground water and sea water are necessary to satisfy water needs. Water supply and demand in Egypt is shown in Fig. (6)

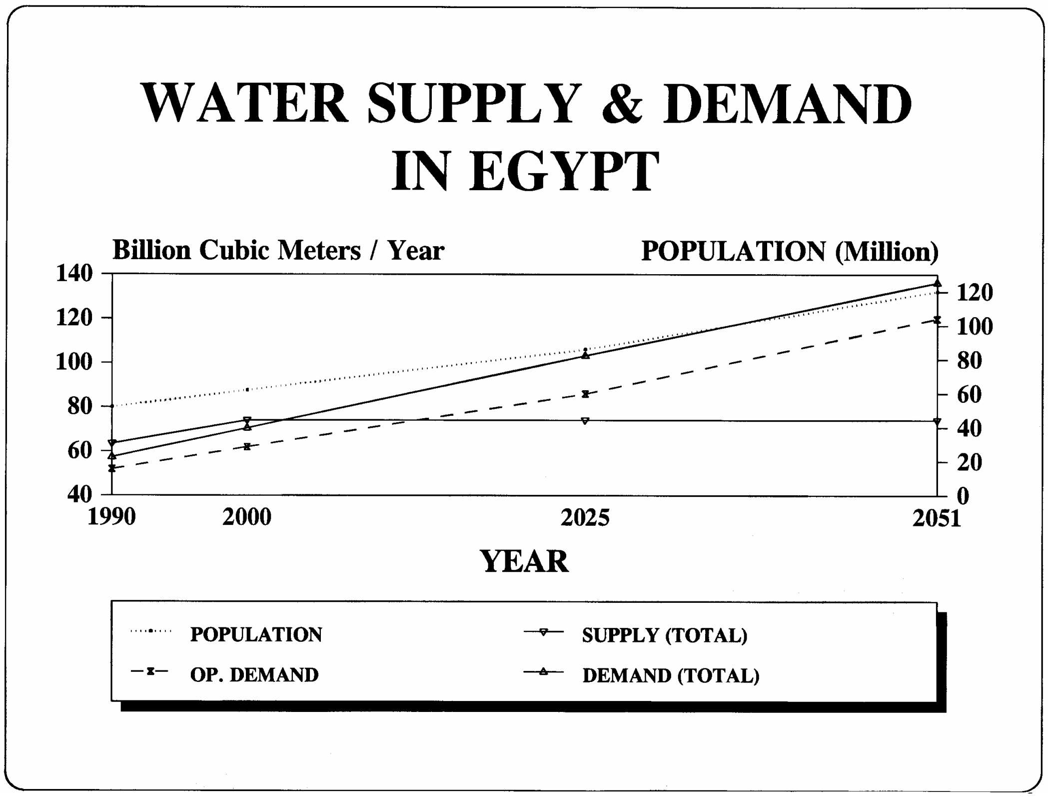
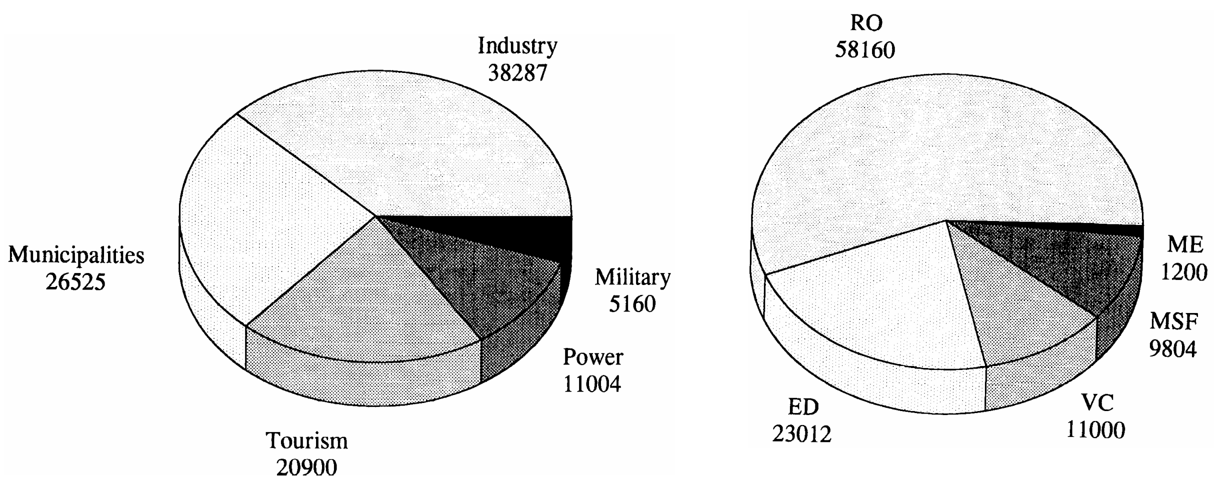


Fig. 6. Water supply and demand in Egypt

Figure 6 shows that after the year 2010 Egypt is going to face an increasing deficit in water. The gap between the water supply and demand may be narrowed by water desalination. Desalination started in Egypt more than 100 years ago, by a large distillation pond in Helwaan, south to Cairo. The main objective was to produce fresh water for domestic use far from the public water network, at that time. However, with the continuous growth and urban expansion along the coastal zone, and in remote areas such as oil fields, some military units, service stations, hospitals and others. Egypt began to apply desalination technologies in the mid seventies. Three different models of electrodialysis plants were installed by IONICS, Incorporation US Co., in Egypt during the period 1975 to 1982. These models differ in capacity from 50 to 1000 m^3/day. The feed water varies in salinity between 2,000 to 10,000 ppm, while the salinity of the produced water was in the range of 275 to 500 ppm.

At present, Egypt is encouraging, not only the public sector but also the private sector, to apply modern technologies for desalination, which historically started with Distillation and Elecrtrodialysis and followed by Reverse Osmosis (suitable for high saline feed water). The great achievements in desalination technology have now moved the costs for desalting in many applications from the realm of "expensive" to "competitive". Current technology is feasible for tourist villages in the north coast and the Red Sea, due to its far distances from conventional sources that makes the cost of water conveyance very high and subject to pollution problems. The military plants in Egypt and some water companies are partially producing or assembling water treatments unit including water desalination, mainly RO. However, in spite of research and developments, still the energy requirement and membrane know-how are limiting factors. Figure 7 illustrates the distribution of desalination capacity by water type, by end user and by process in Egypt at the end of 1996. Table (10) presents the capacities of different desalination methods commonly used in Egypt.



(a) By end user **(b) By process**

Fig. 7. Distribution of desalination capacity in Egypt at the end of 1996

Table (10): Desalination Inventory in Egypt

Process	MSF	MED	VC	RO	ED	Total
Capacity (M^3/day)	**33,652**	**2,577**	**12,350**	**139,133**	**33,385**	**221,624**
% to total	15.2%	1.2%	5.6%	62.8%	15.1%	1.3%

- No. of units = 230
- Source: (2000 IDA Worldwide Desalting Plants Inventory, by Wangnick).

7. Prospects of Renewable Energy Utilization for Water Desalination in Egypt

Egypt's future vision is non-traditional in the field of desalination. It is based on a real breakthrough towards the use of renewable energy; namely, solar energy to be harnessed for operating high compression pumps needed for reverse osmosis modular systems. The reasons are obvious, since Egypt has a great potential of brackish water wells, immense amounts of solar radiation in remote areas and future integrated development projects are located at a distance from the Nile water.

7.1. Renewable Energy Sources in Egypt

The strategy projections in the latest New and Renewable Energy Authority (NREA) five years plan for renewable energy comprise an expectation of reaching by year 2005 more than 4% of the primary energy consumption to be from renewable energy sources. Of this, solar energy should provide 69%, wind energy 26% and biomass 5%, [15]. From this, one can conclude that solar and wind energies are the most important renewable energy sources in Egypt. And thus, each of them ought to be discussed in more details.

7.2. Solar Energy in Egypt

Solar energy is the major undepletable source of energy. It is quite ironic that the abundance of solar energy is the cause of the water problems in arid areas.

Solar energy is by all means the most important renewable energy not only in Egypt but also in the Arab world. Most Arab countries including Egypt enjoy about 3000-3500 hours of sunshine per year and receive more than 5.0 kW/m^2 of solar energy per year [16]. Figure 8 shows the annual average incidence of solar energy in Egypt.

Solar energy in Egypt has the advantage of being abundant than any other renewable energy source. Other advantages of solar energy include its being a clean source of energy, with no wastes, hazards, or bad environmental effects, the very low maintenance required since there are no rotating parts, no fuel costs or running costs, and suitability or remote and hard-to-access regions.

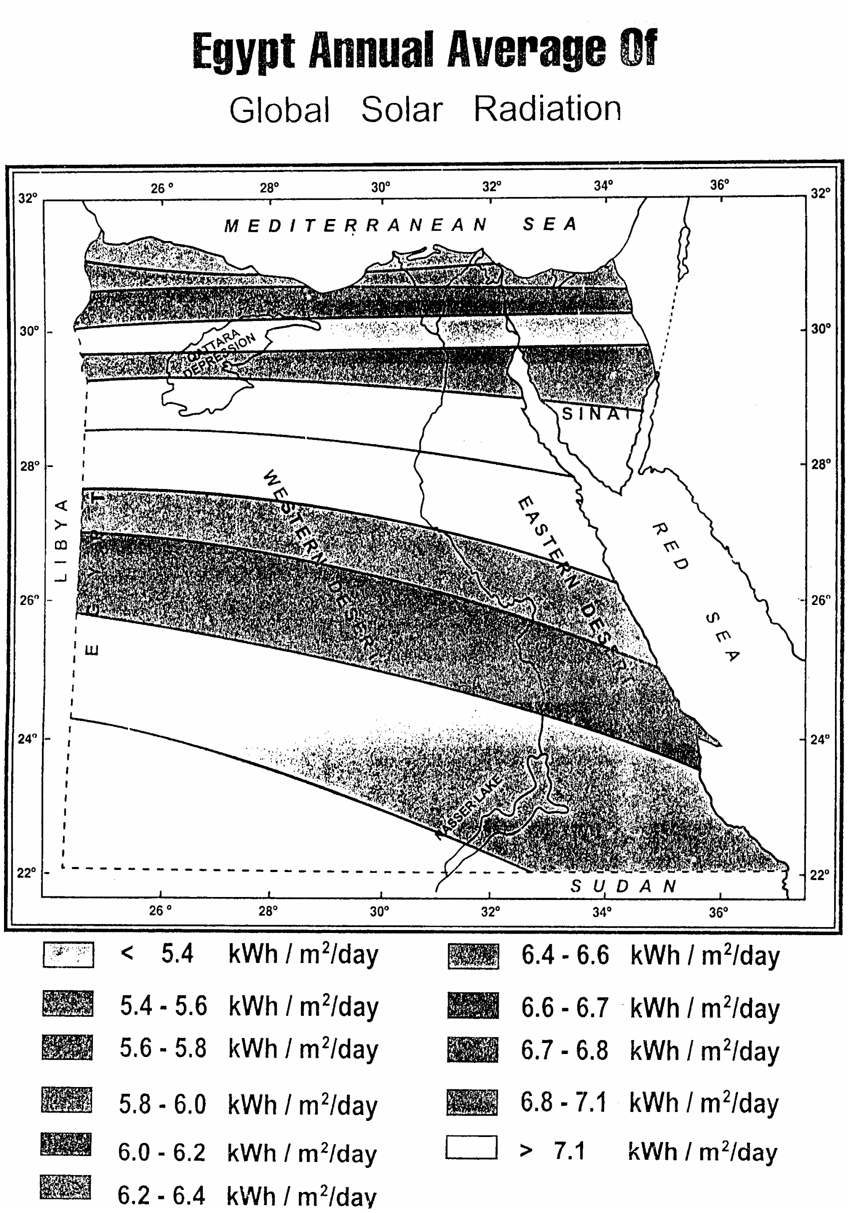


Fig. 8. Egypt annual average of global solar radiation

7.3. Solar Desalination in Egypt

The technologies adopted in Egypt for water desalination should be independent of the expected depletion of fossil fuels, on the one hand, and also should not be polluting the environment, on the other hand.

Egypt's efforts in the desalination business are constrained by the lack of capital. When these important constraints are taken into consideration one can find no way but solar energy for desalination. The task of finding cheaper and more reliable energy self-sufficient mans to produce clean, potable water from saline water should become the top priority not only in Egypt but also in the Arab world. After so many years of studies and investigations, it seems that the dream is becoming true, that was due to the revolutionary development, based upon the fact that the use of solar energy will bring about a drop in the production cost, beside it is not contributing to the depletion of fossil fuels. This could - of course - have a great impact on the viability of intensive horticulture and the integrated plans for the development of arid areas. Solar energy is the major undepletable source of energy. It is quite ironic that the abundance of solar energy is the cause for the water problem in arid areas. Solar energy and more generally renewable energies are widely perceived as peaceful forms of energy, as compared to other energy sources. Solar energy, unlike nuclear and fossil energies or biotechnologies, does not lend itself offensive applications. Solar energy is by all means the most important renewable source of energy in Egypt as well as in all the Arab world, because of the abundant solar radiation incident on the area all year around.

The use of direct solar energy for water desalination has been investigated and used for some time, [17]. The devices used in this respect generally imitate a part of the natural water cycle in that the saline water is heated by sun rays so that the production of water vapor increases and is then condensed on a cool surface. An example of this type of process is the green house solar still, in which the saline water is heated in a basin on the floor and the water vapor condenses on the sloping glass roof that covers the basin. In general for solar stills, a solar collection area of about one square meter is needed to produce 4 L of water per day [18]. It is obvious that normal methods of collecting sun rays through the solar panels was not the most efficient means of providing the energy for desalination on a sufficiently large scale requiring rather large collection areas.

Other methods of solar sea water desalination would call for large of photovoltaic cells which convert sun energy into electricity to be used for highly pressurizing and pumping sea water through membranes using the well know principle of reverse osmosis. Battery storage means would also be necessary to overcome the strongly intermittent nature of solar radiation [19]. Nowadays simple reliable and low cost methods to collect and store the necessary heat for a continuous day – and- night production of water by means of low temperature sea water evaporation and condensation cycles similar to a normal multi–stage flash desalination (MSD) and multiple effect desalination (MED) are having wide application in the Gulf area. In these operations seawater is being heated by the solar system and evaporates via a vacuum process. Water normally boils at 100°C, but if a vacuum is created, the boiling point drops to point where it is possible to boil off water down to only 35°C. In these operations it is possible to recuperate the high amount of evaporation heat by condensing the vapor with the help of the colder sea water which enters and runs through the plant, thus getting preheated before picking up the solar heat for its evaporation.

The demand for fresh water is increasing in all over the Arab world. A recent study shows that the demand for potable water in Egypt is estimated to be 12.9 x 10^9 m^3 /yr. by the year 2025, almost 3.5 times the present demand of 3.7 x 10^9 m^3 /yr., and the water required in order to respond to the economic development plants – if it will increase in the same manner- will be 150 x 10^9 m^3 /yr, [9, 20].

7.4. Wind Energy in Egypt, [15]

At least two regions in Egypt have sufficient average daily and annual wind speeds considered high enough for the development of wind power generator. Available data demonstrates that the Mediterranean Sea Coast has an average annual wind speed of about 5.6 m/s, and Red Sea Coast approximately 6.1 m/s. Usable electric energy output in these areas is estimated to be 650 kWh/m^2 of windmill swept area. Table (11) shows exploitable wind energy in different locations in Egypt.

Table (11): Wind Energy in Egypt (different locations)

Location	**Wind Energy kWh / m^2 year**	**Location**	**Wind Energy kWh / m^2 year**
Hurghada	2482	Kharga	1314
El-Dabaa	1919	Alexandria	1024
Marsa-Matruh	1785	Farafra	752
Sidi-Barrani	1546	Tahrir	429
Wadi-Elnatroon	1496	Dakhla	364
Ras-Elhikma	1480	Siwa	313
El-Sallum	1394	Giza	290

USAID financed the development of 1 MW wind farm at Ras-Graham on the Red Sea. This five-turbine demonstration project will prove the feasibility and economics of wind power. The Egyptian Ministry of Defense is testing 1 MW wind-diesel system near the Libyan border.

8. The Cost of Desalination: A Comparative Study

Table (12) shows a comparison between the most important economic parameters in different desalination plants [18]. Each item in the first column of the table is composed of smaller items; e.g. the fixed and variable annual costs is composed of the following items: operation and maintenance crew, spare part costs, membrane replacement, electricity, flocculent agent, chlorinating agent, antiscalant agent, descalant agent, coagulant agent, PH adjustment agent, membrane biolog cleaning, membrane colloidal cleaning, membrane restoring cleaning, RO multimedia filters, RO micro cartridge filters, steam, ….., etc. From Table (12) one can easily find out that the cost of water produced from the VVC plants is the lowest, compared to the other plants.

Table (12): Comparison of the Most Common Desalination Plants

	Types of the desalination plants					
Item	**RO**	**VVC**	**MSF with F.c.g.P.**	**RO with F.c.g.P.**	**MSF without G.t.g.P.**	**RO with G.t.g.P.**
1. Nominal capacity (cu m/day)	2500	2500	2304.0	46898.0	2112.0	28791.0
2. Total/capital cost (US$/year)	467,064	368,519	621,000	9,220,000	582,000	5,693,000
3. Fixed/annual costs (US$/year)	748,048	654,587	651,000	16,118,000	606,000	10,376,000
4. Total annual costs (US$/year)	1,215,112	1,023,106	1,272,000	25,338,000	1,188,000	16,069,000
5. Cost of water (US$/cu m)	1.665	1.108	1.680	1.640	1.71	1.70

The vacuum vapor compression (VVC) desalination process is generally used for small- and medium-scale seawater desalination units. The heat of evaporating the water comes from the compression of vapor rather than direct exchange of heat from steam produced in a boiler. In this process, the compressor creates a vacuum in the vessel and then compresses the vapor taken from the vessel and condenses it inside of a tube bundle also in the same vessel. Seawater is sprayed on the outside of the heated tube bundle where it boils and partially evaporates, producing more vapor [12].

Table (13) shows the cost estimate for the desalination units at Taba City in Sinai [21]. The cost of water desalination in the Taba units is comparable to the cost of units given in Table (12) and, of course, is also comparable to the cost of potable water in a city like Marsa-Matrouh, if conveyed from Alexandria all the way along the North-West Coast. And as a matter of fact the estimates of the worldwide photovoltaic market [22] predicted a decrease in the cost of kW produced by the year 2000.

Solar energy is an inexhaustible supply of energy that is available in any part of the world. The Arab world is an optimum location for the utilization of solar energy since there is abundant and stable sunlight. It also has the advantage that the once the solar collector is installed, energy will be available permanently during the lifetime of the collector, with a maintenance cost. The disadvantages include that the energy density is low and has large variations (day and night, four seasons, and the weather) and that it cannot be controlled. Therefore a solar desalination will require an adjusting interface.

Table (13): Cost estimate of the Taba City Desalination Units

Item		Cost (L.E.)
1.	Total capital investment/cu m of produced water	0.985
2.	Cost of wells/cu m of produced water	0.019
3.	Cost of pumps/cu m of produced water	0.111
4.	Cost of storing tanks/cu m of produced water	0.059
5.	Cost of civil works/cu m of produced water	0.021
6.	Cost of electric installations/cu m of produced water	0.271
7.	Cost of pipelines	0.148
8.	Cost of operation and maintenance/cu m of produced water	0.334
9.	Cost of membrane replacement/cu m of produced water	1.120
10.	Cost of fuel/cu m of produced water	0.160
11.	Cost of chemicals/cu m of produced water	0.153
12.	Cost of manpower/cu m of produced water	0.194
13.	Cost of electricity	0.600
	Total	**4.175**

Conclusions

1. The cost of potable water produced from desalination plants using solar energy as the main source of energy can be less than the cost of the same water produced from desalination plants using conventional types of energy.
2. The cost of potable water produced from solar desalination plants will be less than the cost of water from the Nile in arid and coastal on the Mediterranean and Red Sea.
3. As a matter of fact, while the cost of Nile water is going up by time specially in arid coastal areas, the cost of fresh water produced by solar desalination is going down.
4. Since solar desalination has flourishing prospects in Egypt and the Arab world, it is strongly recommended to pay more attention for the economic conversion of solar energy into electric energy.

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