A Joint Desalination and Power Plants for Water and Development
A Case study for Sinai-Gaza

Raed Bashitialshaaer[*1], Kenneth M Persson[*2], Ronny Berndtsson[*1]

[*]Department of Water Res. Eng., Lund University-LTH, Box 118; SE-221 00 LUND-Sweden
[1]Center for Middle Eastern Studies, Tel.: +4646222-4367, Fax: 4435, ralshaaer@yahoo.com
[2]SYDVATTEN AB, Skeppsgatan 19, 211 19 MALMÖ-Sweden; kenneth_M.persson@tvrl.lth.se

Abstract

Desalination can be a cost-effective way to produce fresh water and possibly electricity. The Gaza Strip has had a complex hydro-political situation for many years. Gaza (enclosed area) is bordered by the Mediterranean in the west, by Israel in the north and east and by Egypt in the south. Water and electricity consumption in the Gaza Strip is expected to increase in the future due to the increasing population.

In this paper, a solution for Sinai and the Gaza Strip is suggested involving the building of a joint power and desalination plant, located in Egypt close to the border of Gaza. Results of capital and unit costs have been derived from bench-mark studies of 18 different desalination projects mainly in the Middle East countries. The suggested joint Egypt-Palestine project would increases drinking water supply by 500,000 m^3/d and the power supply by 500MW, whereof 2/3 is suggested to be used in Gaza and 1/3 in Sinai. The present lack of electricity and water in Gaza could be erased by such a project. But Egypt will probably gain more. More water and electricity will be available for the future development of Sinai; a significant value will be added to the sale of Egyptian natural gas used for water and power production in the project; more employment opportunities can be offered for people living in Sinai and Gaza; the domestic market for operation and maintenance of desalination plants can be boosted by the suggested project. Egypt may naturally and peacefully increase its cooperation with and presence in Gaza, which should lead to increased security around the border between Egypt and Gaza. This type of project could also get international support and can be a role-model for cooperation and trust-building between neighbours in the Middle East region. This study have also compared with more than five different alternatives.

Keywords: Desalination; Power plant; Palestine-Gaza Strip; Unit costs; Water resources; Environmental impact.

1. Introduction

The Gaza Strip is a small, densely populated area in the Middle East in which groundwater is the main water source. Gaza has several water problems; inefficient water use by the agricultural sector, limited fresh water supply and high water demand, groundwater contamination, seawater intrusion and wastewater disposal. In the Gaza Strip area of Palestine, there is a large gap between water resources and demand. Groundwater is also diminished by pollution, increasing demands, misuse by local people and control by neighbouring countries of Palestinian water resources (Baalousha, 2006). The citizens of the Gaza Strip have pursued several alternatives to increase water supply; water desalination (house units), use of bottled water, imported water and storm water harvesting (El-Nakhal, 2004). Agriculture accounts for 70% of fresh water use (Al-juaidi, 2009). Water resources in the Gaza Strip have a water balance deficit of about 30% (El-Sheikh et al, 2003). Annual water availability from the Gaza aquifer is 147 decreased to 125 MCM/year, i.e. almost 15% (Aljuaidi et al., 2009).

The lack of progress was due partly to deteriorating security conditions, which have made implementation of development projects problematic, and partly to the inadequacy of existing agreements with Israel which impede Palestinian water sector development (Gray, 2009). The lack of project funding at the present time is the major impediment to the development in Palestine. It also contributes to the generally inadequate allocation and inappropriate location of water resources to the Palestinians (ADC, 2007). At present, maintenance is too difficult for the water sector and pipes and cement are for instance being impounded for Gaza peoples. Despite the pledge of $4.5 billion dollars of aid money to rebuild Gaza which was made at the conference in Sharm el Sheikh held in March, 2009 (PCHR, 2009). The present average water consumption per capita by the Palestinian population is approximately 55 L/cap/d, or 55% of the WHO design value of 100 L/cap/d (Abu Zahra, 2001).

According to the United Nations Environment Programme, the total inputs and outputs of the Gaza coastal aquifer (in 1998) were estimated at 123 and 154 MCM, respectively (UNEP 2003). The Palestinian Water Authority has studied the water quality of 111 municipal wells in the Gaza Strip. Only 9% of these wells are suitable for human consumption (PWA, 1995). One of the major options for the remedy of water shortages in the Gaza Strip of Palestine and the protection of its coastal aquifer is the utilization of desalination technology (Assaf, 2001). Desalination is already practised in Gaza but on a small scale.

In this study, a bench-mark analysis of seawater desalination was performed for reverse osmosis systems. The basic parameters of cost analysis such as capacity, recovery, membrane life, energy, chemical costs and flux were evaluated based on the effects on capital, operating and total production costs (Akgul et al. 2004). A reverse osmosis desalination project to improve water quality and quantity was previously proposed (El-Nakhal, 2004). According to the PWA plan, desalination seems to be the only viable alternative for water resources (Baalousha, 2006). It has been estimated that the Gaza Strip will need to develop a seawater desalination capacity of about 120,000 m^3/d by 2008 and an additional 30,000 m^3/d by 2016 (Ghabayen et al., 2004). Desalination plants in the Gaza Strip area with a capacity of up to 150,000 m^3/d have also been suggested, but very little has been implemented until now, partly due to political conditions (Baalousha, 2006). To address this, the new desalination plant is suggested to be located in Egypt but/and also in Gaza to serve two different countries. The suggestion of this project was not possible to cooperate with the Israeli for some reasons such as controlling the whole production and the cost will be more than Egypt.

1.1. Current situation in Gaza

The production capacity of the desalination plants in Gaza varies between 20 and 150 m^3/d (Jaber & Ahmed, 2004). These private plants are very small and produce a total of about 2000 m^3/d of desalinated water (El-Sheikh, 2004). There are four sources of drinking water, namely municipal water wells (50 MCM/y), agricultural water wells (90 MCM/y), water from an Israeli company "Mekkorot" (5 MCM/y) and brackish water reverse osmosis plants (4 MCM/y) (El-Sheikh, 2003). Many desalination plants have been discussed and many projects initiated, yet few have been taken into full operation. In 1998, USAID financed a BWRO plant built by an American company Metcalf and Eddy in Gaza Industrial Zone with production capacity of 1000 m^3/d (El-Sheikh, 2003). France and Austria have also financed two seawater RO plants with a capacity of 2400 m^3/d and 5000 m^3/d respectively (El-Sheikh, 2003).

A small scale desalination plant was built in Gaza but the larger one which was suggested has not yet been built due to the many reasons listed above. Even some of the small plants have been stopped and electricity production is limited in the Gaza Strip. It was reported in UNOCHA (2006) that the electrical capacity in the area remains insufficient most of the time despite the installation of new transformers. This leaves most of the population in Gaza without electricity for up to 18 hours per day and without water for more than 20 hours per day. Without electricity, the reverse osmosis plants cannot operate either. The current electricity demand in the Gaza Strip, according to the President's Office and the Gaza Power Generating Company (GPGC), is 215 MW but this is expected to increase to 225 MW during the winter months (UNOCHA, 2006). The current supply available to Gaza, which totals 184 MW, originates from three sources: Gaza Power Generating Company (GPGC) 60 MW (maximum), Israel Electrical Company (IEC) 107

MW and Egypt 17 MW. The Gaza Power Generating Company (GPGC) estimated that the maximum power generated from the power station did not exceed 60 MW while the potential of the original transformers was up to 140 MW (UNOCHA, 2006).

1.2. Water prices

In general, the cost of water and source of energy is important for the production of fresh water in low income and poor countries. The existing agricultural water system in Gaza has a low economic water use efficiency of about $0.34/m^3 compared to a water cost of about $0.60/m^3 for seawater desalination (Issac, 2000; Metcalf & Eddy, 2000; MoA, PWA, and PHG, 2004). Akgul et al. (2008) studied different designs for Mediterranean SWRO membranes. The average unit costs of RO processes have declined from $5.0/m^3 in 1970 to less than $1.0/m^3 at present (Zhou & Tol, 2005).

Large RO-plants have lower specific production costs despite location. The Ashkelon desalination plant, which is also located on the Mediterranean coast, has presented cost figures as low as $0.52/m^3 (Busch & Mickols, 2004). Another example is the Perth desalination in Australia, which consumes only 3.7 kWh/m^3 of desalinated water (Gary, 2006). Pankratz (2004) reported that the production costs decreased from roughly $2.5/m^3 in the late 1970s, $1.5/m^3 in the early 1990s to around $0.50/m^3 by 2003.

El-Sheikh (2003) reported that customers in Gaza are paying an average of 0.25-0.50 $/m^3 for municipal water distribution and they will be able to pay 1.0 $/m^3 of the desalinated water because they already pay $1.25 for 1m^3 desalinated seawater old projects. The energy prices were calculated in the range of 6–9 cent/kWh electricity (Akgul et al., 2008). Egypt's natural gas sector is expanding rapidly with production of about 1.9 trillion cubic feet (Tcf) and consumption of 1.1 trillion cubic feet in year 2008 (1000 ft^3 = 28.3 m^3). According to the Oil and Gas Journal, Egypt’s estimated proven gas reserves stand at 58.5 Tcf, the third highest in Africa (U.S. Energy: last update Jan., 2011).

1.3. Purpose

The important purpose of this study is to increase water availability in Gaza and Sinai for a maximum number of people. Another purpose is to stress the importance of joint projects between countries of the Middle East to reduce tensions and to increase cooperation, mutual trust and security. The proposed joint project can minimise the cost of water and electricity and improve the other sectors, e.g. agriculture or industry. With examples from Europe, the century long conflict between France and Germany could be settled by economical and political cooperation. In 1950, the Schuman declaration stated that “Europe will not be made all at once, or according to a single plan. It will be built through concrete achievements which first create a de facto solidarity.” Through initial cooperation on coal and steel, the countries could gradually work towards a position that formed the EEC in 1957 and further on to the EU. In 2010, 27 European countries cooperate closely within the EU and more European countries want to join.

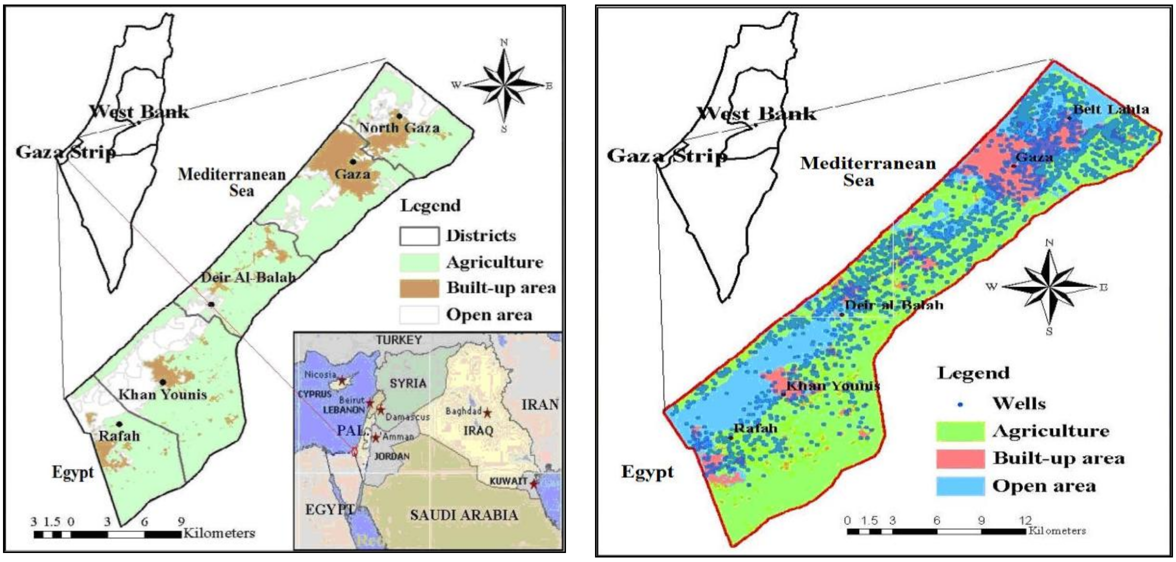
HRH Prince El Hassan bin Talal of Jordan has in several presentations, speeches and articles argued for the urgent need of a similar development in the Middle East countries. Bridging towards peace and trust between countries must be reached through concrete actions. Yet, peace and trust are both possible if comprehensive processes are adopted in several areas such as security, basic and current; economy with a human content such as health care, fresh water, electricity and education. He has been asking for several years why a plant for solar desalination and electrification of Gaza on the Egyptian side of the Gaza border could not be established. In the opening of WOCMES 2010 in Barcelona, Spain, HRH Prince El Hassan bin Talal said that “The need of stress to promote cultural ties among Middle East nations, noting the importance of developing joint policies to enhance contact at various levels”.

Why Egypt? It would be a great opportunity for the Palestinians if Egypt agrees to construct a combined desalination and power plant in the first 5 km from the Gaza border. Cost effective energy that is cheaper than Israeli pricing and possibly less politically sensitive should be of interest to both Egypt and Gaza. A good alternative could be the use of Egyptian natural gas in the power plant supplying electricity not only to the desalination project, but also to Sinai and the Gaza Strip.

2. Study Area

2.1. An overview

Gaza has a semi-arid climate with a total area of about 365 km^2 and a population of 1.55 million with a growth rate of 3.2% (Aljuaidi et al., 2009). The Gaza Strip forms a transitional zone between the semi-humid coastal area in the north and the semi-arid Sinai desert in the south. The Gaza Strip is 40 km long and has an average width of about 9 km. Its area is surrounded by the Negev desert, Israeli, Egypt and the Mediterranean Sea (Figure 1). The Gaza Strip area is part of the Palestinian Autonomous areas according to the Oslo agreement that was signed by the USA, Egypt and Israel in 1993. Gaza is divided in five districts known as Gaza, North Gaza, Deir Al-Balah, Khanyounis and Rafah. The locations of the agricultural areas are also shown in (Figure 1). Gaza is located on the western-most part of the shallow coastal aquifer that is exploited for municipal and agricultural water supply. The aquifer in the Gaza Strip is part of the coastal aquifer, which extends from Mt. Carmel in the north to the Sinai desert in the south with a variable width and depth. The total area of the coastal aquifer is about 2000 km^2 with 400 km^2 beneath the Gaza Strip (EXACT, 1998).



a) b)

Fig. 1. Gaza strip overall map for a) districts and b) agricultural areas (from: Al-juaidi, 2009)

Annual average rain in the Gaza Strip is between 200 mm (in the south) and 400 mm (in the north), which falls mainly in winter. Groundwater is the main water source in Gaza (El-Nakhal, 2004). The evaporation rate is very high compared with rainfall. The average amount of open water evaporation is about 1,300 mm/year (PBS, 2000). The water scarcity in Gaza is a significant problem and concerns have been highlighted in many studies. Immigration of Palestinian refugees after the 1948 Israeli-Arab war to the Gaza Strip, coupled with the high fertility rate, increased the population of that Palestinian coastal land strip from 50,000 in 1948 to more than 1.5M in the year 2009 (PBS, 2000). Still Gaza faces a high population growth rate and the majority of the population has relatively low incomes (Aljuaidi et al., 2009). Economic development is restricted, among other things by water scarcity and unreliable power supply.

2.2. Water balance in Gaza

It is important to analyse the water balance in the Gaza Strip and to compare water supply with water demand. In 2020, there will be more than 2 M Gazans, double the year 2000 population (PBS, 2000), and the water demand could easily also double from 154 MCM/y, a conservative projection being 216 MCM/y (Metcalf and Eddy, 2000). In Gaza there are no surface water resources except for an occasional water flow in Wadi Gaza during heavy rainfall, which temporarily occurs in 2-3 of the winter months. Another environmental problem is the infiltration of nitrates into the aquifer from the uncontrolled and excessive use of fertilizers by vegetable growers in their irrigated fields to increase productivity. A further problem is high levels of organic matter in groundwater leakage from sewers and septic tanks where there is no wastewater collection (Assaf, 1997; Shawwa, 2000, and MPIC, 1995). The available groundwater is severely overused due to high rates of population growth and economic development in all areas. Pollution resulting from saline water intrusion, inadequate wastewater treatment, waste disposal and intensive agricultural activities continues to reduce the amount of water available per capita (Ghabayen et al., 2004).

Baalousha (2004) reported that the average annual net sustainable groundwater recharge from precipitation is about 43.3 MCM. Although the total amount of annual inflow to the Gaza aquifer is about 109 MCM, only part of this amount can be considered as a safe yield (about 60 MCM/y). The result reported in this table excerpted from (Baalousha, 2004). Based on PWA records, the domestic water demand for 2000 was 55 MCM. This domestic demand was predicted to be increase to 182 MCM in 2020 (Metcalf and Eddy, 2000). Also the annual deficit was found about 37 in the year 2000 and predicted to about 107 MCM in 2020 (Metcalf and Eddy, 2000). Water resources should thus be increased by 110-120 MCM/y (330,000 m^3/d) to meet this shortage.

2.3. Water quality in the Gaza Strip

Of the approximately 50 L/capita/d of water delivered to the residents of the Gaza Strip, only about 13 L/capita/d meets WHO quality standards (PWA, 2000). The problem of groundwater quality especially in Khanyounis city is rather complicated. Both NO_3 and Cl are major pollutants of the aquifer attributed to human use as well as the scarcity of the water resource (Al-Agha, 2005). PWA suggested in year 2000 that the Gaza Strip should develop a seawater desalination plant of about 150,000 m^3/day in order to maintain a fresh water balance in the coastal aquifer and meet water demand for different uses (PWA, 2000).

Maximum nitrate values of 433 mg L^{-1} and mean of 166 mg L^{-1} have been measured, exceeding the WHO standards (45 mg L^{-1}) (WHO, 1996). The corresponding values have also been reported in the case of chloride, where the maximum value is about 1,290 mg L^{-1}, and the mean value is 491 mg L^{-1} compared to the WHO standard of 250 mg L^{-1} (World Health Organization, 1996). According to the PWA, more than 60% of the total amount of groundwater in the Gaza Strip aquifers is of bad quality and not potable according to WHO standards (PWA, 1999). It is believed that fertilizers, in combination with the leached wastewater from septic tanks and non treated wastewater, are responsible for high level of nitrate.

High fluoride content is also a problem Sansur et al. (1991) concluded that with an increase in salinity in many of the artificial wells in the Gaza Strip, the health effect on the population has become serious and stated that this condition is due to high fluoride content. In the Gaza strip, many people are affected by yellow staining, and discoloration plus mottling (decay) has been observed on the teeth of adult Palestinians in the central and southern Gaza Strip (Assaf, 2001).

3. Methodologies

3.1. Proposal overview

Desalination projects are always related to a number of parameters and factors such as water scarcity, water quality, energy recovery, cost per cubic meter, capital cost, location, land use, operations and maintenances as well as environmental impact. In general, any project has to meet at least the minimum requirements such as:

- Desalination plant allocation systems
- Consumer income and economic acceptance
- Availability of operational materials and chemicals in the area
- Annual cost optimization including workers
- Costs of supply, conveyance and pre and post treatments
- Study different scenarios and comparisons
- Environmental impact analysis
- Economic benefits of water use and net benefits of overall operations.

A Bayesian belief network model based on equations from Poullikhas, (2001) was developed for the Gaza Strip for a seawater RO desalination plant. Poullikhas assumed that the contribution of capital recovery cost varies between 30 and 50% of the cost of produced water, depending on several variables such as plant size, site, process type, etc. Energy is also considered as the major component of the cost which usually lasts up to 30 years for major plants. The O&M cost ranges between 15% and 30%, mainly depending on plant capacity (Bushnak, 1996). More information and details regarding the equations calculation can be found in (Poullikhas, 2001). The model yielded a minimum specific capital cost of 0.224±0.064 US$/m^3 and the minimum operation and maintenance cost was found to be 0.59±0.11 US$/m^3.

The joint project will supply fresh water and electricity to the two areas with one third to the Egyptian part (Sinai) and two thirds to the Palestinian part (Gaza). The advantages are much greater than disadvantages and it is almost no disadvantages for the Egyptian. In this project

Egypt will get their amount for free plus selling natural gas, improving water quality and quantity, employers opportunities, materials and tools for repairing and chemicals. All these parts will be supplied from Egypt and considered as advantages. Figure 2 shows the border line between Egypt and Palestine as well as the end point along the Mediterranean Sea coastline. In Figure 2, the triangle on the south-west part of the map encloses possible locations for the proposed project within a 10 km area on and around the Mediterranean coast. It is suggested that the brine from the desalination plant first be mixed with the power plant cooling water and then discharged to the sea to minimise the impact. The closer the plant to the Gaza border, the cheaper it will be to distribute external power, environmental electricity and water to the Gaza Strip.

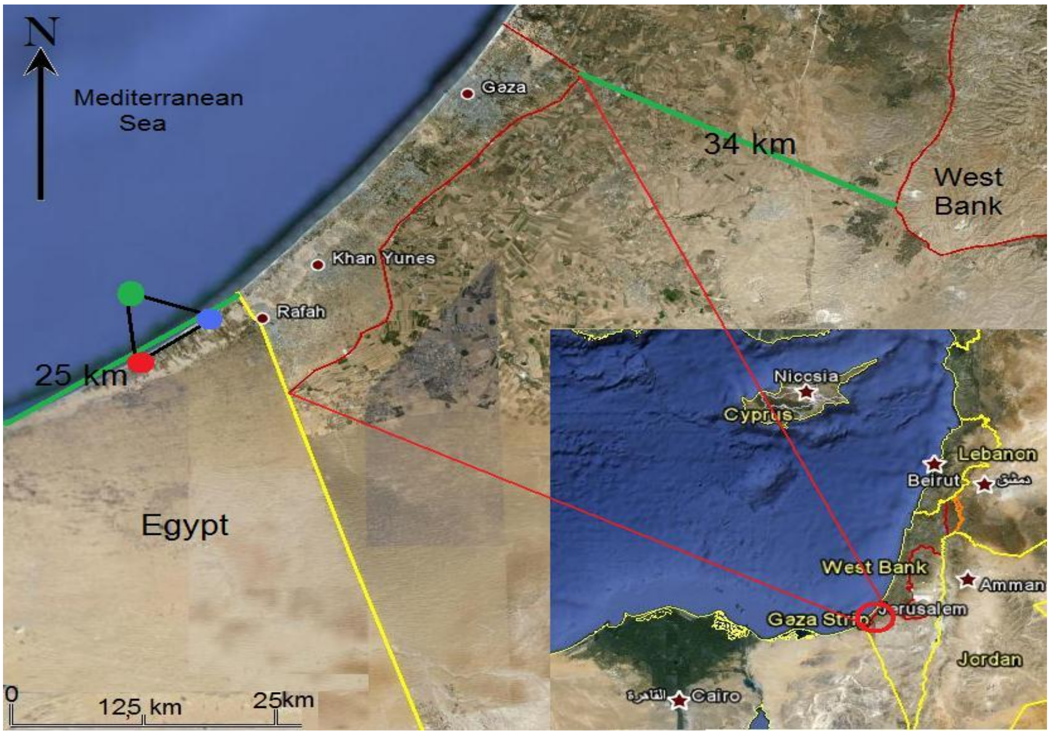


Fig. 2. Proposed desalination and power plant projects in the study area (From: Google Earth 2009)

3.2. Examples of water transport

The transfer water from Sinai to Gaza should not cause any problems. There are many practical examples of water transport from one city to another or from one country to another, see Table 1. Some calculations on transportation costs of water are presented in (Zhou & Tol, 2005). Comparison of these estimates to those of other studies suggests that Kally (1993) may have been overly pessimistic, but most of these studies suggest that the actual costs would have been higher, see Table 1. Kally's estimation is still used because his calculation takes account of not only horizontal distance but also vertical lifting cost. It is important to search for independent sources of energy that might be as cheap as Israeli pricing. A good alternative for energy supply to the power plant could be off-shore gas discovered in the sea close to Gaza (Baalousha, 2006).

Table 1. Cost of water transport to selected projects (from Zhou & Tol, 2005)

City Country	Project Name	Distance Km	Amount MCM	Cost $/m³	Reference
Gaza Palestine	Nile to Gaza	200	100	0.214	Zhou & Tol, 2005
Turkish Cyprus	Turkey to Turkish Cyprus	78	75	0.25-0.34 0.26	Gruen, 2000 Kally, 1993
Barcelona Spain	Ebro to Barcelona	900	1000	0.36 0.52	Uche et al. 2001 Kally, 1993
Colorado USA	Colorado river to Phoenix and Tucson	550	1800	0.05 0.74	Hahnemann, 2002 Kally, 1993
Yangtze China	Yangtze to China's north	1150	32	0.10-0.16 0.38	Liu & Zheng, 2002 Kally, 1993

3.3. Alternatives water supply solution

3.3.1. Water transport

Water transport was one of some alternatives were proposed to supply fresh water to Gaza peoples. As seen in Table 1, Nile to Gaza was suggested as one alternative by Zhou & Tol, (2005), it is comparable with desalinated water. The transport cost per cubic metre is about $0.214, it is cheaper then desalination but not possible now due to increase in demand by the countries around the river. Water quality from the Nile River will not be good as the desalinated water.

Connecting the West Bank to the Gaza Strip is one possibility, first proposed by Assaf (1985, 1986). It entails connecting the West Bank and the Gaza Strip using a 60-70 km long pipeline of fresh water derived from Lake Tiberia (with Israeli permission) from the West Bank mountain aquifer and/or from the Israeli National Water Carrier. The solution was considered to be highly politically dependent and is now not possible because its level has dropped in recent years due to drought. Further on, water resources are not abundant on the West Bank and increased water consumption in Israel and Jordan.

3.3.2. Artificial recharge

Artificial recharging was previously planned as one possible solution for the Gaza aquifer, advocated in 1985 (Assaf & Assaf 1985) using floodwaters of Wadi Gaza and/or treated wastewater. There are many problems with this supply due to poor water quality in the Wadi of Gaza and lack of wastewater collection systems. Wastewater amount in the Gaza strip is about 13 MCM annually (CAMP, 2000). Approximately 70-80% of the domestic wastewater produced in Gaza is discharged into the environment without treatment; either directly or through leakage. Also, there are about 18 different pipelines of wastewater discharged into the Mediterranean (UNEP, 2003). Almost all wastewater treatment plants in the Gaza Strip do not function effectively. The flood water amount is approximately 2 MCM/y which not meets the needs of Gaza and decreases of precipitation amount and increasing in the evaporation rate over Gaza are important.

3.3.3. Desalination

A large scale seawater desalination system set up in the Gaza Strip has been suggested previously (Assaf, 2001). A model for a set up like this with a BOO (build, own and operate) contract was demonstrated on the Florida coast in the USA with a fresh water cost of only $0.6/m^3 (Metcalf and Eddy, 2000). Solar plants have been suggested for desalination purposes. Three stages of a co-generation plant with a planned water capacity of 100 MCM/year, a power capacity of 2.5 billion kWh/year and a total panel area of approximately 13 km^2 have been proposed (Lubna et al., 2008). It was calculated that about 5 km^2 is required for the collector field to produce 1 TWh/year of electricity (Knies et al., 2005; Trans, 2004). The estimated total cost of this proposal is approximately 1.1–1.3 billion US$, which is high compared to a joint power and desalination plant. The total land use would be huge and solar panels are expensive.

The desalination plant for the Gaza Strip was designed with a production capacity of 60,000 m^3/d in the first phase and 150,000 m^3/d in the second phase (El-Sheikh et al., 2003; El-Sheikh, 2004). Ghabayen et al. (2004) planned desalination plant capacity of 140,000 m^3/d to produce water quality at maximum 400 ppm TDS, at a recovery rate of 50%. It is obvious that the water supply situation in the Gaza Strip is unsafe. But the localization of a desalination plant here may be jeopardized by insecure political and logistic conditions. Plant localization inside the Gaza Strip is unrealistic for three reasons; political problems, interior problems and energy availability.

In Gaza, there is no guarantee of a power supply to water projects. For example, no safe supply of operational and maintenance materials can be guaranteed. The interior situation in Gaza is characterised by lack of control of available water (chaos due to war) as well as leaks of information and technology. The energy availability and power supply is functioning most of the time despite the political problems. A joint plant catering to both Egyptian and Palestinian needs may decrease the tension. At present it is not realistic to suggest a joint Israeli-Palestinian desalination or power project. Therefore, as safely as possible and away from any political escalation in the region, the proposal should be planned to supply people with fresh water. To build desalination and a power plant in the same area will currently be the best solution for producing fresh water and electricity to both Gaza and Sinai.

4. Results and Recommendations

4.1. Unit and capital cost results

The reported production unit cost of seawater desalination dropped significantly from 1955 to 2020 and will probably reach less than US 0.5 \$/m^3 in 2020, as shown in Figure 3. Four different technology types were studied and compared for long-term seawater desalination: membrane processes containing reverse osmosis (RO), thermal processes including multistage flash evaporation (MSF), multiple effect evaporation (ME) and vapour compression (VC), see Figure 3. Bashitialshaaer & Persson (2010) extracted data from the International Desalination Association (IDA) yearbook 2006-07, 2007-08, 2008-09 and 2009-10. The data presented in Table 2 were derived from these yearbooks to help us achieve a better result. These data were collected from 18 different projects mainly in the Middle East countries and some projects with similar intake salt concentration. The desalination plant capital cost for the production of 1 m^3 a day was found to be about 1080 \$US (approx. 1 million \$US to produce 1000 m^3/d) (Bashitialshaaer & Persson, 2010). The average unit costs presented in Table 2 are well compared with that predicted in Figure 3.

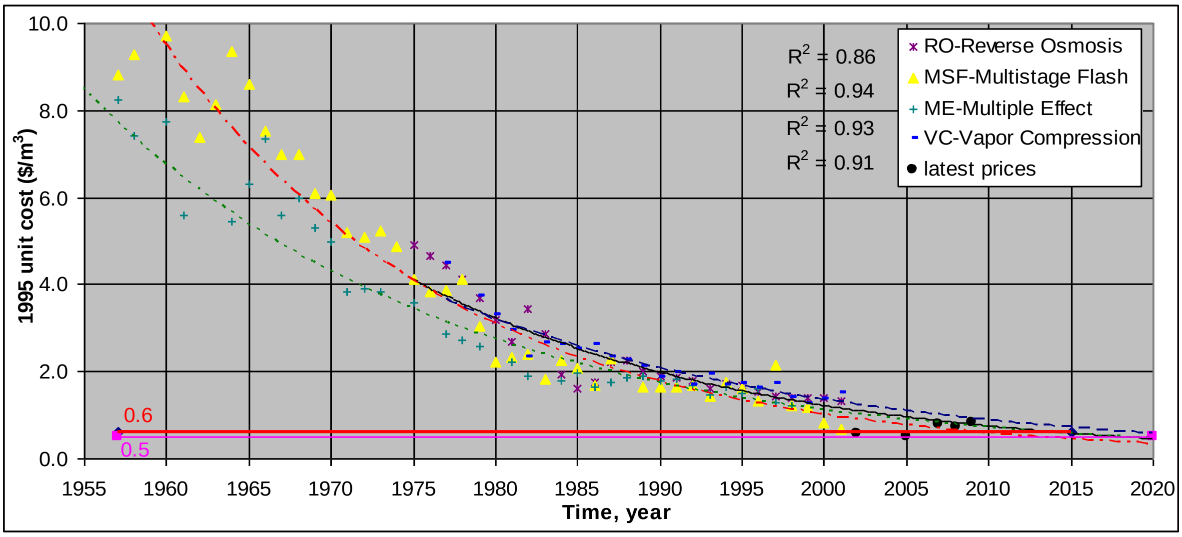


Fig. 3. Unit costs for seawater desalination 1955-2020 for four technologies (Bashitialshaaer & Persson, 2010)

Also, the mean cost of production for 1 m^3 was found to be about 0.79 \$US and the mean energy consumption approximately 4.5 kWh/m^3, for a raw water with Mediterranean Sea salt concentration. Building desalination and power plants in the same location has been practised in Israel, Saudi Arabia and the UAE to supply electricity to the desalination plant directly and the surplus to the power grid. It was found that the average cost of producing 1 Watt from the power plant is equal to about 1 \$US (approx. 1 million \$US to produce 1 MW) (Bashitialshaaer & Persson, 2010).

In Table 3, population change, growth rate and land area for some countries in the Middle East are presented. The population growth rate for the Gaza Strip is very high, with a simultaneous increase in water requirements. The growth rate from mid year of the whole period is the most common way of expressing annual population growth as a rate. The annual population growth rates over 100 years from 1950 and predicted for year 2050 were taken from the U.S. Census Bureau (2008).

Table 2. Data from 18 different desalination plants including six power plant projects

Project name IDA year book	Date	Total Capacity m^3/day	Input	Output	Capital cost $US/$m^3$	Energy	cost	Within project MW
			TDS, mg/l			kWh /m^3	$US /$m^3$	
(2006-2007)								
Ashkelon SWRO, Israel	2005	326144	40679	300	650	3.9	0.53	
Carboneras SWRO, Spain	2002	120000	39000	<500	792	4	0.57	
Fujairah, UAE	2003	454000	40000	<180	843	4.5	NA	500
Shuweihat, UAE	2004	454000	44000	<250	819	3.7	NA	1500
Tuas SingSpring, Singapore	2005	136360	35000	<250	851	4.3	0.47	
(2007-2008)								
Dhekelia, Cyprus	1997	40000	40570	<500	1025	5.3	1.19	
Larnaca, Cyprus	2001	54000	40300	<500	1600	4.52	0.76	
Perth, Australia	2007	143700	36500	30	2400	4.0	1.2	
(2008-2009)								
Hidd (IWPP), Bahrain	07-08	408780	44000	<50	910	NA	0.69	910
Ras Laffan B (IWPP), Qatar	2008	272520	42000	<25	694	NA	0.8	1025
Hamma (SWRO), Algeria	2008	200000	39000	<500	1250	NA	0.82	
Palmachim SWRO, Israel	2007	110000	40233	<300	1000	3.8	0.78	
Skikda SWRO, Algeria	2008	100000	39332	<450	1100	3.6	0.73	
(2009-2010)								
Ghar Lapsi Plant, Malta	85-94	69500	39000		NA	3.2	0.72	
Barcelona-Liobregat, Spain	2009	200000	44800	400	1135	4.2	NA	
Marafiq IWPP-Jubail, KSA	2009	800000	42000	<25	957	1.6	0.83	2745
Alicant 1 & 2, Spain	03-08	130000	40000	400	1185	4	NA	
Rabigh IWSPP, KSA	2007	218000	39600	<10	2249	4.8	NA	360

IDA-International Desalination Association Yearbook; SWRO-SeaWawter Reverse Osmoses; WEB-Water Energiebedrijf; APP-Atomic Power Project; Independent Water Power Project (IWPP); Seawater Reverse Osmosis (SWRO); Integrated water steam & power project (IWSPP); KSA-Kingdom of Saudi Arabia

Table 3: Population, land area and population growth rate (U.S. Census, 2008)

Country or area	Population			Area	Annual Population growth rate
	1950	2008	2050	Km^2	
Egypt	21,197,691	81,713,517	127,563,256	995,450	1.79
Israel	1,286,131	7,112,359	10,828,462	20,330	2.13
Palestine	1,016,540	4,149,173	9,789,347	6,000	2.26
West bank	771,165	2,611,904	5,580,321	5,640	1.98
Gaza Strip	245,375	1,537,269	4,209,026	360	2.84

The amount of fresh water needed for the Gaza Strip can be calculated from census and population progress data. If we consider a population of about 2 million living in Gaza in 2020 and that the daily fresh water requirement is about 100 litres per capita, the water supply should be 200,000 m^3/day. The expected electricity demand is about 350 MW. A combined water production and power plant will have a capital cost of about US $200 million in addition to the energy cost used for the desalination plant. The people in the Gaza Strip will also increase this amount. The proposal put forward in this study is projected to produce up to 500,000 m^3/day of desalinated water and about 500 MW electrical energy. The total amount will be distributed to the Gaza Strip in Palestine and Sinai in Egypt. It will also be possible in the future to transport any excess water from the Gaza Strip to the West Bank. The distance from the last point in the Gaza strip to the closest point on the West Bank is approximately 34 km.

The proposed project should be initiated as soon as possible. The final results and production distribution of the proposed desalination and power plants are presented in Table 4. The proposal presented in this study is planned to five years but production should be started at the end of the first year and be continued at the same level. It could be distributed as follows: two thirds to Gaza and one third to Egypt from both desalination and power plant projects. Details on how to finance the investment need to be sorted out later, but this type of project is expensive, thus it might be more convenient to carry out the projects step by step. It is possible to get international support from donors such as the World Bank, SIDA and the European Union. If the investment can be financed, then the project schedule time can be made shorter.

As described above, the results in Figure 3 and Table 4 have been derived from bench-mark studies of 18 different desalination projects mainly in the Middle East countries. The calculated mean desalination plant capital cost is about 1080 $US/$m^3$ a day (approx. 1 million $US to produce 1000 m^3/d and/or 1 $US to produce 1 l/d).

Table 4. Sample calculation for desalination and power plant proposal

Date	**Total Capacity**	**Within project**	**Capital Cost, $US**	**Gaza Strip**	**Egypt Sinai**
	m^3/d	**kW**	**million**	**m^3/d**	**m^3/d**
2010	0	0	0	0	0
2011	100000	100000	200	66667	33333
2012	200000	200000	200	133333	66667
2013	300000	300000	200	200000	100000
2014	400000	400000	200	266667	133333
2015	500000	500000	200	333333	166667
Finally	500000	500000	1000	333333	166667

4.2. Impacts and recommendations

Joint-project advantages: Cooperation between the two countries especially water and electricity will could provide secure and trustworthy relationships, in the same manner as has happened between Germany and France.

Environmental effects: In the Gaza Strip, many householders use desalination home units, resulting in a local production of brine that ends up in the sea and increases the salt concentration of the seawage water, making the process of wastewater reuse more difficult and costly (El-Nakhal, 2004). In the absence of stability in the Gaza Strip, there are no regulations for desalinated water, thus there is very little control of the quality of desalinated water or the brine discharge. A safe supply of desalinated water should decrease the need for home units. With a RO-plant, less brine will be discharged on land in Gaza.

Maintenance impact: The maintenance process needs trained people, and preventing damage to the RO membrane will be costly. In Egypt, it is possible to recruit qualified personnel, and operation and maintenance costs here could be similar or lower compared with world prices.

Groundwater contamination: Brine water is presently disposed off together with domestic wastewater in shallow drainage wells as well as in septic tanks, where it directly infiltrates the aquifers and affects the groundwater (El-Nakhal, 2004). Furthermore, the high pumping rate of groundwater causes seawater intrusion into the Gaza Strip coastal aquifer (Yakirevich, 1998). By supplying alternative drinking water, the need to extract groundwater decreases.

More available water: Currently there is no obvious right to water for the people of Palestine and sanitation in Gaza is inadequate, threatening water quality. With increased safe water supply, it will be possible to promote cooperation among countries sharing water resources and technology in the Middle East and to reduce water stress in the neighbouring countries.

Land impact: The area of the Gaza Strip is small in relation to a large scale safe water supply from an internationally controlled desalination plant. To locate the plant in the Gaza Strip will lead to an expensive desalination project with a high capital cost. Implementation of this project away from the border of Gaza requires a pipeline and pumps with additional energy needs to transport the fresh water to the municipalities.

Energy impact: The cost of energy in desalination plants is about 30% to 50% of the total cost of the water produced. Comparison of the cost components of reverse osmosis for two different energy supplies reveals that energy costs constitute the largest part of the operating costs (70%) (Akgul, 2008). In Gaza almost all the RO plants only operate for 8 hrs a day due to lack of electricity (Baalousha, 2006). The total cost of desalination can be reduced by designing the process as a hybrid (Awerbuch, 1997). In addition, a power plant was established in the Gaza

Strip consisting of six turbines, with a total production capacity of 136 MW when fully completed (Baalousha, 2006). This plant is normally out of operation due to damaged parts and lack of appropriate maintenance.

Obviously, to improve safe water and electricity supply in Gaza will immediately help the population of Gaza. Since the cost of water and electricity will be on par or lower than the present unreliable supply in Gaza, the economy of the project will not be a problem for Gaza either. But interestingly enough, also Egypt will gain substantially from the proposed project. The most important incentives and advantages to Egypt are listed below:

1. This project will increase water quality and quantities and electricity that will be available for the growing population of Sinai,
2. Egyptian natural gas can be used in the project adding value to the gas sales,
3. The plant will need staff. This gives employment opportunities for the people of Sinai,
4. Materials, chemicals and tools for repairing and maintenance of the desalination plant will also be provided from Egypt, which will increase the domestic M&U market
5. Politically, this is an opportunity for Egypt to increase cooperation with and be more present in Gaza; this will lead to increased security around the border between Egypt and Gaza. Already there is an electricity cooperation in operation between Egypt and Gaza governments.

5. Conclusions

Clearly both the desalination and the power plant are vital in the Gaza Strip to supply water and electricity to the people. Desalination as a source of water supply has many advantages and few disadvantages. In the Gaza Strip, sources of energy for desalination and power plant projects are very important in order to create an independent source of electricity, but nothing is secure in this situation. The people of Gaza lack infrastructure and rely on a clean water supply in order for their services to function normally. Although RO is a promising technology, highly professional people are required to operate the desalination plants. Supplies of chemicals required for desalination mean that continuous operation of a plant in Gaza may prove difficult and many existing small units have stopped production for this reason.

Why Egypt? Locating the desalination and power plant in Egypt on the Mediterranean coast is a good solution for both Egyptians and the people of Gaza. Improving neighbourhood relationships in both sides. From the current experience the cost of water and electricity will be lower than cooperation with the Israeli and the workers are also much lower. This proposal should improve agriculture as well as the socioeconomic and industry of both areas. More fresh water will be supplied to the peoples and more electricity will be supplied to the industry that may increase the productions. The environmental issue must be studied in great detail before implementing the desalination plant project.

However costs may be reduced by the use of natural gas to produce energy in the same location. The distribution of the production of water and electricity will be supplied as 1/3 for free to Sinai peoples for their land and natural Gaza usage. The rest of the outcome of this project from Gaza peoples will be used for repairing, maintenance and workers costs. One possible solution is to sell all the production from desalination and power plant in order to get back the capital cost in few years and the same time to payback the land rent, gas cost and repairing and maintenance. The only need to start this project is the stepwise capital cost and then the project benefits must cover all expenses.

References

[1] A. Bushnak, The economy of water desalination, Proc., GULF96, 1996, pp. 2-34.

[2] Abu Zahra B. A. A. (2001). Water crisis in Palestine, Desalination 136, 93-99.

[3] ADC-Austrian Development Cooperation (2007). *Water Sector Review.* Jansen and Consulting Team, Ramallah. January 2007.

[4] Al-Agha M. R. (2005). Hydrogeochemistry and carbonate saturation model of groundwater, Khanyounis Governorate-Gaza Strip, Palestine. Environ Geol 47, 898–906.

[5] Alice Gray, Water development in the Palestinian Territories since the Oslo Interim Agreement in 1995. Water Policy 11 (2009) 525-536.

[6] Al-juaidi A. E. (2009). Water Allocation for Agricultural Use Considering Treated Wastewater, Public Health Risk and Economic Issues. PhD theses, Utah State University.

[7] Al-juaidi A. E., Rosenberg D. E. and Kaluarachchi J. J. (2009). Water Management with Wastewater Treatment and Reuse, Desalination, and Conveyance to Counteract Climate Change in the Gaza Strip. AWRA Climate Change Conference Anchorage, Alaska May 4-6.

[8] Al-Khateeb M. (1993). Palestinian water supplies and demand. A proposal for the development of a regional water master plan, IPCRI, Jerusalem.

[9] Akgul D., Çfakmakcı M., Kayaalp N., Koyuncu I. (2008). Cost analysis of seawater desalination with reverse osmosis in Turkey. Desalination 220, 123–131.

[10] Assaf S. A. (2001). Existing and the future planned desalination facilities in the Gaza Strip of Palestine and their socio-economic and environmental impact. Desalination 138, 17-28.

[11] Assaf S.A. (1997). The pollution of Gaza's underground water resources by nitrates, Conf. on Water and Environment, Technion, Haifa, Israel.

[12] Assaf K. and Assaf S.A. (1986). Water resources and utilization in the Arab World, Arab Fund, Kuwait Publishers, pp. 93.

[13] Assaf S.A. and Assaf K. (1985). Food security in the West Bank and Gaza Strip, a comprehensive study for ESCWA/FAO Joint UN Division and AOAD of the Arab League, UN Publication, October.

[14] Avlonitis S.A. (2002). Operational water cost and productivity improvements for small-size RO desalination plants, Desalination, 142, 295-304.

[15] Awerbuch L. (1997). Dual-purpose power desalination/hybrid systems/energy and economics. IDA Desalination Seminar, Cairo.

[16] Baalousha H. (2006). Desalination status in the Gaza Strip and its environmental impact. Desalination 196, 1–12.

[17] Baalousha H. (2004). Risk Assessment and Uncertainty Analysis in Groundwater Modelling. Shaker Verlag, Aachen.

[18] Bashitialshaaer R. and Persson K. (2010). Desalination and Economy Prospects as Water Supply Methods. Water desalination conference in the Arab countries, Riyadh-Saudi Arabia, April 2010.

[19] Busch, M., and Mickols B. (2004). Economics of desalination—Reducing costs by lowering energy use, Water Wastewater Int., 19(4), 18–20.
[20] CAMP (2001). Water Quality Baseline Survey- Final Report, Coastal Aquifer Management Program, Palestinian Water Authority, Gaza, pp. 1-54.
[21] Dima N. W., Maarten A. S., Zaag P. V., Mimi Z., and Gijzen H. J. (2008). Water Footprint of the Palestinians in the West Bank. Journal of the American Water Resources Association (JAWRA) 44(2), 449-458.
[22] El-Nakhal H. A. (2004). Alternatives to tap water: a case study of the Gaza Strip, Palestine. Environmental Geology 46, 851–856
[23] El-Sheikh R. (2004). Regulatory challenges of Palestinian strategies on distribution of desalinated water. Desalination, 165, 83–88.
[24] El-Sheikh R., Ahmed M., Hamdan S. (2003). Strategy of water desalination in the Gaza Strip, Desalination 156, 39-42.
[25] Ettouney, H. M., et al. (2002), Evaluating the economics of desalination, Chem. Eng. Prog., 98, 32– 39.
[26] EXACT (1998). Executive Action Team, Overview of Middle East water resources. Water Resources of Palestinian, Jordanian, and Israeli Interest.
[27] Gary C. (2006). Desalination in Australia, IDA News, September/October.
[28] Ghabayen McKee S., M. and Kemblowski M. (2004). Characterization of uncertainties in the operation and economics of the proposed seawater desalination plant in the Gaza Strip. Desalination 161, 191-201.
[29] GTZ Study, Tahal (1996). Water Planning for Israel Ltd, Middle East regional study on water supply and demand development, Phase II, Options to close the gap -- seawater desalination. Tel Aviv, Israel.
[30] GTZ Study, Tahal (1995). Water Planning for Israel Ltd., Middle East regional study on water supply and demand development, Phase I, Review of assessment of existing plans. Tel Aviv, Israel.
[31] Heitmann H.G. (1990). Saline water processing, VCH, New York, Chaps. 12-13.
[32] HRH Prince El Hassan bin Talal, Opens WOCMES 2010, The World Congress for Middle Eastern Studies (WOCMES 2010) organized by the European Institute of the Mediterranean (IEMed), Barcelona, Spain, 19-24 July, 2010.
[33] HRH Prince El Hassan bin Talal, Regional Cooperation with International Facilitation. Strategic Foresight Group Conference Water Security in the Middle East, Geneva, Switzerland, 15-16 February, 2010.
[34] HRH Prince El Hassan bin Talal, "Improving Regional Cooperation on Water: A Key Opportunity for Preventive Diplomacy" The Parliamentarian Network for Conflict Prevention and Human Security, Jordan, Amman, 3-5 November 2009.
[35] HRH Prince El Hassan bin Talal, The Global Economic Crisis and its impact on Fragile States. Switzerland,Caux, 7/17/2009.
[36] IDA-International Desalination Association Yearbooks 2006-2007, 2008-2009 and 2009-2010.
[37] Isaac, J. (2000). Essentials of sustainable water resource management in Israel and Palestine. Arab Studies Quarterly 22(2), 13-32.
[38] Jaber I. and Ahmed M. (2004). Technical and economic evaluation of brackish groundwater desalination by reverse osmosis (RO) process. Desalination, 165, 209–213.
[39] Kally, E. (1993). Water and Peace: Water Resources and the Arab-Israeli Peace Process, Greenwood, Oxford, U. K.
[40] Knies G, Kabariti M, Seifter P, Makhool B, Daibes F. A solar water and power source for Gaza. Paper presented to Forum 2000 in Prague, 9–10 October 2005.
[41] Lubna K. Hamdan, Maryam Zarei, Russell R. Chianelli, Elizabeth Gardner, Sustainable water and energy in Gaza Strip. Renewable Energy 33 (2008) 1137–1146.
[42] Metcalf and Eddy Consultants (2000) (Camp Dresser and McKee), Coastal aquifer management program, integrated aquifer management plan (Gaza Strip). USAID Study, Task 3, Executive Summary, Vol. 1, and Appendices B-G. Gaza, Palestine.
[43] Metcalf and Eddy, Inc. (2000). Integrated aquifer management plan: Final report. Gaza Coastal Aquifer Management Program (CAMP). USAID Contract No. 294-C- 00-99-00038-00. 550 p.
[44] MoA (2007). Ministry of Agriculture, Palestinian Water Authority (PWA), and Palestinian Hydrology Group (PHG). 2004. Technical report and partial results for the 2003 season of agricultural monitoring development support program (Beit Lahia Site).
[45] MPIC (1995). Ministry of Planning and International Cooperation PA. Govt. of The Netherlands Nitrate pollution study, Gaza environmental profile, Phase II, Environmental Series No. 3, Euroconsult and IWACO Consultants for Water and Environment, Gaza, Palestine, September.
[46] Pankratz T. (2004). An overview of Seawater Intake Facilities for Seawater Desalination, The Future of Desalination in Texas Vol 2: Biennial Report on Water Desalination, Texas Water Development Board.
[47] PBS (2000). Palestinian Bureau of Statistics, Ramallah, the West Bank, Palestine.
[48] PCBS (1997–2004). Palestinian Central Bureau of Statistics, Mid-year projected population in the Palestinian Territory by Governorate. http://www.pcbs.org/inside/selcts.htm.

[49] PCHR-Palestinian Center for Human Rights (2009). *Press Release. 4th May 2009.* Available on PCHR website: http://www.pcbrgaza.org/tiles/PrcssR/English/2008/Of)-05-2009_2.html (last visited 12/05/2009).
[50] PWA (2000). Palestinian Water Authority, Water desalination study for Gaza Strip.
[51] PWA (1999). Palestinian Water Authority, Water Resources and Planning Department, Gaza Water Resources.
[52] PWA (1995). Palestinian Water Authority, Hydrogeological data books of the Gaza Strip, Water Resources Action.
[53] Poullikkas A. (2001). Optimization algorithm for reverse osmosis desalination economics, Desalination, 133, 75-81.
[54] Sansur R.M., Askar S. and Mashagi H. (1991). Naturally occurring fluorides in underground water and their effect on dental fluorosis among UNWRA schools' children in the Gaza Strip, Center for Environmental and Occupational Health Sciences, Birzeit University, Birzeit, West Bank, Palestine.
[55] Sbeih M. Y. (1996). Recycling of treated water in Palestine: Urgency, obstacles and experience to date. Desalination 106, 165-l 78.
[56] Shawwa I. (2000). Desalination, country focus on the Gaza Strip watermark, MEDRC (Middle East Desalination Research Center), Muscat Oman.
[57] Sommariva C., Hogg H. and Callister K. (2003). Cost reduction and design lifetime increase in thermal desalination plants: thermodynamic and corrosion resistance combined analysis for heat exchange tubes material selection. Desalination 158, 17-21.
[58] Trans-Mediterranean Renewable Energy Cooperation TREC. A renewable energy and development partnership EU-ME-NA for large scale solar thermal power and desalination in the Middle East and in North Africa, 15 April 2004.
[59] UNEP (2003). Programme United Nations Environmental Program Desk study on the environment in the occupied Palestinian Territories. UNEP, Switzerland, pp 188.
[60] UNOCHA (2006). United Nations Office for the Coordination of Humanitarian Affairs, OCHA Situation Report Gaza occupied Palestinian territory, Gaza Strip Situation Report 13 December.
[61] U.S. (2008). Census Bureau International: Data Base; World Bank 2008. http://www.census.gov/ipc/www/idb/idbprint.html.
[62] U.S. Energy Information Administration, Independent Statistics and Analysis (Jan., 2011): http://www.eia.doe.gov/cabs/Egypt/NaturalGas.html
[63] WHO (1996). World Health Organization, Guidelines for drinking-water quality, 2nd edn: 2, Health criteria and other supporting information, Geneva.
[64] Wilf M. and Klinko K. (2001). Optimization of seawater RO systems design, Desalination 138, 299-306.
[65] Yakirevich A., Melloul A., Sorek S., Shaath S. and Borisov V. (1998). Simulation of seawater intrusion into the Khan Yunis area of the Gaza Strip coastal aquifer. Hydrogeology J., 6, 549–559.
[66] Zhou, Y., and Tol R. S. J. (2005). Evaluating the costs of desalination and water transport, Water Resour. Res., 41, W03003, 2005.