WATER QUALITY EVALUATION OF SMALL SCALE DESALINATION PLANTS IN THE GAZA STRIP, PALESTINE

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ABSTRACT

The Gaza Strip is a highly populated, small area in which the groundwater is the main water source. During the last few decades, groundwater quality has deteriorated to a limit that the municipal tap water became brackish and unsuitable for human consumption in most parts of the Strip. To overcome this serious situation, the reverse osmosis (RO) technology is used to replace the tap water or to improve its quality. Several privet Palestinian water investing companies established a small-scale reverse osmosis (RO) desalination plants to cover the shortage of the good quality of drinking water in the whole Gaza Strip. The purpose of this paper is to investigate the chemical and bacteriological water qualities of different small scale of (RO) desalination companies in the Gaza Strip. The results of the chemical and bacteriological parameters were compared with World Health Organization (WHO) standard. It was concluded that all chemical analyses of RO produced water are within the allowable WHO limits. Bacteriological analyses indicate that 25% of produced water samples exceeded the maximum allowable value of the total coliform bacteria.

Keywords: Gaza Strip; Desalination; Drinking water supply; Water crisis

INTRODUCTION:

The Gaza Strip is a narrow area lying along the southwestern portion of the Palestinian coastal plains; its area is about 360 km^2 (Figure 1). The length is about 45 km on the western Mediterranean coast and the width varies from 7 km to 12 km. The Sinai Desert is located in the south, the Naqab Desert in the east and the Mediterranean Sea in the west, Nakhal [1]. The population density in the Gaza Strip is considered the highest in the world, with a population of 1.3 million people and a growth rate of 3.5% annually, PCBS [2]. The Gaza Strip is located in an arid to semiarid region, all the rainfall occurs between October to April, and the annual precipitation ranges from 230 mm in the south to 410 mm in the north, Aish [3]. The Gaza Strip Pleistocene granular aquifer is an extension of the Mediterranean seashore coastal aquifer. It is extends from Askalan (Ashqelon) in the North to Rafah in the South, and from the seashore to 10 km inland. The aquifer is composed of different layers of dune sandstone, silt clays and loams appearing as lenses, which begin at the coast and feather out to about 5 km from the sea, separating the aquifer into major upper and deep sub aquifers. The aquifer is built upon the marine marly clay (Saqiye group) from the Neocene Fink [4], having a hydraulic conductivity of about 10^{-8} m/s, Goldenberg [5]. In the east-south part of the Gaza Strip, the coastal aquifer is relatively thin and there are no discernible sub aquifers Melloul and Collin [6]. The groundwater abstraction is around 145 Mm^3/y, Metcalf and Eddy [7].

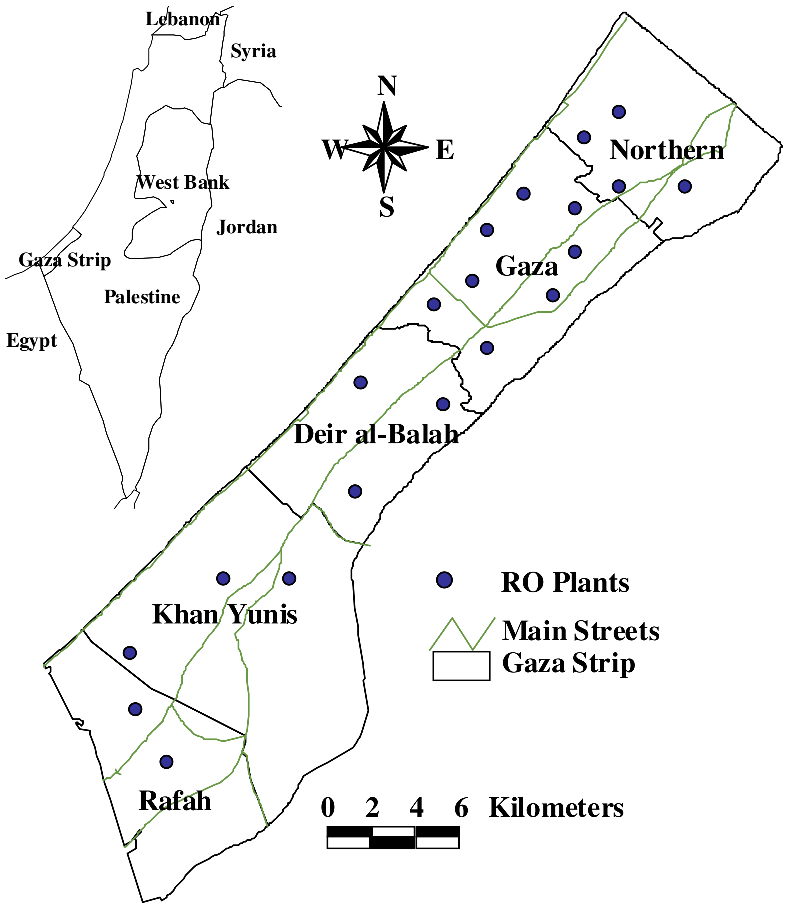

Fig. 1: A map of the Gaza Strip with geographic location of the RO plants.

Mainly the population growth and socio-economic development control water demand for the different uses. In year 2005, it was estimated that approximately 150 Mcm/yr of water was pumped from about 4100 wells. Of which, about 90 Mcm/yr of water was used for irrigation and 60 Mcm/yr were pumped for domestic and industrial from 100 municipal wells, PWA [8]. The domestic and industrial (D&I) demand presents quantity of water at water supply source that should be delivered to the D&I customers. It is clear that in the case of the Gaza Strip, the total D&I water needs will reach to about 182 Mcm by 2020 assuming an overall efficiency of 20%. If the demand for irrigation is calculated on the basis of the food requirements of the growing population, it appears that it will increase from the present usage of about 90 Mcm/yr to 185 Mcm/yr by 2020. However, this figure is not a realistic projection for

Gaza Strip, because neither the water nor the land to support an increase in agricultural activity exists. Therefore, the estimated future demands for agriculture are based on the actual water amounts of today. Generally, the overall water demand in Gaza Strip is estimated to increase from the present value of about 150 Mcm/yr to about 260 Mcm/yr in 2020. Generally, the overall water demand in Gaza Strip is estimated to increase from present of about $150x10^6$ m^3/y to about $260x10^6$ m^3/y in 2020, as shown in Figure 2. This includes D&I demand at water supply source and agricultural demand, PWA [8].

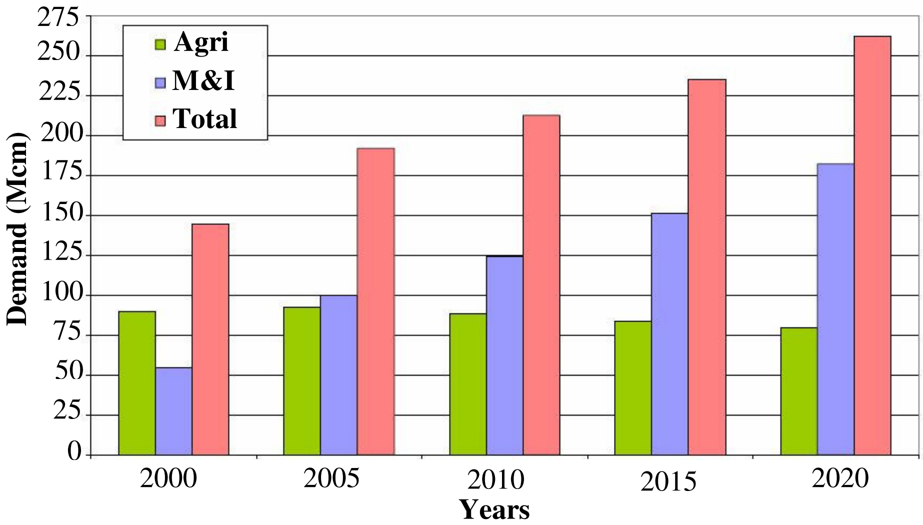

Figure 2: Overall water demand in the Gaza Strip

The groundwater is the main water resources in the Gaza Strip. The aquifer is intensively exploited through more than four thousands of pumping wells. As a result of its intensive exploitation, the aquifer has been experiencing seawater intrusion in many locations in the Gaza Strip. The groundwater quality changes in both horizontal and vertical directions. The fresh groundwater is not distributed evenly throughout the whole of the Strip. Salinity of the groundwater increases over time due to seawater intrusion and mobilization of incident deep brackish water caused by over abstraction of the groundwater. In most parts of the Gaza Strip, the chloride and nitrate content of domestic water exceeds the WHO guidelines WHO [9]. Table 1 shows the water quality in the different governorates of the Gaza Strip according to the concentration of NO_3, TDS and Cl respectively. Nitrate concentration ranges from 12 mg/l to 380 mg/l, total dissolved solids ranges from 265 mg/l to 3650 mg/l and chloride concentration ranges from 30 mg/l to 1582 mg/l. Therefore, the most serious water problems in the Gaza Strip are the shortage and contamination of the groundwater.

Table 1: Water quality in the Gaza governorates regarding NO_3, TDS and Cl concentrations

Water Quality	NO_3^-, mg/l		TDS, mg/l		Cl^-, mg/l	
	Range	Mean	Range	Mean	Range	Mean
North Gaza	13 - 280	101.1	355 - 1241	623	42 - 470	129
Gaza	27 - 224	111.6	365 - 2600	1352	30 - 802	381
Middle Gaza	17 - 95	49.6	238 - 2170	1295	65 - 1015	442
Khan Younis	29 - 380	201.0	332 - 3650	1864	54 - 1582	740
Rafah	12 - 230	90.1	256 - 3200	1171	46 - 1136	364

Source: Metcalf and Eddy [7]

One of the major options for resolving the water problems is the utilization of desalination technology for both sea and brackish water Al-Jayyousi and Mohsen [10]. More than 90% of the population of the Gaza Strip depends on desalinated water for drinking purposes Al-Agha and Mortaja [11]. There has been dissemination of many small scale brackish water desalination companies in the Gaza Strip (privet RO plants).

A brief description of typical privet RO Plant used in Gaza Strip is shown in Figure 3. The water is pumped from pumping well to the storage tank, then water flows through a 5-micron cellulose filter. This filter is usually used as pre-filters because it is an economical way to remove 98% of suspended solids, dirt, rust and other sediment. It also protects elements downstream from fouling or clogging. After that, the water is stored in tank A. Next, water flows through another 5-micron cellulose filter to ensure effective filtration. Water is split into two paths; in the first path water flows to the softener. The softener has a small tank full with NaCI, the softener function is to replace Mg^{++} and Ca^{++} with Na^+, and this process is called Ion Exchange. In this stage the hardness of water is reduced and the water becomes soft. The other advantage of the softener is that it lengthens the life of components downstream. Then, water flows to activated carbon filter, which is made from cool, coconut, lignite and wood. In the next stage of the process, water flows to the RO membrane system. RO membranes are capable of rejecting practically all particles, bacteria, and viruses. In water purification systems, a pump with 14 bars will provide enough pressure for RO application; pressure will be applied to the concentrated solution to counteract the osmotic pressure. Pure water is driven from the concentrated solution and collected downstream of the membrane. Also, to increase the amount of water, another membrane is used, that increases the capacity of the system. Water pressure also affects the quantity and the quality of the water produced. In the second path water flows to 2 series of activated carbon filters. These filters remove chlorine, sulfur, volatile organics and the remaining bad taste and odors from water. Water from the first path and the second path mixed in tank B. This mixing will increase TDS to give the water adequate test. A post treatment is performed to ensure a better quality of water. A pump of 6 bars pushes the water to 3 series filters. The first one is 5-micron cellulose filter, the second one is an activated carbon filter, and the third one is 1-micron cellulose filter. These 3 filters are installed to ensure the quality of water. They perform another treatment to remove the last remaining traces of resin fragments, carbon fines, colloidal and microorganisms. Finally, water flows to an ultraviolet unit, UV, where radiation is used as a germicidal treatment for water, some of RO companies are used UV light. Later, water flows to 1 micron cellulose filter. Finally, water is stored in tank C for domestic use.

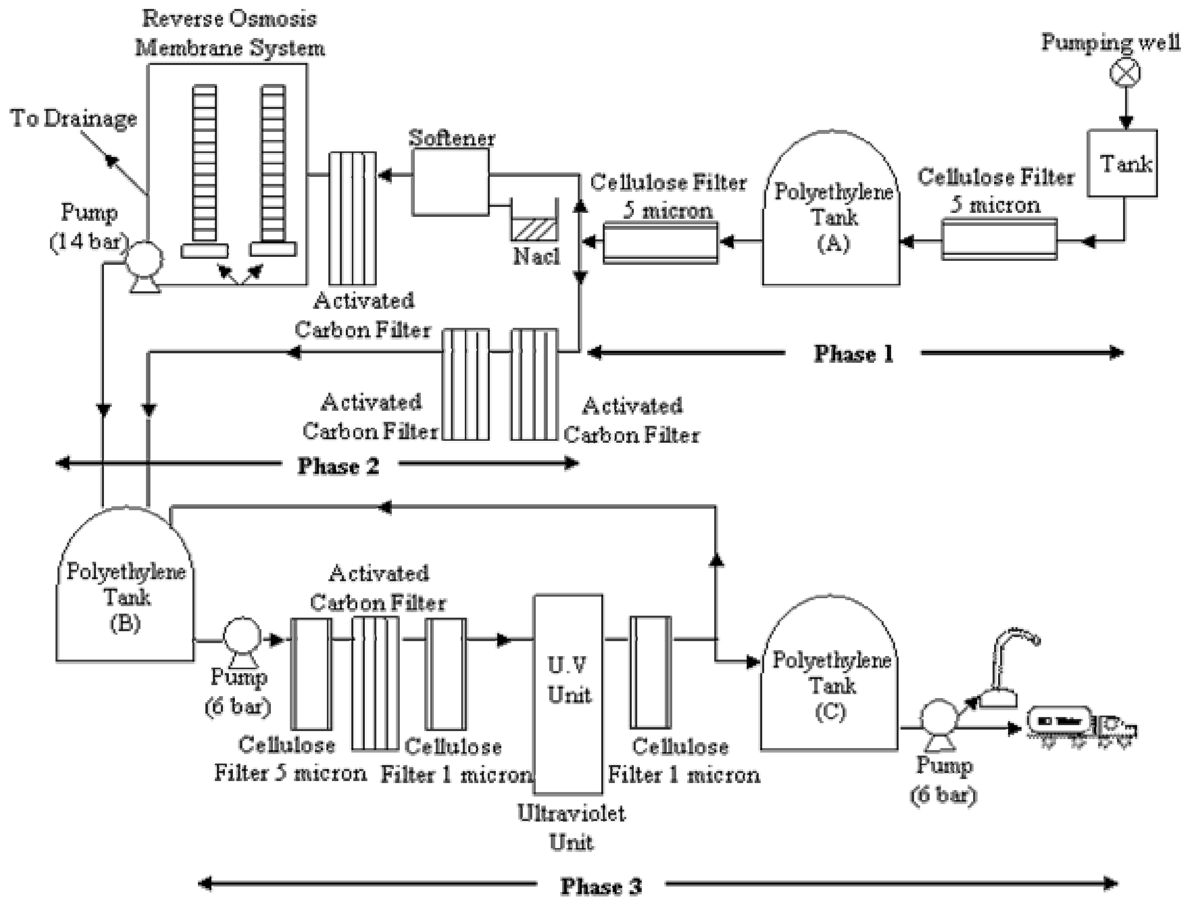

Figure 3: Typical RO unit used in the Gaza Strip

METHODOLOGY

The water samples were collected from the inlet and product of 20 different RO plants (companies) an analyzed to evaluate the chemical and bacteriological quality of desalinated water in the Gaza Strip. Electrical conductivity and pH were measured directly in site. Chemical analyses have been done at Palestinian Hydrology Group and Al-Azhar university laboratories where the sodium and potassium are analyzed using a Flame Photometer and nitrate is determined by the cadmium reduction method, followed by spectrophotometric measurement at 540 nm wavelength. The calcium and magnesium are determined with EDTA; while the titration with mercury nitrate is used to determine chloride. For alkalinity, a titration with 0.01N sulfuric acid is used and a turbidity method is employed for the sulfate analyses, Andrew et al. [12].

Bacteriological analyses of water samples were analyzed for total coliform and fecal coliform in duplicate samples. Total coliform and fecal coliform bacteria were enumerated by the membrane filter method using m-FC agar. 250 ml of the water sample was filtered through a sterile membrane filter 0.45 mm.

RESULTS AND DISCUSSION

Small desalination plants in the Gaza Strip are owned privately, which try to maintain adequate amounts of fresh water for the population. The majority of these plants were established from 1998 to 2003. The companies use the RO desalination system to produce desalinated water. They distribute this water by tankers. The small private desalination plants have a production capacity of about 20 m^3/d to 120 m^3/d, and brine water rejection ranges from 30 m^3/d to 240 m^3/d (Table 2). Brine from these commercial desalination plants is disposed of in the sewer system, irrigation and Wadi Gaza. Table 3 shows the chemical analysis of water samples of these private desalination plants compared with WHO drinking water standards. The quality of produced water is in the range of the WHO standard guidelines. After the chemical and bacteriological examination, the water was observed to have the following characteristics.

Table 2: Private RO desalination plants in the Gaza Strip

Plant name	Establishment (year)	Production of water (m^3/day)	Brine quantity (m^3/day)	Disposal
Alkawther	1999	120	240	Irrigation
Alkhayreya	2002	20	50	Sewage
Alsabra	2001	34	40	Sewage
Salsabeel	2002	60	180	Sewage
Alisraa	2000	30	65	Sewage
Aleen	2001	40	60	Irrigation
Sahha	2001	20	46	Sewage
Algemma	2003	30	30	Sewage
Ferdaws	2003	100	100	Sewage
Alsahaba	2003	30	30	Sewage
Akwa	2000	120	120	Wadi Gaza
Methalee	2002	50	70	Irrigation
Mash. Amr	2001	40	60	Sewage
Rasheed	2002	30	40	Sewage
Alredwan	2000	45	80	Sewage
Alneel	2002	50	130	Sewage
Ghadeer	2003	30	48	Sewage
Yafa	2003	50	90	Sewage
Alforat	2000	30	85	Irrigation
Aljanoub	1998	48	140	Wadi Gaza

Table 3: Comparison of physico-chemical properties of inlet and product (RO) water samples with drinking water standards (WHO)

Parameters	Type of water	Values from collected samples					WHO
		Minimum	Maximum	Median	Average	Stdev	
pH	Inlet	6.5	7.7	7.0	7.1	0.3	6.5 – 8.5
	Product	4.8	7.1	5.9	6.0	0.7	
TDS (mg/l)	Inlet	460.0	2295.0	1132.0	1238.4	553.3	1000 mg/l
	Product	39.0	142.0	96.0	97.6	25.9	
TH (mg/l)	Inlet	280.3	1084.9	478.1	514.2	187.9	500 mg/l
	Product	16.4	76.9	34.2	35.7	13.7	
Mg^{2+} (mg/l)	Inlet	16.6	172.6	58.7	61.2	37.2	60 mg/l
	Product	1.8	10.4	4.4	4.6	2.2	
Ca^{2+} (mg/l)	Inlet	10.8	179.6	103.9	105.3	38.7	100 mg/l
	Product	3.2	14.5	5.7	6.7	3.1	
Na^{+} (mg/l)	Inlet	35.5	619.3	186.2	231.1	180.9	200 mg/l
	Product	6.9	27.6	17.5	17.7	6.1	
K^{+} (mg/l)	Inlet	2.3	7.5	3.7	4.2	1.4	5 mg/l
	Product	0.1	1.6	0.3	0.5	0.4	
HCO_3^- (mg/l)	Inlet	193.6	583.9	286.9	325.9	102.4	200 mg/l
	Product	7.9	42.9	22.2	24.1	10.6	
Cl^- (mg/l)	Inlet	77.5	1148.9	285.4	389.9	319.8	250 mg/l
	Product	12.5	54.2	22.6	25.1	10.4	
NO_3^- (mg/l)	Inlet	28.7	227.4	83.5	110.0	70.3	45 mg/l
	Product	4.0	31.4	16.8	17.7	7.6	
SO_4^{2-} (mg/l)	Inlet	9.8	218.9	27.5	46.3	49.3	250 mg/l
	Product	0.1	2.9	0.3	0.6	0.7	

Chemical Analyses

pH

The pH is controlled by the amount of dissolved carbon dioxide CO_2, carbonates CO_3^{2-} and bicarbonate HCO_3^-, Domenico and Schwartz [13]. The pH analytical data in the inlet (Raw) water samples show that 100% of the samples have pH under WHO standards (6.5 – 8.5). Due to the desalination process and the elements removal, the pH value of some desalinated water became under the minimum concentration that recommended by WHO. So after desalination, water needs correction to the pH by adding NaOH, but if this operation does not happen at all RO plants, the pH of the water will be very low. The pH analytical data in the product water samples show that 70% of the samples have pH lower than 6.5, the rest 30% of the samples have pH between 6.5 – 7.11 (Figure 4).

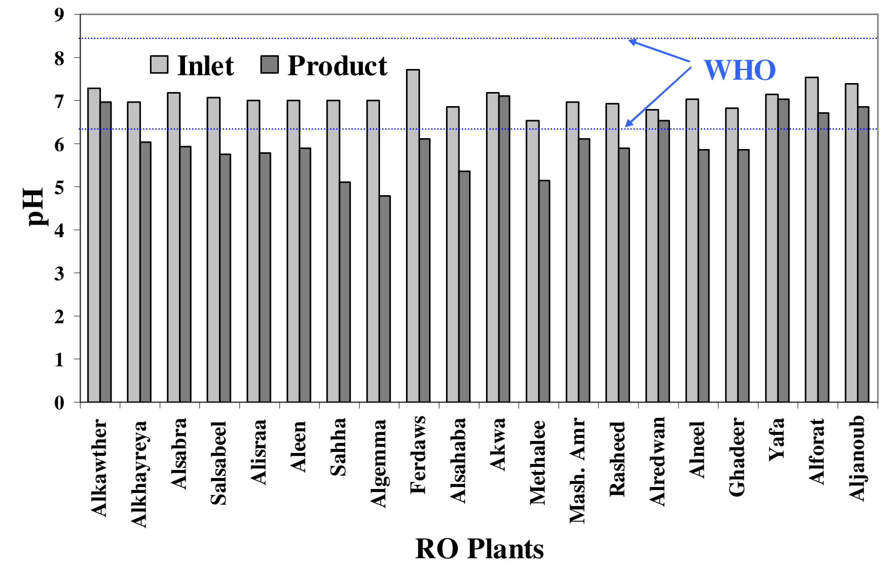

Figure 4: pH concentration in inlet and product water samples

Total Dissolved Solids (TDS)

The total dissolved solid TDS can be estimated by multiplying the electrical conductivity measurement by a predetermined factor. This factor, which is determined gravimetrically, ranges between 0.55 and 0.9. In the present case, a value of 0.62 was used. The TDS of 55% of the inlet water samples were under WHO standards (1000 mg/l). The rest of the water samples 45% have TDS concentration higher than the WHO standards. The all product water samples have TDS concentration accepted by WHO standards. The TDS concentration in product water samples ranges from 20 mg/l to 200 mg/l (Figure 5).

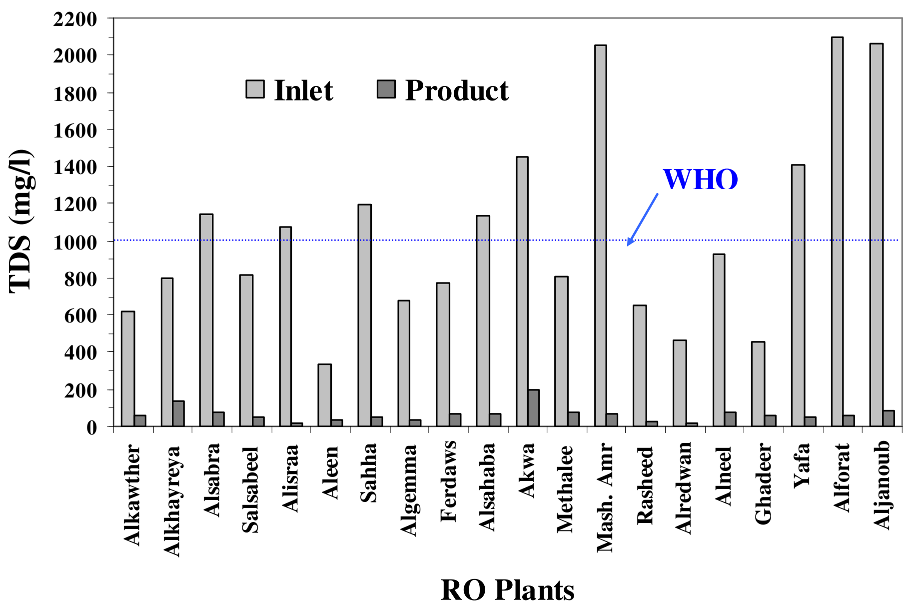

Figure 5: TDS concentration in inlet and product water samples

Calcium (Ca^{2+})

The analytical data of inlet water samples show that 40% of the samples have calcium concentration less than the recommendations of WHO standards (100 mg/l) and 60% of the samples higher than WHO standards. All product water samples have calcium concentration accepted by WHO standards. The calcium concentration in product water samples ranges from 0.6 mg/l to 14.5 mg/l (Figure 6).

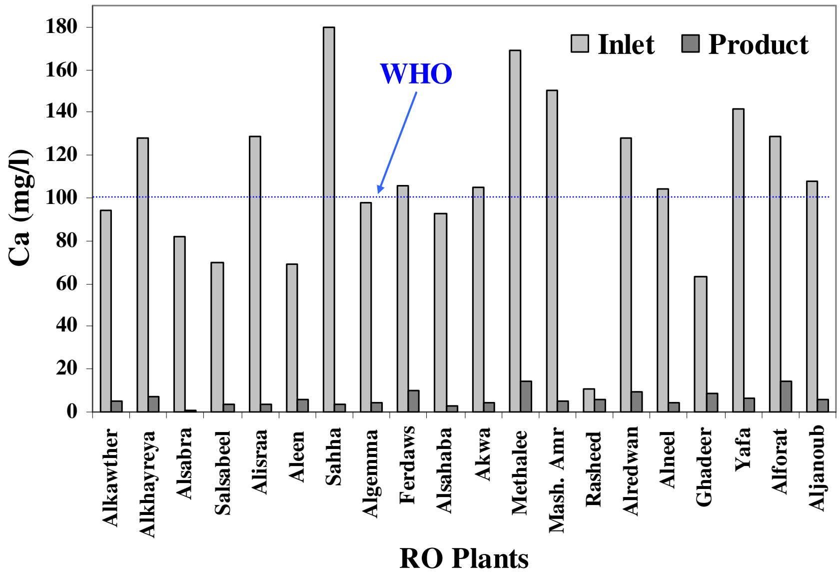

Figure 6: Calcium concentration in inlet and product water samples

Magnesium (Mg^{2+})

Magnesium concentration of 50% of the inlet water samples is under the WHO recommendation standard (60 mg/l) and 50% of the water samples have magnesium concentration higher than the WHO standard. In the product water samples, the magnesium concentration of all samples is less than 25 mg/l. 95% of the product samples contain magnesium concentrations less than 10 mg/l (Figure 7).

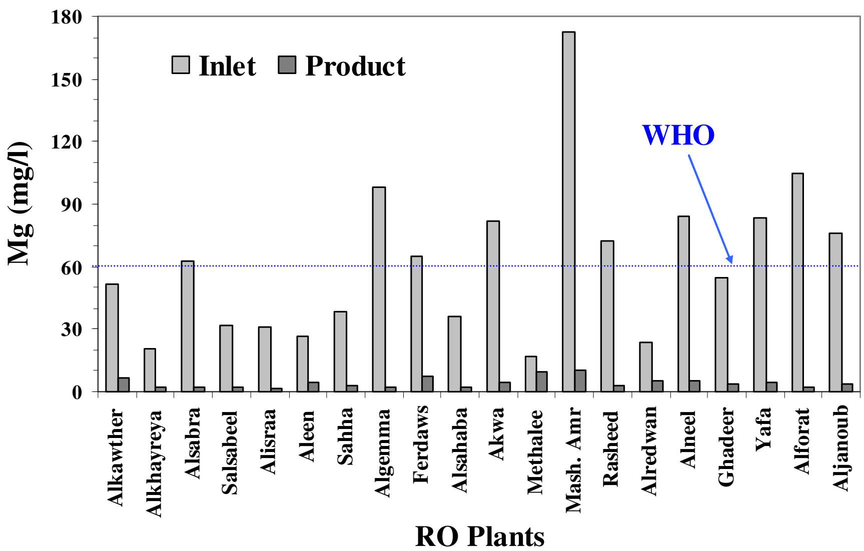

Figure 7: Magnesium concentration in inlet and product water samples

Total Hardness (TH)

The WHO states that the maximum allowable value of total hardness concentration for drinking water is 500 mg/l. The analytical data of inlet water samples show that 55% of the samples have TH concentration less than the recommendations of WHO standards and 45% of the samples higher than WHO standards. All product water samples have TH concentration accepted by WHO standards. The total hardness concentration in product water samples ranges from 16.4 mg/l to 76.9 mg/l (Figure 8).

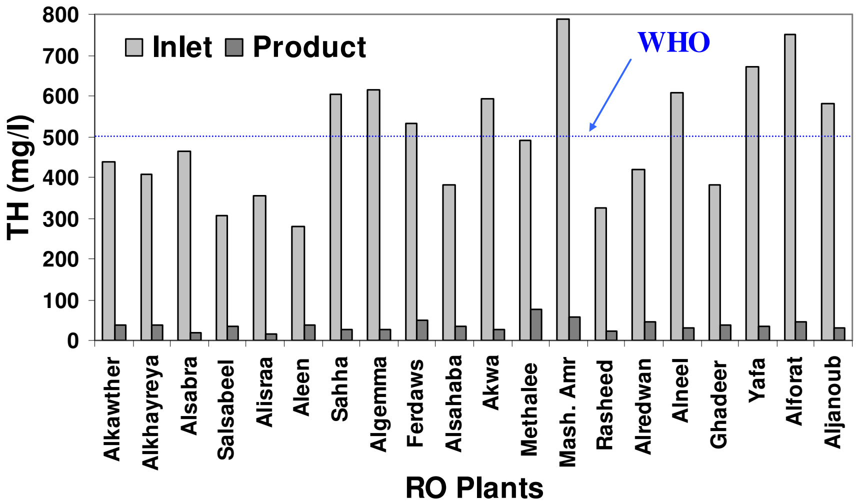

Figure 8: Total hardness concentration in inlet and product water samples

Sodium (Na^+)

The data analysis of inlet water samples show that 50% of the samples contain Sodium concentration less than the WHO recommendation standard (200 mg/l). The data analysis of the product samples show that 100% of the samples contain Sodium concentration less than 30 mg/l (Figure 9).

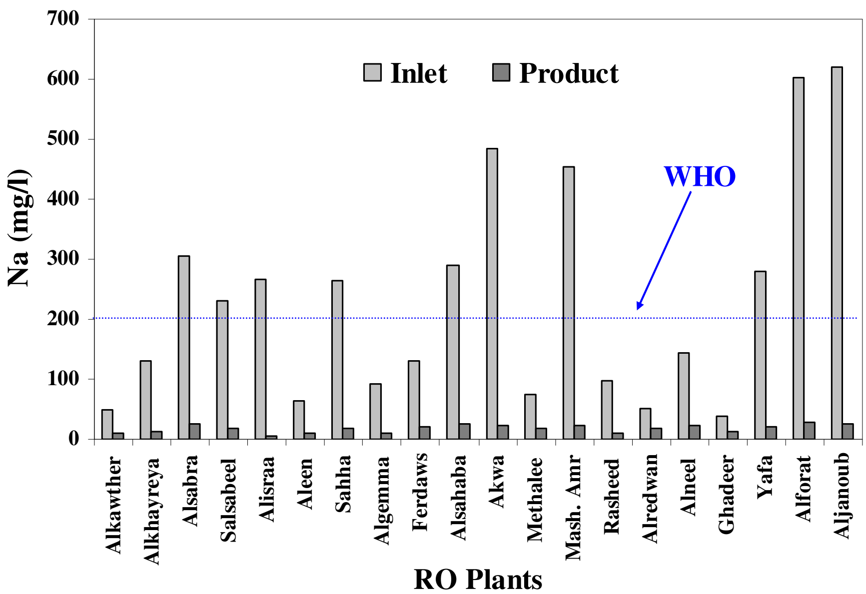

Figure 9: Sodium concentration in inlet and product water samples

Potassium (K^+)

Potassium concentration of 75% of the inlet water samples is under the WHO recommendation standard (5 mg/l). In the product water samples, 80% of the Potassium concentration of the water samples is less than 0.5 mg/l (Figure 10).

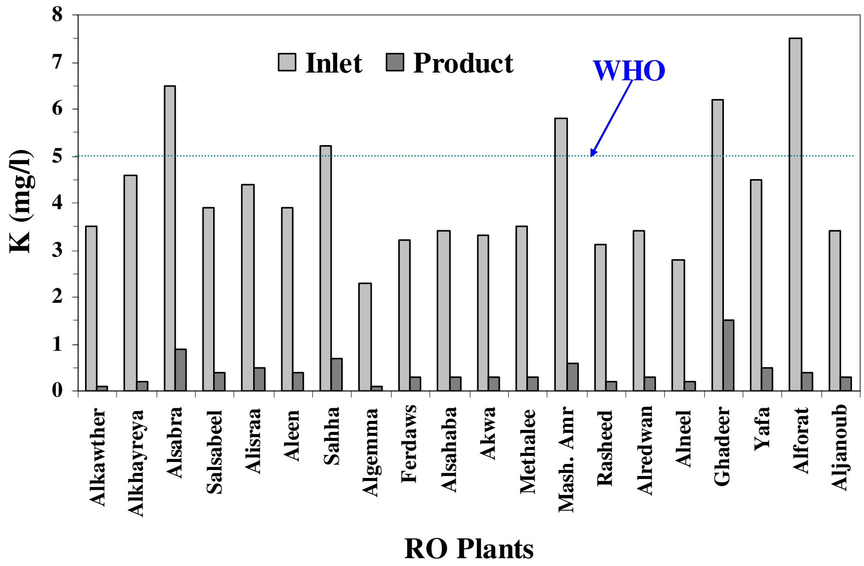

Figure 10: Potassium concentration in inlet and product water samples

Alkalinity (HCO_3^-)

The data analysis of inlet water samples show that 90% of the water samples contain Alkalinity concentration higher than the WHO recommendation standard (200 mg/l). The data analysis of the product water samples show that all of the samples contain Alkalinity concentration less than 50 mg/l (Figure 11).

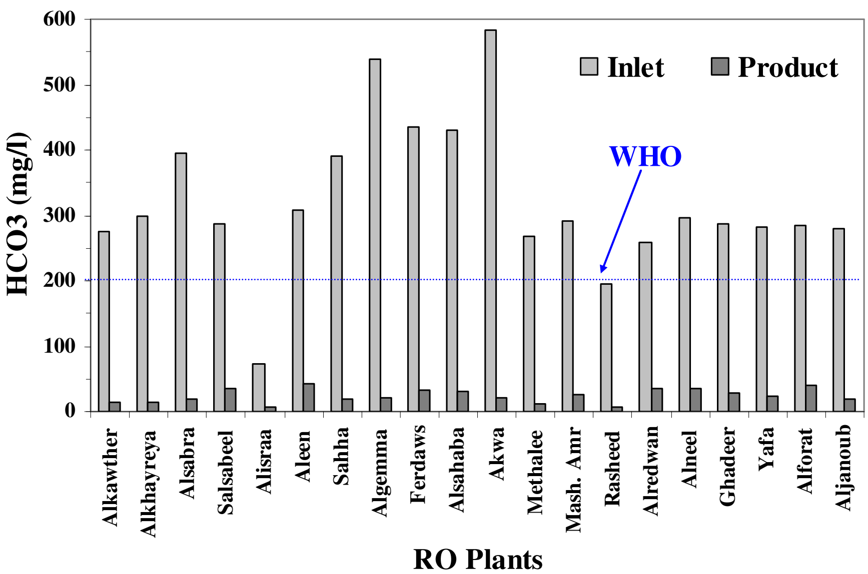

Figure 11: Alkalinity concentration in inlet and product water samples

Chloride (Cl^-)

The chloride concentration of 30% of the inlet water samples is under the WHO recommendation standard (250 mg/l) and 70% of the water samples have chloride concentration higher than the WHO standard. In the product water samples, the chloride concentration of all samples is less than 50 mg/l (Figure 12).

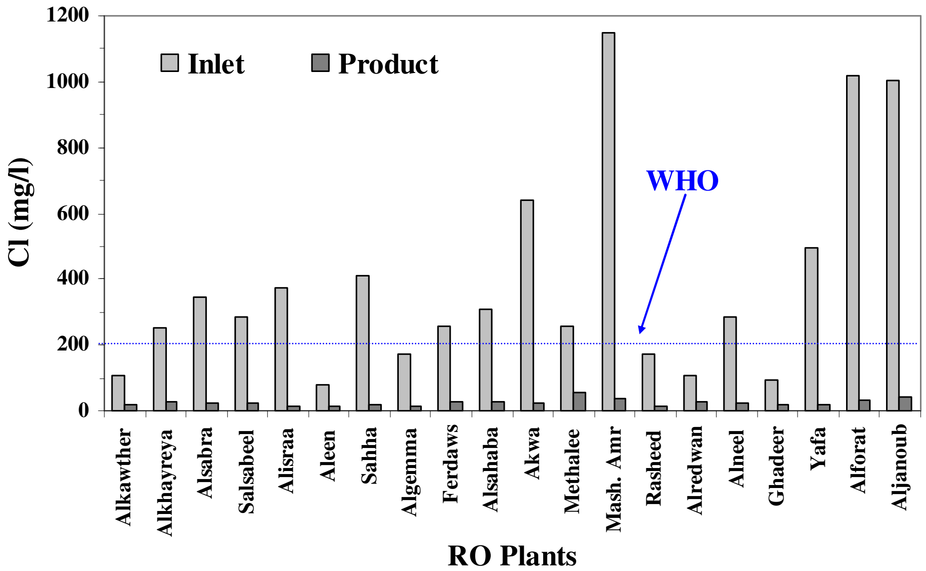

Figure 12: Chloride concentration in inlet and product water samples

Nitrate (NO_3^-)

The nitrate concentration in 15% of the inlet water samples is less than WHO recommendation standard (45mg/l) and 85% of the water samples have nitrate concentration higher than WHO standards. In the product water samples, the nitrate concentration of all samples is less than WHO standards (Figure 13).

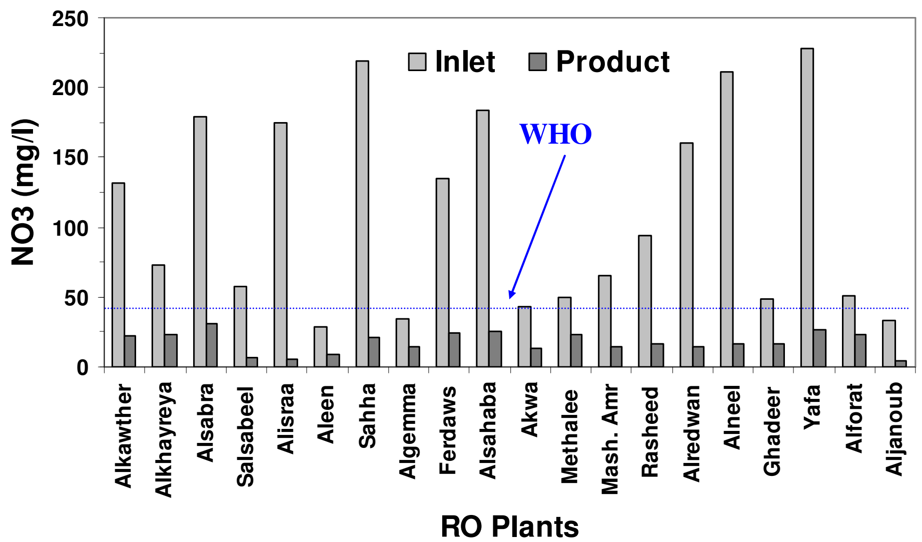

Figure 13: Nitrate concentration in inlet and product water samples

Sulfate (SO_4^{2-})

The analytical data of inlet water samples show that all of the samples have sulfate concentration less than the recommendations of WHO standards (250 mg/l), also the all product water samples have sulfate concentration accepted by WHO standards.

The chemical characteristics and the quality of water samples of the RO companies were evaluated to detect the changes in their properties according to WHO standard. Table 4 summarizes the results of evaluation of inlet and product water samples in RO desalination Plants in the Gaza Strip.

Table 4: Summary of evaluating inlet and product water samples

Parameters	WHO	Inlet water		Product water	
		suitable	unsuitable	suitable	unsuitable
pH	6.5 – 8.5	100%	0%	30%	70%
TDS (mg/l)	1000 mg/l	55%	45%	100%	0%
TH (mg/l)	500 mg/l	55%	45%	100%	0%
Mg^{2+} (mg/l)	60 mg/l	50%	50%	100%	0%
Ca^{2+} (mg/l)	100 mg/l	40%	60%	100%	0%
Na^+ (mg/l)	200 mg/l	50%	50%	100%	0%
K^+ (mg/l)	5 mg/l	75%	25%	100%	0%
HCO_3^- (mg/l)	200 mg/l	10%	90%	100%	0%
Cl^- (mg/l)	250 mg/l	30%	70%	100%	0%
NO_3^- (mg/l)	45 mg/l	15%	85%	100%	0%
SO_4^{2-} (mg/l)	250 mg/l	100%	0%	100%	0%

Bacteriological Analysis

The water samples were analyzed for total coliform and fecal coliform in duplicate samples. Total coliform and fecal coliform bacteria were enumerated by the membrane filter method using m-FC agar. 250 ml of the water sample was filtered through a sterile membrane filter 0.45 mm. Membrane filter were aseptically transferred into a surface dried sterile m-FC agar plate and then incubated at 35°C for 24 hour and 44°C for detection of fecal coliform bacteria. The water analyses indicate that 10% of inlet water samples were contaminated by total coliform and 5% of water samples were contaminated by fecal coliform. 25% of product water samples were contaminated by total coliform and 15% of water samples were contaminated by fecal coliform. Table 5 shows the contamination percentage of total coliform and fecal coliform in the inlet and product water samples.

Table 5: Contamination percentage of total coliform and fecal coliform in the inlet and product water samples

Parameter	Water source	Sample No.	Contamination %	Water source	Sample No.	Contamination %
Total Coliform	Inlet	20	10	Product	20	25
Fecal Coliform	Inlet	20	5	Product	20	15

Brine Water Management

The constituents of brine water discharged from desalination plants depend on the desalination technology used; the quality of the inlet water; the quality of water produced; and the pretreatment, cleaning, and RO membrane storage methods used. Disposal of brine is a primary environmental issue associated with deal with the unfavorable impact of its disposal, where there are very limited options of using brine on site or to discharge it into empty areas or the sea. New ways have to be found and implemented for environmentally friendly brine disposal. Figure 14 shows the brine water management of RO companies in the Gaza Strip.

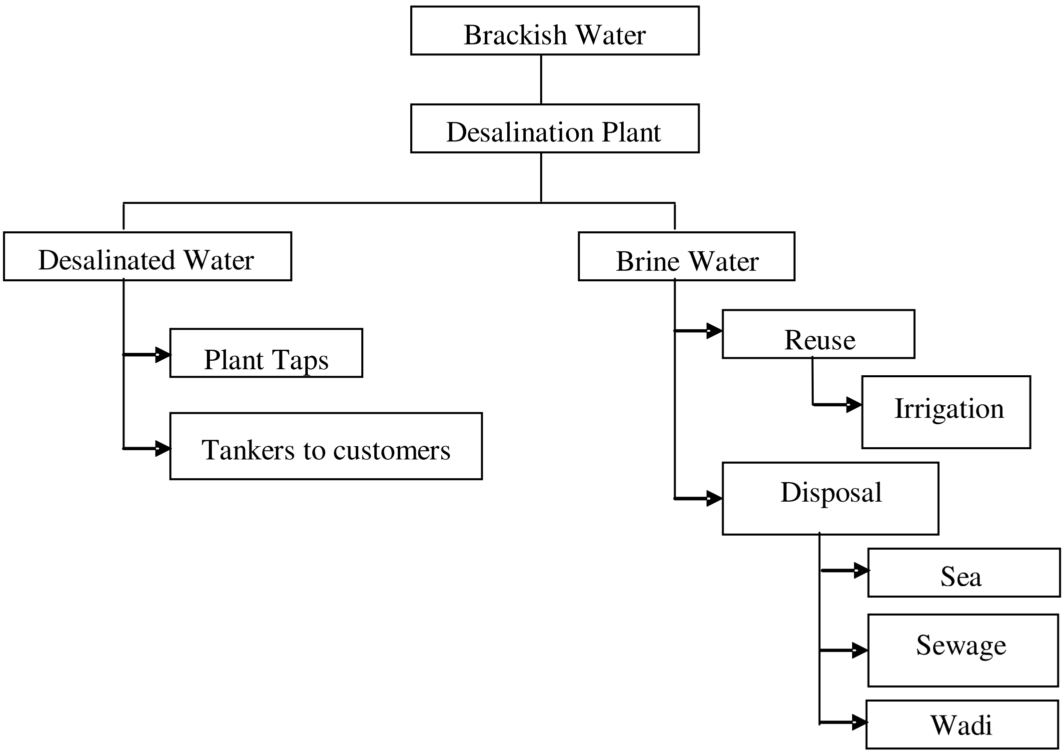

Figure14: Brine water management of RO companies in the Gaza Strip

CONCLUSIONS

Due to the bad quality of municipal water in the Gaza Strip, using of desalinated water increases by the costumers, small desalination plants become a more popular way to obtain potable water. Also, the growing demand for safe, clean water, combined with drought conditions and increasing populations, are driving the market for desalination plants (companies). This market is expanding to offer fresh opportunities to new and established market participants. The number of competitors in the market is expected to increase as the number and size of desalination plants grows. Desalination plants seem to offer a reasonable source of water supply for the area. Therefore, seawater and brackish water desalination plants are very important methods that could be used to address and overcome these problems in the Gaza Strip. The chemical analyses of RO produced water are within the allowable WHO limits. Bacteriological analyses indicate that 25% of produced water samples exceeded the maximum allowable value of the total coliform bacteria. The level of contamination in product water was higher than that in inlet water. The following can be concluded regarding water quality assessment of RO plants (companies):

- The RO desalination plants are preferable in the Gaza Strip to other known technologies.
- Small RO plants are good solution for water supply because of relatively low well capacities and simple maintenance.
- Several RO water samples from various RO plants proved to be in compliance with WHO standards for drinking water.
- Desalinated water can provide a partial solution for the water problems in the Gaza Strip.

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