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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 private Palestinian water investing companies established a small-scale reverse osmosis (RO) desalination plants to cover the shortage of 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 the World Health Organization (WHO) standards. It was concluded that all chemical analyses of RO produced water are within the allowable WHO limits. Bacteriological analyses indicate that 25% of the produced water samples exceeded the maximum allowable value of the total coliform bacteria.

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

1. 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 (Fig. 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 [1]. The population density in the Gaza Strip is considered as the highest in the world, with a population of 1.3 million people and a growth rate of 3.5% annually [2]. The Gaza Strip is located in an arid to semiarid region; all the rainfall occurs between October and April. The annual precipitation ranges from 230 mm in the south to 410 mm in the north [3]. The Gaza Strip Pleistocene granular aquifer is an extension of the Mediterranean seashore coastal aquifer. It 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 [4], having a hydraulic conductivity of about 10–8 m/s [5]. In the east-south part of the Gaza Strip, the coastal aquifer is relatively thin and there are no discernible sub aquifers [6]. The groundwater abstraction is around 145 Mm^3/y [7].

The population growth and socio-economic development mainly control water demand for the different uses. In the year 2005, it was estimated that approximately

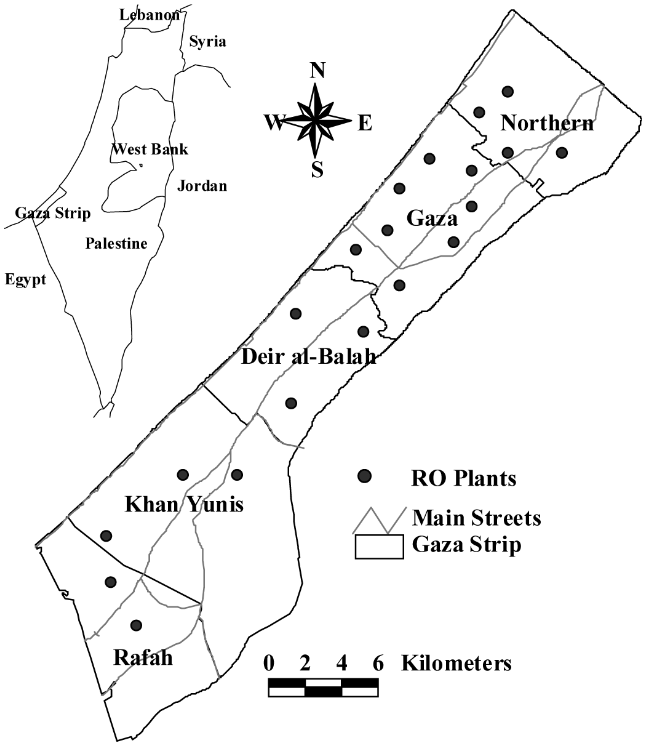

Fig. 1. A map of the Gaza Strip with geographic location of the RO plants.

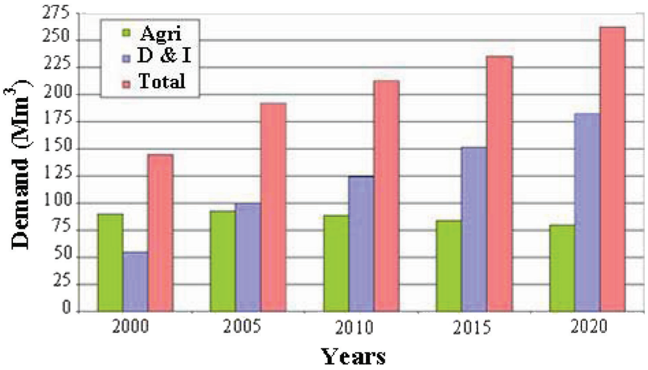

Fig. 2. Overall water demand in the Gaza Strip.

150 Mm^3/y of water was pumped from about 4100 wells, of which about 90 Mm^3/y of water was used for irrigation and 60 Mm^3/y were pumped for domestic and industrial (D&I) from 100 municipal wells [8]. The domestic and industrial demands present the quantity of water supply source that should be delivered to the domestic and industrial customers. It is clear that in the case of the Gaza Strip, the total domestic and industrial water needs will reach about 182 Mm^3 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 the demand for irrigation will increase from the present usage of about 90–185 Mm^3/y by 2020. However, this figure is not a realistic projection for the demand of the Gaza Strip, because neither the water nor the land does support an increase in the existing agricultural activities. Therefore, the estimated future demands for agriculture are based on the actual water amounts of today. Generally, the overall water demand in the Gaza Strip is estimated to increase from about 150 Mm^3/y in 2000 to about 260 Mm^3/y in 2020, as shown in Fig. 2. This includes domestic, industrial and agricultural demands [8].

The groundwater is the main water resource 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 [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.

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

A brief description of typical private RO plant used in Gaza Strip is shown in Fig. 3. Water is pumped from pumping well to the storage tank, then flows through a 5-micron cellulose filter. This filter is usually used as prefilters 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, 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^{2+} and Ca^{2+} with Na^+, and this process is called Ion Exchange, aiming at reducing the water hardness. Then, water flows to the activated carbon filter, which is made of cool, coconut, lignite and wood. In the next stage of the process,

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

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: [7]

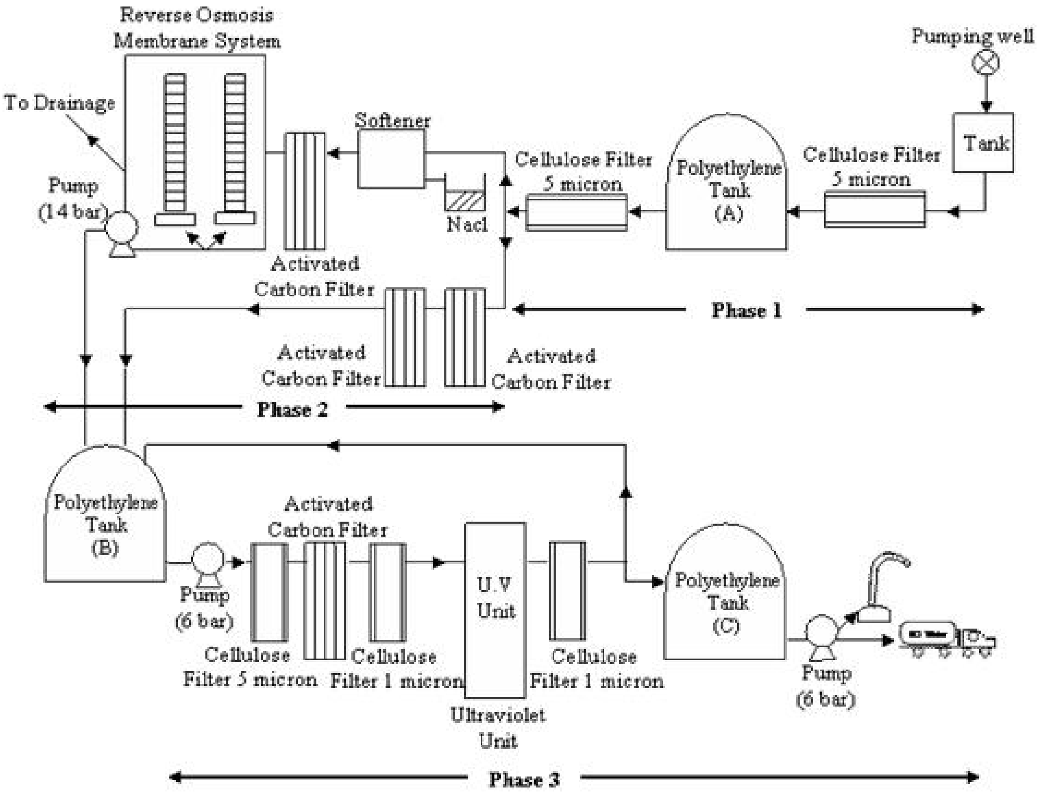

Fig. 3. Typical RO unit used in the Gaza Strip.

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 bar 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. Another membrane could be used to increase the amount of water in order to 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 two 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 is mixed with the second path in tank B. This mixture will increase TDS to give the water adequate taste. 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; few of the RO companies use UV light. Later, water flows to 1 micron cellulose filter. Finally, water is stored in tank C for domestic use.

2. Methodology

The water samples were collected on August 2008, from the inlet and product of 20 different RO plants (companies). Chemical analyses were performed for major ions content using standard methods [12]. Electrical conductivity and pH were measured directly in field using a portable instrument called Electrochemistry made by CIBA-CORNING. Chemical analyses have been done at the 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 0.01 N sulfuric acid is used and a turbidity method is employed for the sulfate analyses. 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.

3. 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 20–120 m^3/d, and brine water rejection ranges from 30 m^3/d to 210 m^3/d (Table 2). Recovery rate of the small RO unit operating in Gaza Strip depend on the manufacture of membrane. These units are imported from the US, Italy, Japan and Korea. 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.

3.1. Chemical analyses

3.1.1. pH

pH is controlled by the amount of dissolved carbon dioxide CO_2, carbonates CO_3^{2-} and bicarbonate HCO_3^- [13]. pH analytical data in the inlet (Raw) water samples show that 100% of the samples have pH under WHO standards

Table 2
Private RO desalination plants in the Gaza Strip

Plant name	Establishment year	Production of water (m^3/d)	Brine quantity (m^3/d)	Brine percentage	Disposal
Alkawther	1999	140	210	60	Irrigation
Alkhayreya	2002	34	50	60	Sewage
Alsabra	2001	34	40	54	Sewage
Salsabeel	2002	120	180	60	Sewage
Alisraa	2000	45	65	60	Sewage
Aleen	2001	40	60	60	Irrigation
Sahha	2001	30	46	60	Sewage
Algemma	2003	30	30	50	Sewage
Ferdaws	2003	100	100	50	Sewage
Alsahaba	2003	30	30	50	Sewage
Akwa	2000	120	120	50	Wadi Gaza
Methalee	2002	50	70	58	Irrigation
Mash. Amr	2001	40	60	60	Sewage
Rasheed	2002	30	40	57	Sewage
Alredwan	2000	60	70	54	Sewage
Alneel	2002	90	130	59	Sewage
Ghadeer	2003	32	48	60	Sewage
Yafa	2003	60	90	60	Sewage
Alforat	2000	57	85	60	Irrigation
Aljanoub	1998	110	140	56	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
	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
	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
	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
	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
	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
	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
	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
	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
	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
	Product	0.1	2.9	0.3	0.6	0.7	

(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 the WHO. So, after desalination, pH needs to be increased by adding NaOH. If this operation does not take place 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 (Fig. 4).

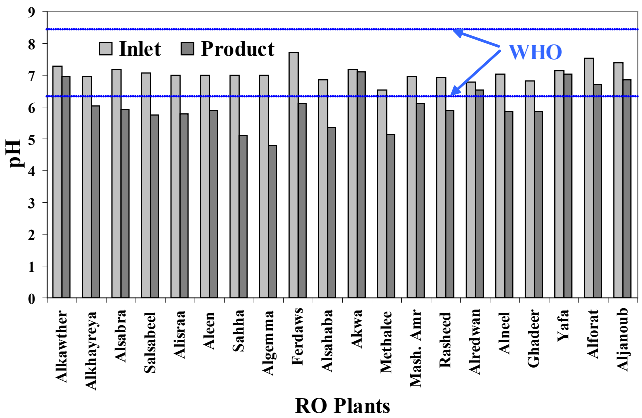

Fig. 4. pH concentration in inlet and product water samples.

3.1.2. 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 below the 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 (Fig. 5).

3.1.3. Calcium (Ca^{2+})

The analytical data of inlet water samples show that 40% of the samples have calcium concentration less than the recommendations of the WHO standards (100 mg/l) and 60% of the samples higher than the WHO standards. All product water samples have calcium concentration

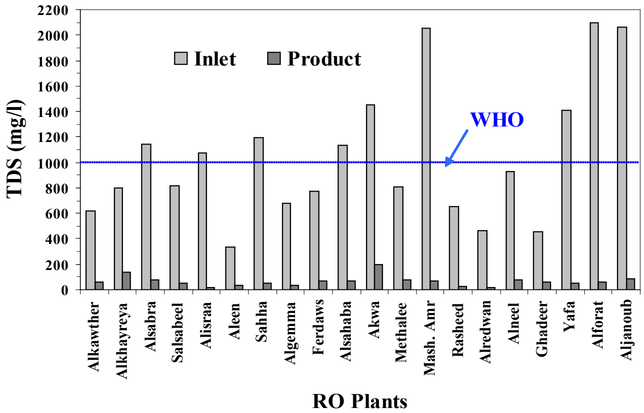

Fig. 5. TDS concentration in inlet and product water samples.

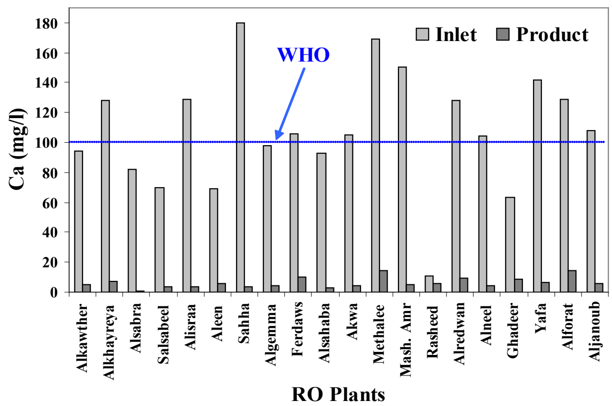

Fig. 6. Calcium concentration in inlet and product water samples.

accepted by the WHO standards. The calcium concentration in product water samples ranges from 0.6 mg/l to 14.5 mg/l (Fig. 6).

3.1.4. Magnesium (Mg^{2+})

Magnesium concentration of 50% of the inlet water samples is below 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 (Fig. 7).

3.1.5. 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 the WHO standards and 45% of the samples higher than the WHO standards. All product water samples have TH concentration accepted by the WHO standards. The total hardness concentration in product water samples ranges from 16.4 mg/l to 76.9 mg/l (Fig. 8).

3.1.6. 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 (Fig. 9).

3.1.7. 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 (Fig. 10).

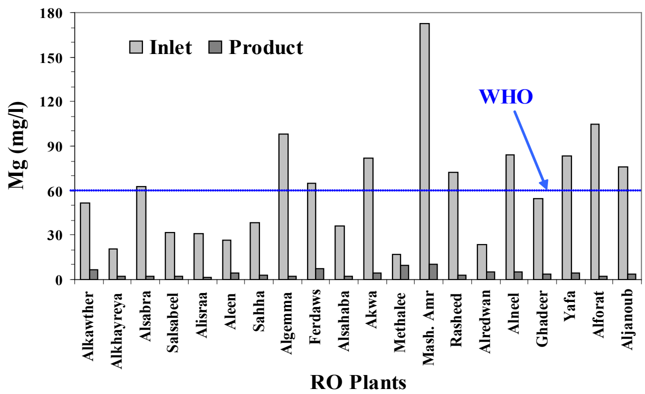

Fig. 7. Magnesium concentration in inlet and product water samples.

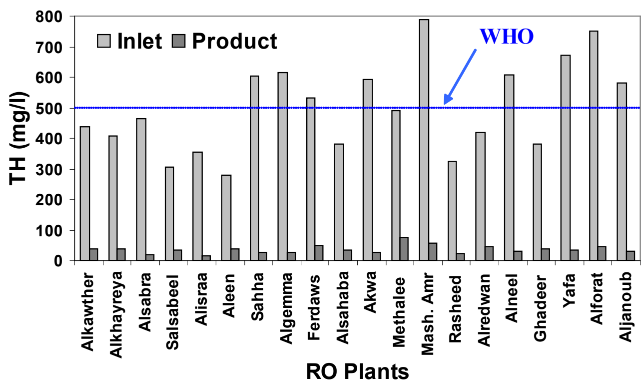

Fig. 8. Total hardness concentration in inlet and product water samples.

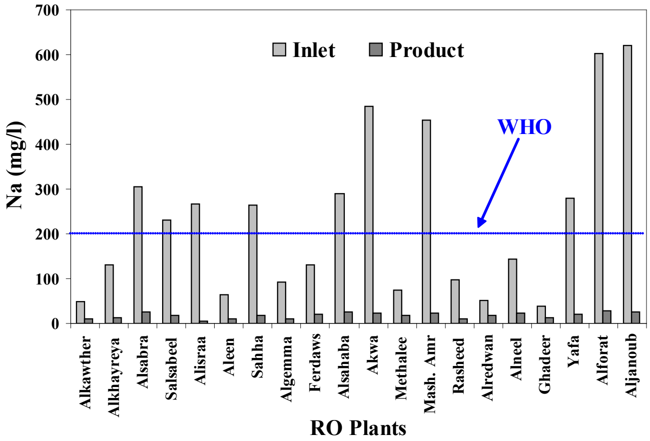

Fig. 9. Sodium concentration in inlet and product water samples.

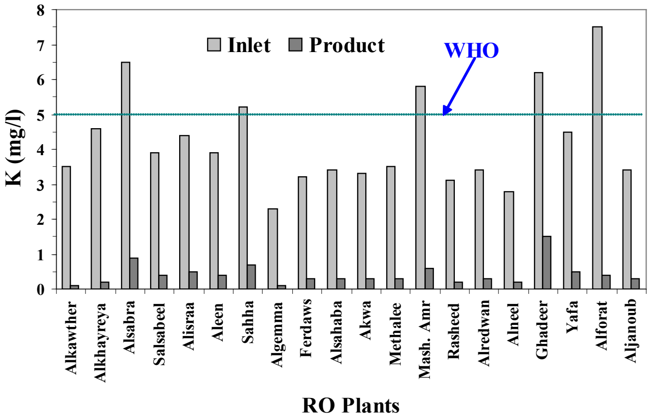

Fig. 10. Potassium concentration in inlet and product water samples.

3.1.8. 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 (Fig. 11).

3.1.9. Chloride (Cl^-)

The chloride concentration of 30% of the inlet water samples is below 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 (Fig. 12).

3.1.10. Nitrate (NO_3^-)

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

3.1.11. 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 the WHO standards (250 mg/l), also all the product water samples have sulfate concentration accepted by the WHO standards.

The chemical characteristics and the quality of water

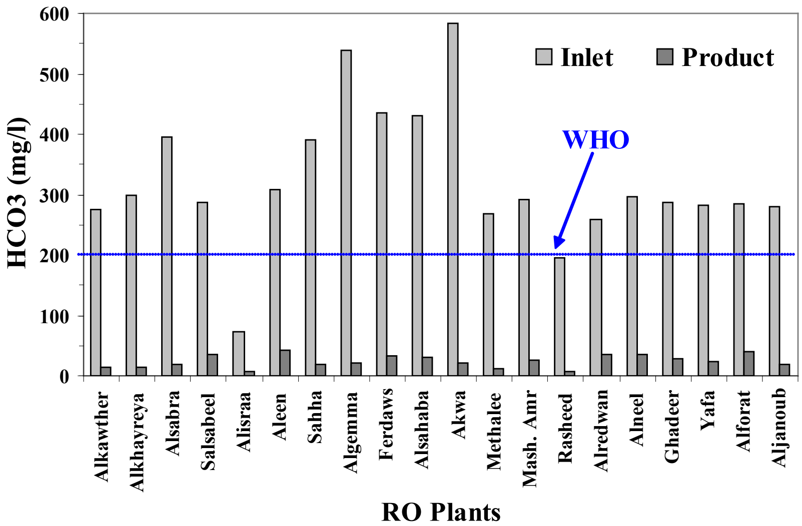

Fig. 11. Alkalinity concentration in inlet and product water samples.

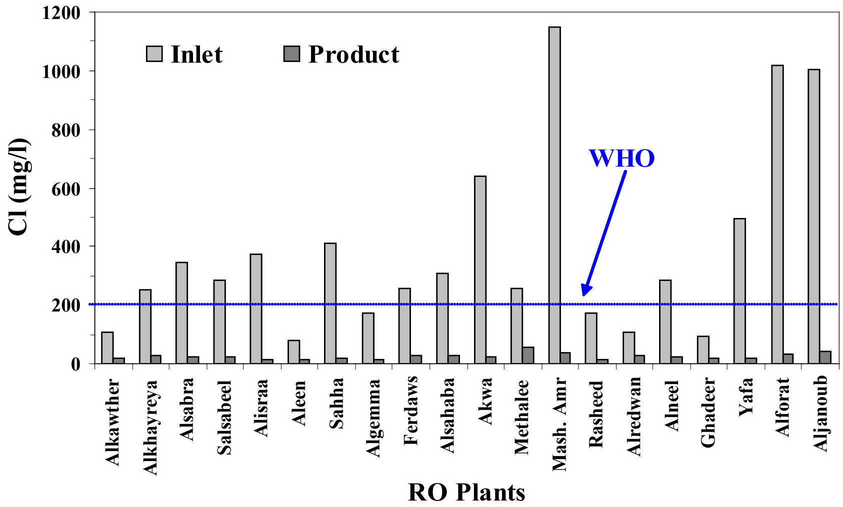

Fig. 12. Chloride concentration in inlet and product water samples.

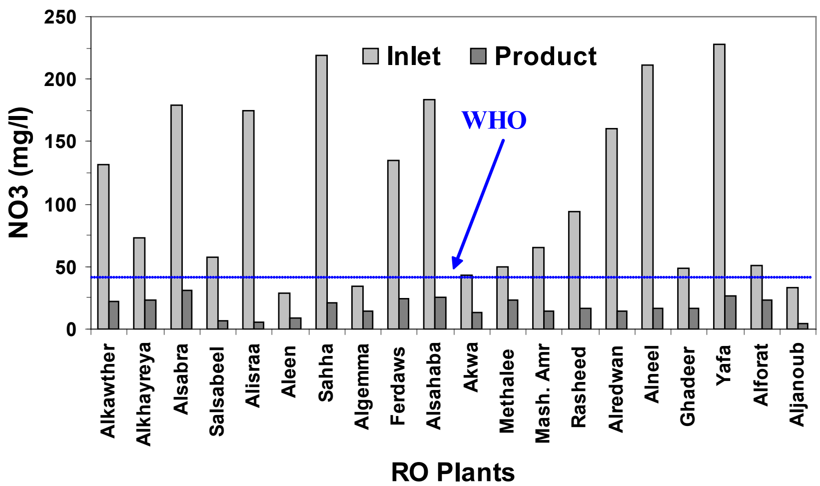

Fig. 13. Nitrate concentration in inlet and product water samples.

samples of the RO companies were evaluated to detect the changes in their properties according to the WHO standard. Table 4 summarizes the results of evaluation of inlet and product water samples in the RO desalination plants in the Gaza Strip. Desalinated water samples had 70% pH values below the WHO limit of 6.5. This is because carbon dioxide passes through the membranes and hydrogen carbonate is rejected. Since pH is governed by the logarithm of the ratio of hydrogen carbonate to carbon dioxide, the pH of the product water is always low [14]. While, the chemical parameters including chloride, calcium, magnesium, potassium, nitrate and sulfate, are within the allowable WHO standards.

3.1.12. 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 h for detection of total coliform bacteria and 44°C for detection of fecal coliform bacteria. The water analyses indicate that 10% of inlet water samples, with bacterial colony count of 19 and 23 in 250 ml, were contaminated by total coliform bacteria. Moreover, 5% of the water samples, with bacterial colony count of 14 in 250 ml, were contaminated by fecal coliform bacteria.

In addition, 25% of the product water samples, with bacterial colony count of 18, 21, 15, 12 and 14 in 250 ml, were contaminated by total coliform bacteria, and 15% of the water samples, with bacterial colony count of 9,

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	55	45	100	0
TH (mg/l)	500	55	45	100	0
Mg^{2+} (mg/l)	60	50	50	100	0
Ca^{2+} (mg/l)	100	40	60	100	0
Na^{+} (mg/l)	200	50	50	100	0
K^{+} (mg/l)	5	75	25	100	0
HCO_3^- (mg/l)	200	10	90	100	0
Cl^- (mg/l)	250	30	70	100	0
NO_3^- (mg/l)	45	15	85	100	0
SO_4^{2-} (mg/l)	250	100	0	100	0

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

8 and 5, were contaminated by fecal coliform bacteria. The level of bacterial contamination in the product water was higher than that in the inlet water, which may be attributed to the bad quality of filters that may play a significant role in the formation of bacterial biofilms inside the filters. Table 5 shows the contamination percentage of total coliform and fecal coliform bacteria in the inlet and product water samples.

3.1.13. 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, the pretreatment, cleaning and the RO membrane storage methods used. Disposal of brine is a primary environmental issue associated with dealing with the unfavorable impact of its disposal, where there are very limited options of using brine on site or to discharge it into open areas or in the sea. New methods need to be implemented for environmentally friendly brine disposal. Fig. 14 shows the brine water management of the RO companies in the Gaza Strip.

4. Conclusions

Due to the bad quality of municipal water in the Gaza Strip, usage of desalinated water increases by the costumers and, therefore, small desalination plants become a more popular way to obtain potable water. Moreover, the growing demand for safe, clean water, combined with drought conditions and increasing populations, are creating a market for the small-scale desalination plants companies. The number of competitors in the market is expected to increase as the number and size of desalination plants grow. 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 utilized to address and overcome these problems in the Gaza Strip. The chemical analyses of the RO produced water are within the allowable the WHO limits. Bacteriological analyses indicate that 25% of the 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 the RO plants companies:

- The desalination plants must be professionally operated according to global standards to protect the quality of desalinated water. This includes implementing necessary pre and post treatment of water, as needed, and maintenance of the desalination units.

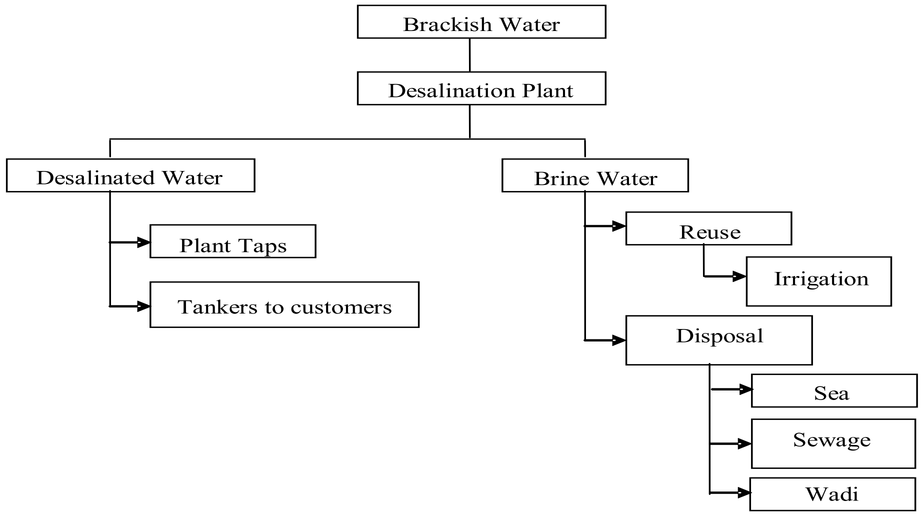

Fig. 14. Brine water management of RO companies in the Gaza Strip.

- Small scale RO plants form a good solution for water supply because of relatively low well capacities and simple maintenance.
- Desalinated water can provide a partial solution for the water problems in the Gaza Strip.

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