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Original Research Paper

Evaluation of Small and Large Scale Reverse Osmosis Desalination Plants Performance in the Gaza Strip During 2013

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ABSTRACT

Gaza Strip is mostly in a catastrophic situation that needs urgent and serious action to improve the water status on the conditions of both quality and quantity. The desalination of brackish and seawater is at present a global motivation that has concerned overall government and public awareness, not only in arid areas, but also in other regions of the world. Desalination offers the only rational option for meeting the rising demand of potable water for the people of Gaza Strip. This paper presents the assessment of small and large scale desalination plants in the Gaza Strip during 2013 in terms of feed and product water quality and desalination capacity to estimate the needed improvements and their performance status. The study was conducted to determine the level of water quality parameters, including pH, electrical conductivity, turbidity, total dissolved solids, hardness, calcium, magnesium, chloride and nitrate. The quality of feed water was found to be noncompliant with WHO and Palestinian Water Authority (PWA) guidelines in most cases except pH and turbidity and some dissimilar results in all plants in case of total hardness. On the other hand the quality of product water was found to be compliant with WHO and PWA guidelines for all plants except one case which found to be higher levels in nitrate concentration. The evaluation made in this study may be helpful for understanding the current status of the plants' performance and recommending the essential improvement required to enhance the performance of desalination plants in the Gaza Strip.

INTRODUCTION

The Gaza Strip is a small area that is highly populated and in which, the groundwater is the only water resource for drinking water. During the last decades, groundwater quality has been deteriorated and become unsuitable for human consumption (Aish 2010). Desalination is the most widely used technology to solve the problem of serious shortage of drinking water. Desalination is defined as a process that removes dissolved mineral deposits from feed-water sources such as brackish groundwater, seawater or industrial wastewater. It can also be known as the process that eliminates additional salts and non preferred minerals from the water. This will make the water healthy for human being consumption or industrial use (Betts 2004). The Palestinian Water Authority (PWA) has reported that the fresh groundwater decreased in the north and southern parts of Gaza Strip, which is characterized by freshwater that has chloride concentration less than 250 mg/L, where chloride concentration has been ranged between more than 2000 mg/L to about 8000 mg/L in some wells in the western of Gaza and Khanyounis governorates, this illustrated the effect of seawater intrusion in these areas (PWA 2013). The rising of nitrate levels in the Gaza Strip has presented a health risk, particularly for infants because the application of fertilizers and pesticides in agricultural areas which is the main source of nitrates and increasing the nitrate level in groundwater, in addition to wastewater discharge which causes a high pollution in the aquifer. PWA has reported that the nitrate concentrations in municipal wells range between 50 to more than 300 mg/L, where 21.5% of them have nitrate concentration less than 50 mg/L while 73.5% of these wells exceed the WHO nitrate standards (PWA 2013).

In the beginning of nineties, three reverse osmosis (RO) desalination plants were constructed in the Gaza Strip as brackish water desalination plants, one in Deir Al Balah and the other two in Khanyounis. The average production per plant is about 30 to 40m^3/hr. These plants were constructed to improve the water quality and to secure acceptable water for drinking purpose. By the time, efficiency of these desalination plants has been decreased due to the increase of the salinity of brackish water wells and lack of experience of local staff in the operation and maintenance of desalination plants. However, using of desalinated water as an alternative source for drinking purpose has been developed and increased as a type of investment projects of the private sectors to cover scarcity of good quality of clean water

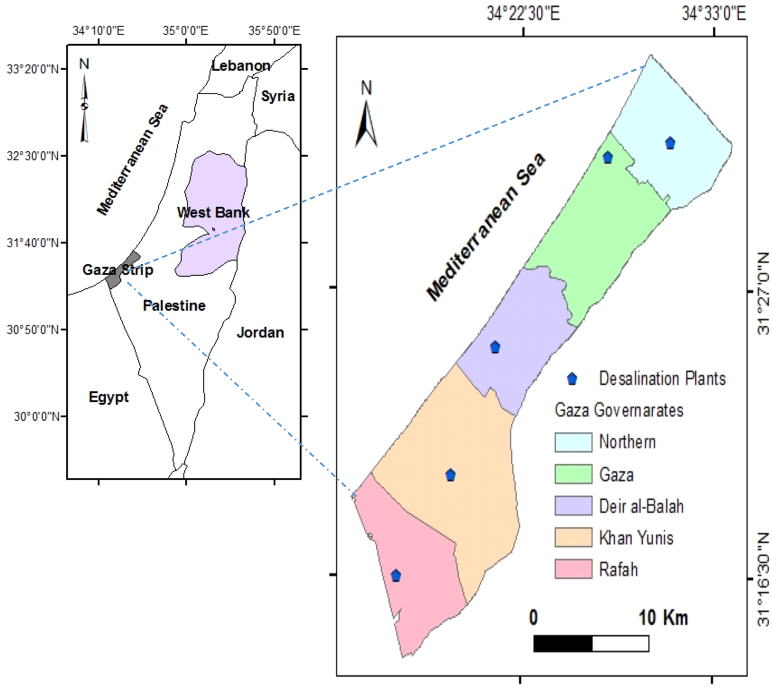

Fig. 1: Map showing the selected desalination plants.

in the whole of the Gaza Strip (Ismail 2003, Aish 2010). At present there are seven large scale RO desalination plants in the Gaza Strip owned and operated by the Palestinian Water Authority (PWA) and different municipalities (Baalousha 2006).

Aish (2010) in his study, investigated the chemical and bacteriological water quality of different small scale of reverse osmosis (RO) desalination business units in the Gaza Strip. The study results were compared with the World Health Organization (WHO) standards. It was concluded that all chemical analyses of RO produced water are within the allowable limits. Al-Khatib & Arafat (2009) had studied the physical and chemical quality of desalinated water, groundwater and rain-fed cisterns in the Gaza Strip. Their study revealed a clear superiority of quality for desalinated water, but also needs to adopt better practices, including maintenance and treatment process in the desalination plants. Hilles & Al-Najar (2011) had studied the chemical properties of the inlet and outlet of small scale desalination plants in the Gaza Strip. The results were compared with the WHO standards and they indicated that the TDS, Cl, NO_3 and Ca concentrations of product water in most of desalination plants is in the allowable ranges, whereas the results of feed water showed that the concentrations of TDS, Ca, Cl and NO_3 exceed the WHO standards in most of the wells. Aish (2013) studied the drinking water quality of private desalination plants, water tankers, distribution points located in stores along the streets, households storage units and from private wells. The results showed that the pH of most samples was below the WHO and Palestinian standards. The TDS, Cl, Ca, Mg, and nitrate levels were very low and found to be in the acceptable standards.

Desalination as nonconventional water resource, offers the only rational option for meeting the rising demand for drinkable water for the people in the Gaza Strip. Water desalination also may play a significant part for diminishing the adverse environmental impacts associated with lack of fresh water for at least drinking purposes and over concern from the coastal aquifer as well. This study, concerted on assessing the water quality of small and large scale desalination plants in the Gaza Strip to point out and recommend possible improvements necessary for the coming future. In addition, an evaluation is made for all selected plants to categorize the order of plants' performance to help in ranking the application of improvements.

MATERIALS AND METHODS

Study area: The Gaza Strip is a narrow strip of land on the eastern coast of the Mediterranean sea, situated in the middle east at latitudes (31°16' and 31°45'N) and longitudes (34°20' and 34°25'E) bordered by the Mediterranean sea in the west and the Negev desert and Egyptian Sinai headland in the south with a total area of 365 km^2 (Aish 2013). Most of the Gaza Strip topographical area is described as flat area gradually sloping with a range from 0 to 5%, westward towards the sea, allowing for surface runoff (Al-Talmas & Mogheir 2012). Five small and large scale desalination plants in the Gaza Strip were selected for this study. The water quality data were generated from the selected five plants from southern, middle area, Gaza city and northern area. They are named as, Al-Salam plant (Rafah), Al-Sharqia plant (Khanyounis), Al-Balad plant (Dier Al Balah), Hanneaf plant (Gaza) and Al-Radwan plant (Beit-Lahia). The selected desalination plants were visited several times during this study period and are shown in Fig. 1.

Collection, processing and analysis of water samples: A total of 120 samples were collected from the study area in the Gaza Strip and analysed for the evaluation purpose of water quality with respect to feed and permeate water, including: pH, total dissolved solids, turbidity, electrical conductivity, hardness, chloride, nitrate, magnesium and calcium. The samples of water were collected once every week for a period of six months from March to September 2013. All analyses were carried out in laboratories of the Palestinian Ministry of National Economy and Al-Azhar University. The collected water samples were analysed according to the standard methods (APHA 1998). The selected parameters for this study include: temperature, flowrate, pH, TDS, electrical conductivity (EC), chloride, hardness, nitrate, calcium and magnesium. The samples were collected from the feeding wells and desalination plants product water. Electrical conductivity and pH were measured directly in the field using a portable instrument called Electrochemistry made by CIBA-CORNING. The temperature was measured in degrees celsius (°C) using a digital thermometer. The total dissolved solids were measured by using the oven method. The permeate Rotameter was used to measure the flow rate of permeate water (m^3/h). The nitrate was determined by a cadmium reduction method, followed by spectrophotometric measurement at 540 nm wavelength. The calcium and magnesium were determined with EDTA, while titration with mercury nitrate used to determine chloride.

Statistical analysis: The water quality data are generated and being used to assess the water quality for understanding desalination plant performance in the Gaza Strip. The generated data were entered in Microsoft Excel sheets, uploaded to Statistical Package for Social Sciences (SPSS) and analyzed using minimum, maximum, mean, standard deviation (StDev) statistics. In addition the Pearson correlation coefficient (a measure of linear association) is used to study the relationship among the water quality parameters and paired *t* test was used to identify the significance variations among the assessed parameters with location/desalination plants in the Gaza Strip.

RESULTS AND DISCUSSION

Water quality parameters: A number of water quality parameters were analyzed for feed and permeate water of the five selected RO desalination plants. The parameters of feed and permeate including: pH, turbidity and nitrate concentration. These are important parameters disturbing water quality and they are most likely found to be major influences to be observed in Gaza groundwater besides salinity. Table 1 shows the water quality tested parameters compared with WHO and PWA guidelines.

The water temperature differed little by plant as indicated by the overall mean and standard deviation analysis. Temperature varied from 15.2 to 26.7ºC. Temperature exceeding the value of 26ºC was relatively rare and was observed during the summer season. Membrane productivity is very sensitive to changes in feed water temperature. As water temperature increases, water permeate flowrate increases almost linearly, due primarily to the higher diffusion rate of water through the membrane. Increased feed water temperature also results in lower salt rejection or higher salt passage. This is due to a higher diffusion rate for salt through the membrane (http://www.apextechnology.in/waterbook.htm).

Levels of pH are significant to be known and controlled as lower and higher values of pH may cause pipe corrosion and coating. Generally, the desalination medium is acidic, which is considered as a common trend for RO membranes applied for desalination (WHO 2003). All feed pH values were within the range of WHO and Palestinian standards with values ranging from 6.96 to 7.84 with an average value of 7.30 whereas the permeate pH values were below the WHO and PWA level of 6.5-8.5 which ranging from 5.12 to 6.87 with average value of 5.89. Generally, all reverse osmosis desalination plants medium tend to be acidic due to desalination process and elements removal, so after the desalination process occur, product water needs correction to the pH value by adding NaOH to the permeate water.

High levels of turbidity affect water taste negatively and indicate the presence of undesirable particles in the water. Principally, turbidity is a determining parameter for drinking water quality. Generally, some suspended matter or impurities such as clay, silt, sand, and other particles may cause water turbidity. The turbidity levels for both feed and permeate water of all plants are found to be below the WHO and PWA guidelines with values ranging from 0.11 to 1.02 NTU for feed water with an average of 0.29 NTU, whereas the values of permeate water are ranging from 0.08 to 0.39

NTU with an average of 0.16 NTU. The increasing pollution of public and individual drinking water wells by nitrate is mostly due to the extensive use of fertilizers and waste (Khademikia et al. 2013). The high levels of nitrate pollution, which are common occurrences in the Gaza Strip, are well thought-out as a health risk, as they are the reason of blue baby disease (Mogheir et al. 2013). The nitrate level concentrations ranged from 53.344 to 404.75 mg/L of all plants feed water with an average of 157.160 mg/L, that means that the concentrations are much higher than the allowable level by WHO and PWA guidelines. Whereas, the permeate water of most plants have lower and allowable concentration levels of nitrates by both WHO and PWA guidelines except for one plant in Khanyounis governorate.

Desalination capacity: Desalination plant capacity is substantially measured by salt elimination. Commonly, conductivity, TDS, hardness and the presence of ions like chloride, sodium, magnesium and calcium show how much the water is brackish.

Electrical conductivity levels are extremely high for feed water samples in all plants except one plant which has values ranging from 861 to 943 μS/cm, whereas, all values ranged from 861 to 6900 μS/cm with an average of 3857.47 μS/cm. It is clear that all feed readings were found to be higher than WHO and PWA guidelines except for Al-Radwan plant which had EC readings ranging from 861-943 μS/cm. Therefore, about 80% of feed samples are not complying with WHO and PWA drinking water standards. These relatively high EC readings of the feeds (2470-6900 μS/cm) were found to be significantly reduced in the product water of all plants (less than 1000 μS/cm) and fit with WHO and PWA. This indicates the high desalination efficiency and salt rejection of the RO membranes of these plants, however, the removal rate among the plants was found to be ranging between 85.81% and 97.88%. As all feed concentrations of all plants were found to be higher than WHO and PWA, however, concentrations of the permeate of all plants reasonably dropped to reach around 100 μS/cm or less for Al-Radwan and Hanneaf plants and 150 μS/cm or less for Al-Salam plant and 250 μS/cm or less at Deir Al Balah plant. Such concentrations comply with both WHO and PWA.

The high levels of TDS and chloride in the groundwater may cause high salinity in the water supply (Hilles & Al-Najar 2011). The desalination productivity is significantly measured by salt removal. From Table 2 it is clear that all feed readings of TDS found to be higher than WHO and PWA guidelines, except for Al-Radwan plant which had TDS concentrations ranging from 534-590.72 mg/L. Hence, about 80% of feed samples are not complying with WHO and Palestinian drinking water standards. These relatively high TDS values of the feeds (1531-6026 mg/L) are found to be extremely reduced in the produced water of all plants. This may show the high desalination efficiency and salt rejection of the RO membranes of the plants, as most of the high TDS measured in the plant feed is caused by the presence of salts at high concentrations. However, the removal rate among the plants was found to be ranging between 85.81 and 97.88%. As all feed concentrations of all plants were found to be higher than WHO and PWA guidelines, on the other hand, concentrations of the permeate of all plants reasonably dropped to reach around 100 mg/L or less for Al-Radwan, Hanneaf and Al-Salam plants, whereas 200 mg/L or less for Deir Al Balah plant and 500 mg/L or less at Al-Sharqia plant. All of these concentrations were found to be with the terms of both WHO and PWA. As indicated in Table 2 the highest and lowest TDS removal was for Hanneaf plant (97.88%) and Al-Sharqia plant (85.81%) respectively.

Water hardness is a key concern attendant with groundwater, as high levels of hardness adversely impact water quality (Bruggen et al. 2001). Hardness concentrations ranged from 260.83 mg/L to 1446.19 mg/L with an average value of 651.349 mg/L for feed water which indicates that some of these results complied with WHO and PWA guidelines, but in general most of the results found to have higher values of hardness as compared with WHO and PWA. However, the results of permeate water were found to be lower than acceptable levels of WHO and PWA, were ranged from 7.920 to 65.736 mg/L with an average of 14.22mg/L. As presented in Table 2 the feeds of Deir Al Balah and Hanneaf were found to have higher values of hardness as compared to WHO and PWA guidelines. On the other hand, feed waters of Al-Radwan, Al-Salam and Al-Sharqia plants were found to have lower hardness values. The permeate hardness of all plants was found to be lower and acceptable levels that meet with both WHO and PWA. In addition, hardness removal percentages were found to vary from 92% to 99%.

The presence of chloride is well known as one of the main causes for groundwater salinity in the Gaza Strip, taking into account that levels of chloride concentrations found in the Gaza groundwater are considerably higher than those permitted by WHO and PWA guidelines. Chloride values ranged from 121.494 to 1879.587 mg/L for feed water with an average value of 989.354 mg/L while the values of permeate ranged from 10.720 mg/L to 153.654 mg/L with an average value of 58.005 mg/L. As given in Table 2, about 80% of all investigated feed samples during this study were found to have high chloride concentrations, ranging from 649.58 mg/L to 1879.58 mg/L. The maximum chloride concentration was found in Al-Balad (Deir Al Balah) plant feed

Table 1: Water quality investigated parameters compared with WHO and PWA.

Parameters		Range		Average	St. Dev.	Removal %	WHO	PWA
		Min.	Max.					
Water temp (ºC)	Feed	15.20	26.70	23.85	1.53	-	-	-
	Permeate	21.80	26.70	24.37	0.99			
pH	Feed	6.96	7.84	7.30	0.27	19.22	6.5-8	6.5-8.5
	Permeate	5.12	6.87	5.897	0.41			
Turbidity (NTU)	Feed	0.11	1.02	0.29	0.15	81.25	5 NTU	4 NTU
	Permeate	0.08	0.39	0.16	0.05			
NO_3 (mg/L)	Feed	53.34	404.75	157.16	74.96	77.89	50 mg/L	70 mg/L
	Permeate	2.91	145.81	34.73	47.34			

Table 2: Desalination capacity of small and large scale plants in the Gaza Strip.

Parameters		Range		Mean	SD	Removal %	WHO	PWA
		Min.	Max.					
EC (μS/cm)	Feed	861	6900	3857.47	1774.18	94.35	2000	2000
	Permeate	16.07	693.00	217.79	193.57			
TDS (mg/L)	Feed	534	6026	2443.55	1146.76	94.47	1000	1000
	Permeate	10.00	430.00	135.02	119.99			
Hardness (mg/L)	Feed	260.83	1446.19	651.34	376.31	97.82	500	500
	Permeate	7.92	65.73	14.21	6.51			
Cl^- (mg/L)	Feed	121.49	1879.58	989.35	516.97	94.14	250	250
	Permeate	10.72	153.65	58.00	39.53			
Ca^{++} (mg/L)	Feed	39.89	384.82	138.49	99.35	98.16	100	100
	permeate	0.79	16.76	2.54	1.77			
Mg^{++} (mg/L)	Feed	5.62	187.23	76.94	52.23	97.48	60	100
	Permeate	0.47	5.78	1.94	0.84			

(more than 1800 mg/L) while the lower level of chloride concentration was found at Al-Radwan plant feed (121.49 mg/L-147.75 mg/L). The feed water of the other three plants was found to have chloride concentrations which range from 1058 to 1674 mg/L. The permeate water of all plants was found to have lower chloride concentrations than what is allowed by WHO and PWA. The removal percentage of chloride concentrations was found to be ranging between 86% and 97%.

Calcium is a very important element for human growth mainly for babies. About 20% of the suggested daily amount mostly comes from drinking water (Hills & Al-Najar 2011). Calcium ranged from 39.891 to 384.826 mg/L for feed water with an average of 138.490 mg/L. This means that the values of calcium concentration varied between plants and the average value is higher than the allowable in WHO and PWA guidelines. However, the permeate water ranged from 0.798 to 16.766 mg/L with an average of 2.546 mg/L which is lower than WHO and PWA. As presented in Table 2 the feed waters of Al-Balad (Deir Al Balah), Hanneaf (Gaza) and al-Radwan plants were found to have higher calcium concentration levels than WHO and PWA. While the feed water of Al-Salam and Al-Sharqia (Khanyounis) plants was found to be lower than WHO and PWA recommended levels.

Magnesium is the fourth supreme copious cation in the human-being bodies and the second greatest copious cation in intracellular runny liquid. It is a co-factor for about 350 cellular enzymes, some of which are intricate in driving metabolism. Furthermore, it is involved in protein and nucleic acid synthesis and is required for regular vascular tone and insulin sensitivity. Low magnesium extents are attendant with endothelial dysfunction, increased vascular reactions, raised circulating levels of C-reactive protein and decreased insulin sensitivity. Low magnesium status has been implicated in hypertension, coronary heart disease, type 2 diabetes mellitus and metabolic syndrome (WHO 2009). Magnesium levels in feed water ranged from 5.626 to 187.23 mg/L with an average of 76.949 mg/L, this means that the values of magnesium level varied between all plants and complied with Palestinian standards but didn't comply with WHO standards. However, the permeate water of all plants has lower and allowable concentration levels of magnesium, compared with both, WHO and PWA guidelines and was found to have values from 0.478 to 5.782mg/L with an average of 1.940 mg/L. From Table 2 it is clear that the con-

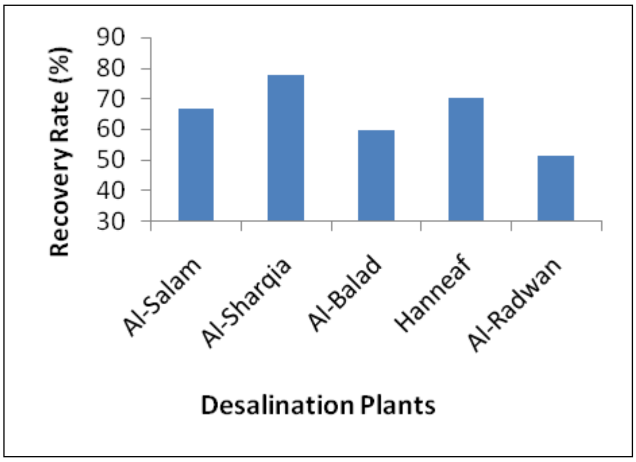

Fig. 2: Recovery rate of all plants.

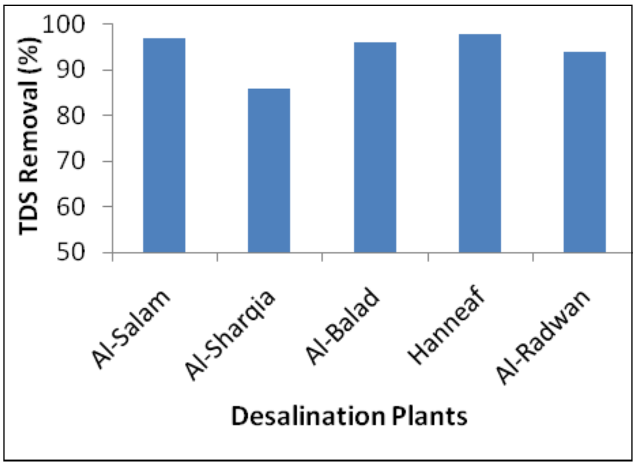

Fig. 3: TDS removal of all plants.

centration levels of Mg^+ in the feed water of Al-Salam, Al-Radwan and Al-Sharqia plants were found to have lower magnesium concentrations than what is allowed by WHO and PWA, while the feed water of Al-Balad (Deir Al Balah) plants was found to be above the permitted guidelines. In contrast, Hanneaf plant, which has higher levels than allowable in the WHO standards, was found to have lower than the allowable in PWA guideline. The permeate water of all plants, however, was found to have lower levels than what is permitted by both WHO and PWA. The magnesium removal percentage was found to be ranging from 94% to 98%. In terms of removal efficiency it is noticed that the high percentage removal was in calcium, hardness, magnesium, TDS, EC, and chloride respectively.

Spatial variation analysis: A major concern in managing water properties, is whether or not water quality variables have changed over time or place. The two-sample student's *t*-test (p-Value) is most likely the utmost commonly used statistical test for this purpose. The *t*-test is appropriate for unequal variances if the sample sizes are equal (Montgomery & Loftis 1987). The results indicated that there are high significant differences in the pH, TDS and EC for most of the measured values at all locations, but no significant differences were noted for water turbidity at some locations. These significant differences justify the performance of water quality monitoring parameters over the Gaza Strip desalination plants and prove that there is a real difference between the plants chosen for the water quality assessment purpose. Pearson correlation in pH, turbidity, EC and TDS among all plants is found to be weak. The results also showed significant differences for chloride, hardness, nitrate, calcium and magnesium. For chloride no significant difference is found at Al-Salam (Rafah) & Hanneaf (Gaza) and Al-Sharqia (Khanyounis) & Hanneaf plants in feed water samples. For hardness, no significant differences are found at Al-Sharqia & Al-Radwan, Al-Balad (Deir Al Balah) & Al-Radwan and Hanneaf & Al-Radwan for permeate water samples and Al-Balad (Deir Al Balah) & Hanneaf plants for feed water samples. No significant differences found at Al-Salam & Al-Radwan and Hanneaf & Al-Radwan plants in permeate water samples for nitrate measured values. In calcium measured values no significant differences were found to be at Al-Balad (Deir Al Balah) & Hanneaf, Al-Balad (Deir Al Balah) & Al-Radwan and Hanneaf & Al-Radwan plants for permeate water samples. In addition, results showed that there is no significant difference in magnesium measured values among Al-Salam & Al-Sharqia, Al-Salam & Al-Radwan, Al-Sharqia & Al-Balad (Deir Al Balah), Al-Sharqia & Hanneaf and Al-Sharqia & Al-Radwan plants for permeate water samples and also the results showed that no significant difference in feed water values among Al-Salam & Al-Sharqia and Al-Sharqia & Hanneaf plants. These significant differences justify the performance of the water quality monitoring tests and prove that there is a real difference between the chosen desalination plants in the Gaza Strip.

Evaluation of desalination plants: Reliable evaluation of all selected desalination plants was made based on recovery rates and TDS removal. The feed and permeate flowrate degree is differed by plant as observed from the overall mean and standard deviation analysis. Al-Salam plant was found to have the highest production rate of about 420 m^3/day at the highest flowrate (60 m^3/h) while Deir AlBalah plant was found to have nearly the same production rate (350-400 m^3/day) at a flowrate of 50 m^3/h. In terms of recovery rate, the best performing plant is Al-Sharqia plant with about 78% while the weakest performing plant is Al-Radwan with 52% recovery rate as shown in Fig. 2. As shown in Fig. 3 the highest and lowest TDS removal was for Al Salam plant-

Rafah (97%) and Al Sharqia plant (85%) respectively. The best performing plant is Al Salam plant and weakest preforming plant is Al Radwan desalination plant. Although the five plants have the same RO membrane type supplied by Koch, they have some slight differences in terms of performance.

CONCLUSION

An effort to assess and observe small and large scale desalination plants in the Gaza Strip in terms of feed and permeate quality and operating conditions was made. Operationally, all plants were found to have almost similar performance except for some slight differences in terms of removal efficiency in the nitrate parameter where noticed that important differences between the minimum value and the maximum value of the nitrate concentration in all plants with regards to permeate water. From a quality point of view, pH, turbidity and magnesium concentration levels for feed water of all plants were found to be within the WHO and PWA guidelines except magnesium concentration which is not in compliance within the WHO level (60 mg/L). Whereas, EC, TDS, hardness, chloride, nitrate and calcium concentration levels were found to be exceeding the maximum concentrations allowed by WHO and PWA recommended guidelines for all plants. However, the permeate water was found to be in compliance with the WHO and PWA except pH value which was lower than these guidelines.

Generally, all plants are performing normally except one plant in the southern governorates which has the lower efficiency in nitrate removal due to the lack of maintenance and outdated plant, but the need to improve and increase their productivity without increasing abstraction of water resources to meet the drinking water demand in the Gaza Strip people. Frequent cleaning of desalination plants and proper adjustment for pH value to comply with the WHO and PWA guidelines are recommended. It is essential to use pre-treatment technologies of feed water to improve plant performance and increase their water production. The TDS values of product water in some of the desalination plants were found to be in very low rate, indicating that the rate of minerals in the water is very small. Hence, it is recommended to mix the desalinated water with brackish water by certain proportions that meeting with the WHO and PWA drinking water quality guidelines. This is required for maintaining access to the healthy water and keeping the level of total dissolved solids within the range.

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