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ScienceDirect
Desalination 196 (2006) 1–12
DESALINATION
www.elsevier.com/locate/desal

Desalination status in the Gaza Strip and its environmental impact

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Received 15 June 2004; Accepted 13 December 2005

Abstract

Due to the sharp shortage of water and the bad quality of groundwater, desalination plants were set up in the Gaza Strip area in Palestine. Currently, there are six reverse osmosis desalination plants in the Gaza Strip owned and operated by the Palestinian Water Authority (PWA) and different municipalities. In addition, there are many small desalination units owned and operated by private investors for commercial purposes. Currently there is a plan for a regional seawater desalination plant with a capacity up to 150,000 m^3/y. According to the PWA plan, desalination seems to be the only viable alternative for water resources. However, large-scale desalination plants seem to be several years in the future. Meanwhile, studies on the environmental impact of desalination should be made in order to take the proper measures to protect the environment. So far, the currently operated plants have unfortunately not taken these measures. The effluent brines from these plants are not properly disposed of and the quality of desalinated water is not monitored. The impact of desalination on the environment was investigated, and possible measures to reduce this impact were introduced.

Keywords: Desalination; Environment; Water resources; Gaza Strip; Brines

1. Introduction

The Middle East countries are suffering from sharp shortage of water resources and increasing water demand due to the increase of population and exploitation of the available water resources. Since all the countries in the region are located in arid or semi-arid zones, the water resources in these countries are very limited. In the last few decades, attention was paid to finding new resources of water in the area. Because of the developing new desalination technology, existence of cheap energy sources such as oil and gas, there has been a rapid increase in the use of desalination of seawater and brackish water, especially in the Arabian Gulf area.

doi:10.1016/j.desal.2005.12.009

In the Gaza Strip area in Palestine, there is a large gap between water resources and demand, and the groundwater aquifer is deteriorated because of pollution, increasing demands and the Israeli control of Palestinian water resources. Since Gaza is very small with the highest population density in the world, urgent action should be taken to meet the increasing demand for water. Therefore, the Palestinian Water Authority (PWA) has planned to use seawater desalination as an alternative source of water supply.

The groundwater in the Gaza aquifer is almost brackish except for some fresh water in the form of shallow lenses. So, the amount of fresh groundwater is negligible and exists only in some locations in the Gaza Strip (i.e., Bait Lahya). Desalination of brackish and saline water seems to be promising, especially in the absence of any other alternatives in the Gaza Strip. However, using desalination technology as an alternative water supply implies many challenges such as energy cost and environmental aspects. On one hand, reliance on desalination as a source of water supply can solve the growing problem of water shortage in the area and overcome the problem of deterioration of water quality. On the other hand, pumping of brackish groundwater for the purpose of desalination can lead to encroachment of deeper saline water to the aquifer deteriorating the fresh groundwater layers above. An environmental impact can also result from the discharge of chemicals used in the desalination process. Certain plants, for example, may use biocides such as chlorine to clean pipes or to pretreat the water. These chemicals should be treated before being released. Besides chemicals used in the plant, the wastewater from desalination plants is another concern because the effluent is a heavily concentrated brine solution.

2. Study area

The Gaza Strip area is part of the Palestinian Autonomies Areas according to the Oslo agreement between the Palestinian Liberation Organisation (PLO) and the Israeli government signed in 1993. It is a very small area of about 365 km^2 located at the eastern coast of the Mediterranean, about 35 km long and between 6 to 12 km wide (Fig. 1) 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 area consists of a littoral zone, a strip of dunes from the Quaternary era situated on the top of a system of older Pleistocene beach ridge, and more to the east, gently sloping alluvial and loess plains. According to the Palestinian Central Bureau of Statistics, the Palestinian population in the Gaza Strip in 2004 was 1.406 million [14].

Fig. 1. Location map of the Gaza Strip.

3. Hydrogeology

The aquifer in the Gaza Strip is part of the coastal aquifer, which extends from Mt. Carmel

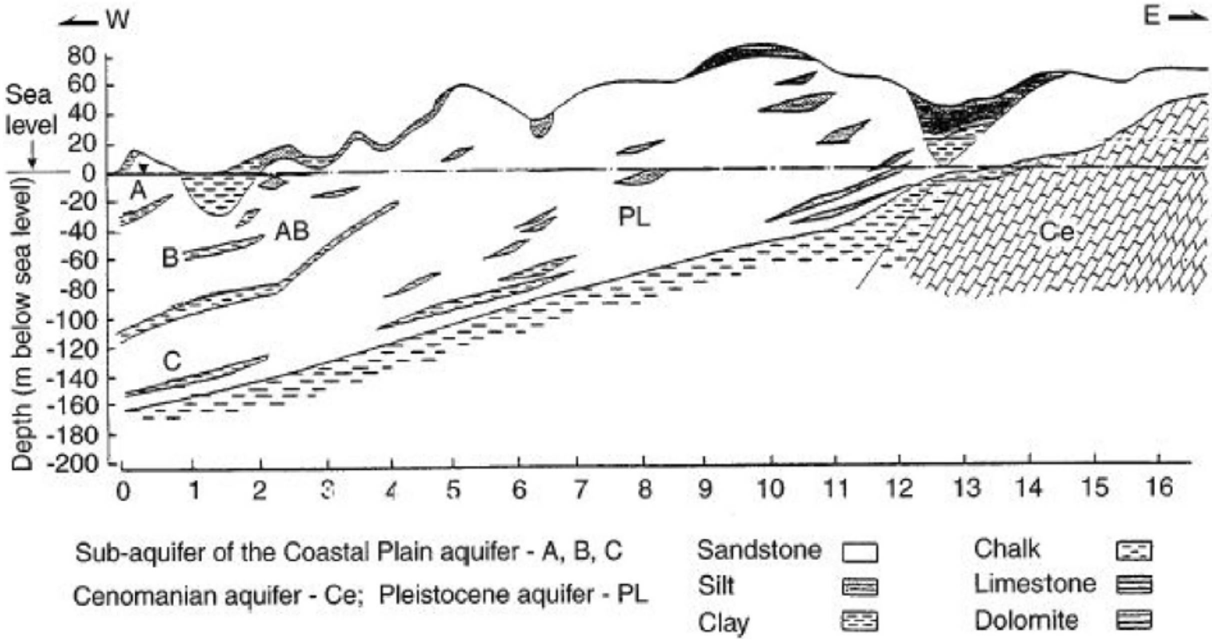

Fig. 2. Typical geological cross-section in the Gaza Strip.

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 [5]. The aquifer media are composed mainly of alluvial sandstone with gravel from the Tertiary era covered with Quaternary sand dunes. These dunes extend along the shoreline up to few kilometres inland. The depth of the aquifer varies from about 170 m at the shoreline to a few meters at the eastern boundary (Fig. 2).

There is a very thick impermeable clay layer underneath the aquifer, the Saqiya formation. This 400 to 1000 m layer forms the bed of the aquifer. Some clay layers of different thicknesses up to 20 m divide the aquifer into three main sub-aquifers (Fig. 2). These clay layers are generally aquiclude and extend from the shoreline to some 5 km inland. The aquifer can be considered as unconfined in the eastern part and confined/ unconfined in the western part. These sub-aquifers were classified into sub-aquifer A, which is at the top; sub-aquifer B; and sub-aquifer C beneath.

3.1. Water balance and projected demand

Rainfall is the main source of groundwater recharge as well as some other minor components that contribute to groundwater recharge. There are some sources of non-fresh water which contribute to aquifer recharge. These sources are the leakage of water and sewer systems, irrigation return flow, lateral inflow to the aquifer, and seawater intrusion. The water balance for the Gaza Strip in 2000 is shown in Table 1 [13].

According to PWA records, the average annual rainfall in the Gaza Strip amounts to about 320 mm based on a 20-year average. Many studies have been carried out to estimate the net groundwater recharge from precipitation [6,7,10, 16]. Based on these studies, it was found that the average annual net groundwater recharge from precipitation is about 43.29 million m^3 [2].

Table 1
Water balance in the Gaza Strip in 2000 (million m^3)

	Amount
Inflow:	
Recharge from rainfall	43
Lateral inflow	10
Irrigation return flow	20
Saltwater intrusion	11
Leakage of sewer system	12
Leakage of water system	13
Total	109
Outflow:	
Municipal abstraction	50
Agricultural abstraction	80
Natural groundwater discharge	11
Total	141

Although the total amount of annual inflow to the Gaza aquifer is about 109 million m^3 as explained in Table 1, only part of this amount can be considered as a safe yield (about 60 million m^3/y).

Based on PWA records, the domestic water demand for the year 2000 was 55 million m^3. This domestic demand is expected to increase to 182 million m^3 in the year 2020 [13]. Furthermore, the agricultural water demand was about 90 million m^3 in 2000. However, agricultural water demand is not expected to increase due to several reasons. Because of rapid growth of urbanisation, the agricultural land is expected to decrease dramatically. Also it is planned to change the crop pattern to reduce the water demand. Therefore, the projected agricultural water demand in the year 2020 is about 80 million m^3. Table 2 shows the current and projected water demand for the period from 2000 to 2020 according to the PWA [13].

As shown in Table 2, the annual deficit in water resources increases annually in addition to the continuous deterioration of the aquifer as a result of seawater intrusion and wastewater discharge. Annual input to the aquifer is expected to increase as a result of on-going desalination projects, in addition to artificial recharge. The annual safe yield of the coastal aquifer is not more than 60 million m^3 (Table 1). Thus, the water available in the aquifer covers only part of the needs, whereas the rest should be secured by other means. According to the PWA plan, the shortage will be eliminated through desalination of brackish water and seawater and through wastewater reuse.

3.2. Water quality

According to the PWA, about 60% of the total amount of groundwater in the Gaza Strip aquifer is of bad quality and not potable according to WHO standards [15]. As pumping increases, the aquifer becomes more deteriorated and more brackish, and saline water encroaches the aquifer. Concentration of chloride, for instance, has recently reached more than 1000 mg/l at many locations because of over-pumping. High chloride concentrations have been detected in Gaza City and the southern area. In Khan Yunis City, seawater intrusion has been detected [12] that leads to high chloride concentration.

Nitrate concentration (NO_3) has also been detected at a high level, up to 400 mg/l, especially in the Khan Yunis area. It is believed that the leached wastewater from septic tanks is responsible for this high level of nitrate. In the northern part of Gaza Strip (Bait Lahya) where the wastewater treatment plant is overloaded and wastewater has been flooded in a wide area around, a high concentration of nitrate up to 500 mg/l has been detected.

3.3. Alternative water resources

Given the miserable water status in the Gaza Strip in quality and quantity, looking for new sources of water supply is a must. Any new water source can alleviate the stress on the aquifer and contribute to improvement of water quality.

Table 2
Projection of water demand and water input in the Gaza Strip (million m^3) [13]

Year	Population	Agricultural demand	Domestic and industrial demand	Total demand	Input to the aquifer	Deficit
2000	1,167,359	91	55	146	109	37
2005	1,472,333	92	100	192	131	61
2010	1,871,144	88	125	213	137	76
2015	2,241,206	86	152	238	145	93
2020	2,617,823	80	182	262	155	107

Artificial recharge can increase the freshwater quantity of the aquifer if implemented. The average annual rainfall in the Gaza Strip is about 320 mm/y based on a 20-year average. However, more than 60% of rainfall is lost to evapotranspiration. The PWA has not yet implemented any project for artificial recharge in Gaza. However, this choice is under investigation and it can be a good alternative to overcome the water shortage problem and improve the water quality [15].

Since the agricultural activities consume more than 60% of the total water demand, using treated wastewater for irrigation can reduce depletion of groundwater significantly. Currently, the effluent of wastewater has not been used for agricultural purposes due to different reasons. Although Israel has been using treated wastewater for irrigation for a long time, the PWA has only recently planned to use recycled wastewater [13].

Desalination of seawater and brackish groundwater is the only alternative source of water supply. The first brackish water desalination plant was designed by Israelis in 1991 and has been used in Gaza (Dier Albalah) for municipal water supply. Many desalination plants have been set up and operated since then.

4. Current desalination situation in the Gaza Strip

Table 3 lists all the currently operated desalination plants in the Gaza Strip. The PWA constructed some other plants in cooperation with different municipalities in addition to dozens of small commercial desalination units. These plants are not yet in operation.

Fig. 3 shows a map of desalination plants in the Gaza Strip. The municipality of Dier Albalah operates the plant with a maximum capacity of 1872 m^3/d. This RO plant uses brackish groundwater as influent to product 1080 m^3/d desalinated water with a recovery rate of 75%.

There are two RO desalination plants located in Khan Yunis City: El-Sharqi, built in 1997, and Al-Saada, built in 1998. Both are owned and operated by the PWA and the Khan Yunis Municipality. The capacity of the El-Sharqi plant is 1200 m^3/d and the capacity of the Al-Saada plant is 1560 m^3/d [3].

In the Gaza industrial zone, a RO desalination plant was built in 1998. It uses brackish groundwater as influent and has a capacity of 1080 m^3/d. It is planned that the desalinated water from this plant will be used for industrial purposes in the area and partially for municipal use in the neighbourhood. However, due to the political situation, the work in this plant was banned [13].

There are also two plants that use seawater as influent. The first one is located in the northern part of the Gaza Strip directly at the beach and uses saline water from beach well as a feed. Productivity of this plant is 1200 m^3/d in the first phase and 5000 m^3/d in the final phase. This plant is not yet completed because of the political situation. The second RO desalination plant is located in the middle area of the Gaza Strip with a

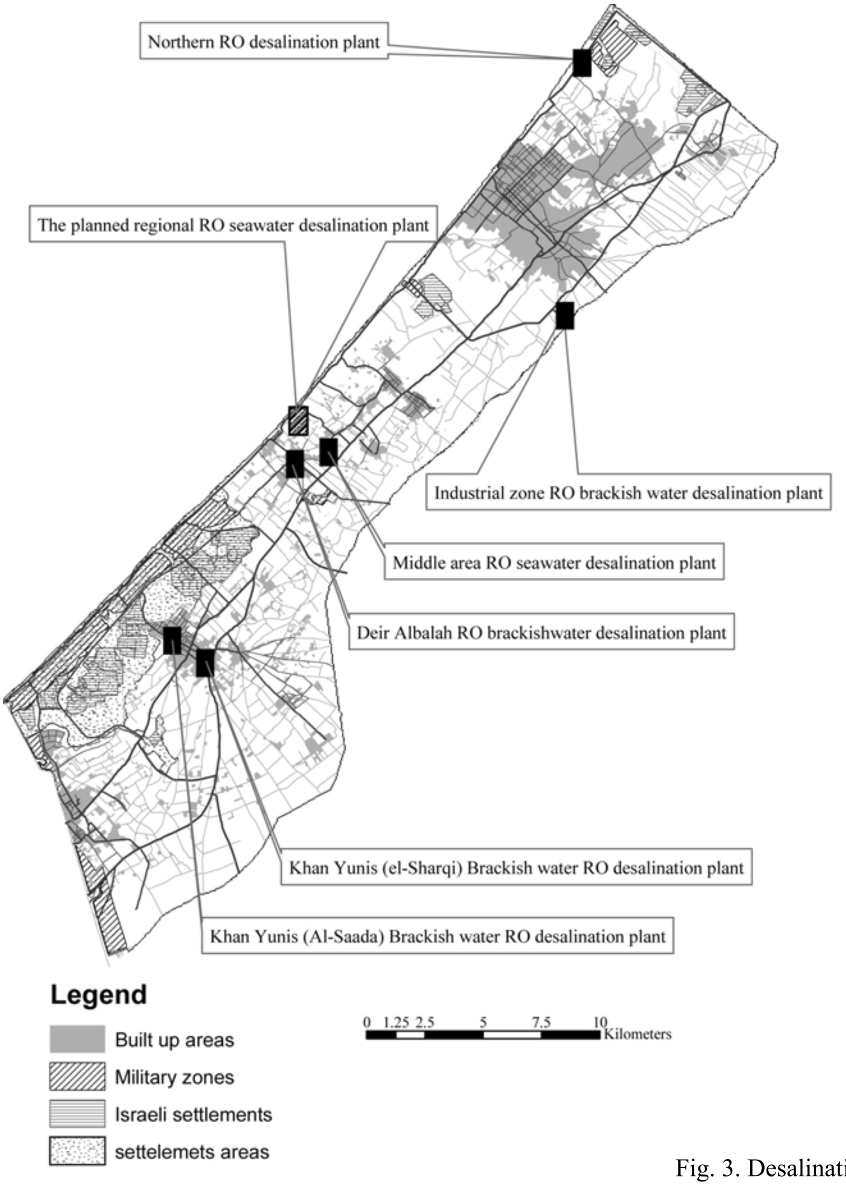

Fig. 3. Desalination plants in the Gaza Strip.

capacity of 600 m^3/d in the first phase, and 1200 m^3/d in the second phase. Influent of this plant is saline water from wells drilled directly at the beach. The latter plant has been operated while the northern one is not operated yet.

There is a plan for a regional desalination plant for the Gaza Strip with a capacity of 60,000 m^3/d in the first phase and 150,000 m^3/d in the second phase [4,11]. This plant will meet partially the increasing demand of water supply in the area for different purposes. Seawater will be used as a feed for this plant (direct intake).

Besides the desalination plants in Table 3, there are others owned and operated by the private sector under the control of the PWA and the Ministry of Health. All these plants use

Table 3
Desalination plants operated in the Gaza Strip (only 8 h/d) [3]

Plant	Owned and operated by	Capacity [m^3/h]	Productivity [m^3/h]	Feed	Usage
Dier Albalah, 1991	Dier Albalah Municipality & PWA	78	45	Brackish groundwater, Well No. J32	Municipal demands
Khan Yunis, Al Sharqi,1997	Khan Yunis Municipality and PWA	80	50	Brackish groundwater, Well No. L41	Municipal demands
Khan Yunis, Al Saada, 1998	Khan Yunis Municipality and PWA	70	50	Brackish groundwater, Well No. L87	Municipal demands
Gaza Industrial Zone, 1998	Gaza Municipality and PWA	75	45	Brackish groundwater	Industrial purposes (stopped)
Middle area plant	PWA	30	25	Seawater from beach wells	Municipal demand

RO technology to desalinate brackish groundwater and the treated water is sold. Nowadays, there are some 18 private desalination plants owned and operated by private investors. The capacity of these plants varies between 20 to 150 m^3/d [8]. These private plants produce a total of about 2000 m^3/d of desalinated water [3].

5. Impact of desalination plants

5.1. Energy consumption

Energy cost in desalination plants is about 30% to 50% of the total cost of the produced water based on the type of energy used. Fossil energy is the best type of energy for desalination from an economic point of view. To increase the efficiency of the desalination plant, it must be operated around the clock and never should be idle. Unfortunately, almost all the RO plants in Gaza are operating for only 8 h per day, and thus the energy consumption is not optimum.

Mixing different types of energy like heat and electricity can reduce the total cost of desalination. This process of mixing is called a hybrid process [1]. Hybrid desalination plants use both RO and distillation technologies to reduce energy needs. The distillation plant draws waste steam from a thermal power station and uses the energy in the steam to heat seawater which is then distilled. The RO plant uses electricity from the power station and operates during periods of reduced power demand. Thus mixing both systems leads to optimization of the overall efficiency of the entire operation. Therefore, the total cost of desalination can be reduced a lot by reducing the energy consumption which is about 50% of the total desalination cost.

Israel has provided energy for the Gaza Strip since it was occupied in 1967. 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). In 2003, the first stage of this station was completed with a power output of 30 kWh which is about 40% of the Gaza Strip needs. However, the cost of power produced locally in the Gaza plant is estimated at \$0.125 per kWh. This is almost double the price of the electricity purchased from the Israeli grid. That means, if the desalination plants are fully based on the Gaza power plant, the cost of the desalination process will be questionable. On the other hand, if the desalination plants are dependent on Israel, that would be a risky alternative since if Israel stops providing energy, these desalination plants could not operate. It is of great importance to look for independent sources of energy that might be as low as Israeli pricing. A good alternative can be the use of gas discovered in the sea of Gaza for energy of the power plant.

5.2. Land requirement

Since the area of the Gaza Strip is so small, and the population density is the highest in the world, the land cost is very high. Thus, the land issue should be investigated and assessed well if the desalination plant to be implemented directly at the beach or away from it. On one hand, locating the desalination plant directly at the beach is a good idea since no transport of saline water or brine effluent is needed. On the other hand, locating the desalination plant at the beach, which is used for recreation, is not a good option. Implementation of a desalination plant away from the shoreline requires a pipeline to transport the feed seawater to the plant which means using pumps with more energy requirement. Furthermore, construction of a pipeline to the sea will be needed to transport brine effluent to the sea. This indeed, increases the costs and implies the risk of pollution as a result of possible leakage.

For a large desalination plant with a capacity of 150,000 m^3/d, a significant land area will be needed. Large pumps required for RO, water pools, tanks, pipelines, and other facilities occupy a considerable area. This is an important factor in the case of the Gaza Strip and should not be ignored. As a result, careful investigations should be carried out to reduce the impact of plant location.

5.3. Environmental aspects

The use of RO desalination plants has the potential for adversely affecting the environment. Impact on the environment can result from the discharge of chemicals used in the desalination process. The membranes used in the RO process have a short life and the cost for replacement of these membranes can account for about half the cost of desalinating seawater. The following sections discuss the impact of desalination plants in the Gaza Strip on the environment.

5.3.1. Maintenance impact

Maintenance of RO desalination plants is so important and essential. The pre-treatment filter should be washed with filtered seawater every few days to avoid clogging and preserve efficiency. This washing process produces a sludge of coagulant chemicals. The produced sludge should be disposed properly either with brine or by transport to landfill. In addition, cleaning of membrane, which must be done every 3 to 6 months, produces hazardous materials. The cleaning process is usually done using diluted alkaline or acid aqueous solution. Sometimes, sodium bisulphate is used as a chemical preservation solution prior of any disposal. These chemicals should be treated to get rid of toxicity. Besides the environmental impact, there is another problem. The maintenance process needs trained people to do this task, and there is a doubt about that in the Gaza Strip. Lacking such experts might lead to rapid corruption of the membranes, and in turn, increase the desalination cost.

5.3.2. Marine impact

Effluent of desalination plant can highly affect the marine environment and destroy the life in the area. Although the brine contains materials that originated in the sea, its high specific weight and potentially harmful chemicals may harm the marine environment around the discharge point. In general, the effluent characteristics of desalination plants are:

- High salt concentration (about double of seawater). This may kill organisms in the vicinity of outfall. Besides, since brine might sink down due to its high density, this may cause severe damage of the marine environment beneath by prevention of mixing and lowering oxygen level. The proper solution would be by treatment of the effluent brine and mixing with other seawater prior discharging to the sea.

- Brine has a higher temperature and turbidity than that of seawater. Fish are usually very sensitive to any change in temperature. Therefore, this difference in temperature between the outflow and seawater might affect the migration pattern of fish along the coastline.
- Brine contains some chemicals from pretreatment like biocide, sulphur dioxide, coagulants, polymers, and in some cases may be combined with the waste stream containing chemicals from pretreatment, flushing, cleaning, etc.

Proper dilution of the brines should be done away from the shore, and the quality of the water in the area should be monitored periodically. In addition to the bad impact of desalination plants brine effluent, intake has also impact on the marine environment. This intake might affect different marine species because of impingement and entrainment. These processes might occur when the species hit the intake or when these species are taken to the plant and killed during the desalination process. Special care must be taken to prevent or to reduce such impact to the lowest possible level.

5.3.3. Groundwater contamination

Characteristics of effluent brine from desalination plants depend on the method of desalination. However, all desalination plants use chloride, which is hazardous to the environment, to clean the pipes in the pretreatment process. In general, salt concentration of brine effluent is almost double that of seawater (seawater has about 35,000 pm of salt concentration, while the brine has 46,000 to 80,000 ppm).

In the Gaza Strip desalination plants, the most widely used technology is RO. Accordingly, effluent of these plants contains some chemicals like anti-scaling, surfactants, ferric chloride, and acids, that may affect the environment if a proper dilution process not followed.

The effluents of brackish water desalination plants which are also used in the Gaza Strip have characteristics totally different from that of groundwater. It has more calcium and magnesium besides other components. In the Gaza Strip, the effluents of these plants are not properly disposed of. In all cases, the effluents are discharged in the nearby field, and thus, it might lead to contamination of groundwater and leachate deposition may denigrate soil productivity. This problem can be solved using evaporation ponds to separate the water of effluents from salt. However, it is not efficient to do so in the Gaza Strip because of land scarcity. Since the desalination plants are small and scattered in the entire area of Gaza, an economic solution would be the transport of the effluent to the sea using tanks. This way is not preferred from an environmental viewpoint since there might be leakage from these tanks. Another alternative could be by connecting the desalination outflow to a pipeline which ends in a post-treatment plant at the beach before getting rid of the brine.

Regulatory issue: In the absence of stability in the Gaza Strip, there are no regulations for desalinated water so there is no control of the quality of desalinated water and the environmental impact of desalination plants. As a result, the owners of commercial desalination plants do not monitor the quality of the produced water or environmental pollution. In addition, there is no public awareness of the poor quality of the water produced by these commercial plants. As such, the PWA, which is the regulatory authority, finds it extremely difficult to control the produced desalinated water and the environmental pollution. Therefore, the PWA should implement a strict monitoring scheme of these plants and should not issue any licence for them without considering environmental impact. Public awareness can be very helpful in this regard to illustrate the possible pollution of the produced desalination water.

Besides commercial desalination plants, use of small RO units at home is very common in the Gaza Strip. The water produced by these units is generally not controlled or tested. In the absence of public awareness, people are using these RO units for a very long time without changing the membrane. As a result, the consumed water from the home units is rather unhealthy and might cause different diseases due to bacteria and virus accumulations.

5.3.4. Upconing of brackish water and seawater intrusion

Freshwater in the Gaza Strip coastal aquifer exists in the form of lenses which lie on more dense brackish water. These freshwater lenses are recharged by infiltration of rainfall and other minor sources (e.g., leakage from water system, sewer system). Over-pumping of freshwater causes upconing of brackish and saline water beneath. Although the desalination projects use brackish water beneath the fresh lenses as a feed, this has an adverse impact on the environment. Withdrawal of brackish groundwater might contribute to imbalance in the groundwater system, which is already very fragile. Continuous pumping of these dense layers of brackish groundwater might lead to lowering of water table above. As shown in Fig. 4, the water table and transition zone between fresh and brackish/saline water will be changed. This change results in a drop in the water table level and thus, may lead to significant land subsidence with consequent damage to structures, drainage and irrigation. In addition, many wells in the area are shallow, and they will be dry because of lowering groundwater table. Also the agricultural activities will be adversely affected since the root zone might turn dry.

In coastal aquifers, like the case of the Gaza Strip aquifer, there is a saltwater boundary between the fresh groundwater and the seawater as shown in Fig. 4. The length of that boundary is highly dependent on the inflow and outflow of groundwater. In natural conditions, the length of the boundary is about tens to hundreds of meters. Extraction of groundwater causes an inland shift of this boundary, consequently affecting the freshwater–saline water balance. This balance is obviously disturbed in the Gaza Strip coastal aquifer. Given the high pumping rate, there is a strong evidence of seawater intrusion [12]. From desalination perspective, any groundwater discharge regardless to its quality, might lead to disturbance of the balance. If the locations of beach wells (which would be or have been drilled for desalination purposes) are not properly chosen, they would adversely affect the groundwater aquifer.

In other words, beach wells should be located in the saline water zone behind the boundary to prevent any extension of the boundary inland. Beside its hydrogeological impact, beach wells have another disadvantage. There is a big doubt about the possibility of water discharge in large amounts using beach wells. These wells cannot supply high amount of seawater due to hydrogeological reasons. Furthermore, clogging can take place in these wells. Therefore, it should be carefully investigated if beach wells to be used as a seawater feed.

5.3.5. Quality of desalinated water

Quality of desalinated water varies based on the desalination method. According to the WHO standards, potable water may contain different minerals up to a certain limit. In the Gaza commercial desalination plants, and in the absence of quality control, the desalinated water has negligible amounts of several minerals. It is reported that the produced water of these plants has less than 20 mg/l Ca, 10 mg/l Mg, 100 mg/l hardness

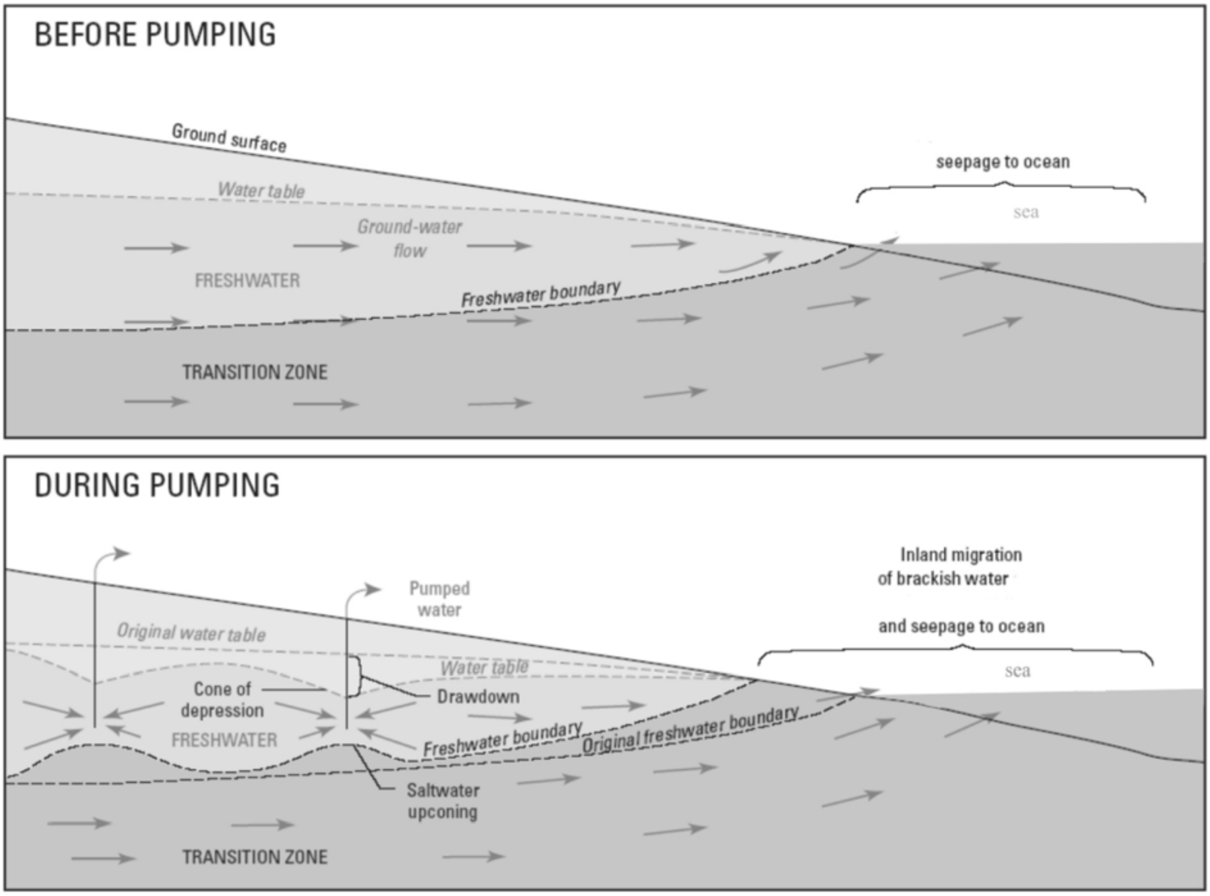

Fig. 4. Effect of groundwater discharge on the water table and seawater intrusion.

and 0 fluorides [9]. Therefore, the produced water contains no elements that are needed for human health.

Another important point in this context is the dissolved organic compounds that could exist in seawater. RO does not remove these dissolved compounds, and the produced water can be contaminated as a result. Therefore, a post-treatment process should be followed to remove these organic compounds. Since many of the desalination plants in the Gaza Strip were established for commercial purposes, and in absence of a proper quality control and proper experienced people, no post-treatment of desalinated water exists. As a result, the desalinated water might contain organic compounds harmful to health.

6. Conclusions and recommendations

Obviously, desalination of seawater and brackish water is a must in the Gaza Strip. Using desalination as a source of water supply has many advantages. It is less affected by natural disasters such as earthquakes that could cut off a region from its imported water supplies. Comparing with other desalination technology, it seems that RO is the best choice in terms of quality of produced water or the cost of treatment. However, the impact of these plants is not well investigated. Desalination has different effects including environmental, social, and economic. In the Gaza Strip, looking for new sources of energy to be used in desalination is very important to create an independent source of electricity.

Even though RO is a promising technology, it requires highly professional people to operate the desalination plants. Otherwise, the membranes will have to be replaced very often which is costly. Also a supply of chemicals required for desalination should be secured so as to ensure continuous operation of the plant.

The environmental issue should be studied well before implementing the regional desalination plant. The PWA should strictly control the private sector that builds desalination units for commercial purposes to ensure that they consider environmental aspects. Currently, the brine of these inland units is disposed in the field or in the street. These brines should be properly disposed of under the control of PWA. The quality of the produced water should be also monitored to ensure that it meets health requirements.

Another important issue is the pumping of brackish water from the aquifer. It is true that this water is not potable, but it is located in layers beneath the underground freshwater. Depletion of these layers of brackish water could lead to lowering of the water table and intrusion of seawater affecting the unsaturated zone. The effect of pumping this brackish water should be studied and investigated to prevent such damage to the aquifer.

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