Bridging the Domestic Water Demand Gap in Gaza Strip-Palestine

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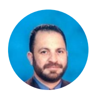

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Bridging the Domestic Water Demand Gap in Gaza Strip-Palestine

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Abstract: *The Gaza Strip is located on the extreme edge of the shallow coastal aquifer that borders the eastern Mediterranean Sea. There is little rainfall and no reliable riparian flow, hence water supply for Gaza residents is limited to that available from the part of the coastal aquifer. The exploitation of the coastal aquifer has resulted in continuous lowering of regional water levels and the worsening of water quality. The greatest threats to existing water supplies are seawater intrusions and up coning of deep brine fossil water. There are serious water quality problems in the Gaza Strip Aquifer. The population of the Gaza Strip will grow to over two million by 2020, and the demands for water will far exceed the sustainable capacity of the aquifer. Continuous urban and industrial growth will place additional stress on the aquifer system, unless appropriate integrated planning and management actions are instituted immediately. It is evident that drastic action must be taken quickly to support its people in the future. This paper presents overall guidelines for the management through year 2020, with associated investment requirements for infrastructure facilities to meet all goals and objectives. It has been estimated that a capital investment program of about US$1.5 billion is needed to finance the implementation of such plan. It has been concluded that seawater desalination as well as brackish water desalination are the main components of the domestic water management plan that will have overall beneficial impacts on the socio-economic aspects.*

Keywords: *water demand management, Gaza Strip, water resources management*.

Introduction

Water is the most precious and valuable natural resource in the Middle East in general and in Gaza Strip in particular. It is vital for socio-economic growth and environmental sustainability. Gaza Strip is in a particularly dire situation that requires immediate and concerted efforts to improve the water situation in terms of both quality and quantity. Demand greatly exceeds water supply. In addition, water quality is very poor and the aquifer is being over pumped. Very limited water supplied for domestic use is potable. About 70% of the total pumped water is used for agricultural purposes.

This paper presents an overview of the current water resources situation, as well as an account of the future water balance for the Gaza coastal aquifer. The problems outlined above are expected to grow and will need new resources to minimize the water deficit and to improve the groundwater quality. Producing additional water through desalination facilities becomes eminent.

Through various studies, which tackle the strategic planning for water resources, it is concluded that Gaza Strip will need to develop both seawater and brackish groundwater desalination to meet the demand up until the year 2020.

Water Resources

Gaza's water resources are essentially limited to that part of the coastal aquifer that underlies its 360 km^2 area (Figure 1). The coastal aquifer is the only aquifer in the Gaza Strip and is composed of Pleistocene marine sand and sandstone, intercalated with clayey layers. The maximum thickness of the different bearing horizons occurs in the northwest along the coast and decreases gradually toward the east and southeast along the eastern border of Gaza Strip to less that 10 m (Figure 2).

The base of the coastal aquifer system is formed of impervious clay shade rocks of Neogene age (Saqiyah formation) with a total thickness ranging between 500-1000 m. Depth to water level of the coastal aquifer varies between a few meters in the low land area along the shoreline and about 70m along the eastern border.

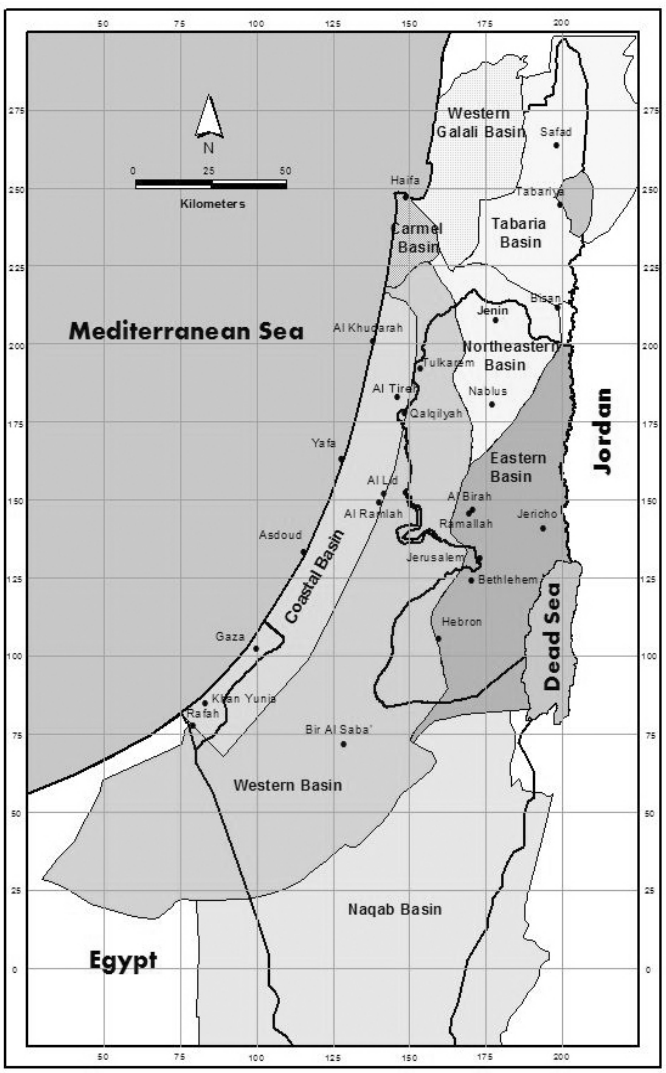


Figure 1. Location map of Gaza Strip

The coastal aquifer holds approximately 5x10^9 m^3 of groundwater of different quality. However, only 1.4x10^9 m^3 of this is "freshwater", with chloride content of less than 500 mg/l. This fresh groundwater typically occurs in the form of lenses that float on the top of the brackish and/or saline groundwater. That means that approximately 70% of the aquifer is brackish or saline water and only 30% is fresh water.

The major source of groundwater recharge to the aquifer is rainfall. Rainfall varies from one year to another (from 400 mm/y in the North to about 200 mm/y in the south). The total rainfall recharge to the aquifer is estimated to be approximately 45x10^6 m^3/y. The remaining rainwater evaporates or dissipates as run-off during the short periods of heavy rainstorms.

The lateral inflow to the aquifer is estimated at between 10-15x10^6 m^3/y. Some recharge is available from the major surface flow (Wadi Gaza). However, because of the extensive extraction from Wadi Gaza in Israel, this recharge is limited to, at its best, 1.5- 2x10^6 m^3 during the ten or fifty days that the Wadi actually flows in a normal year. As a result, the total freshwater recharge at present is limited to approximately 56.5-62x10^{6}m^3/y (PWA, 2000).

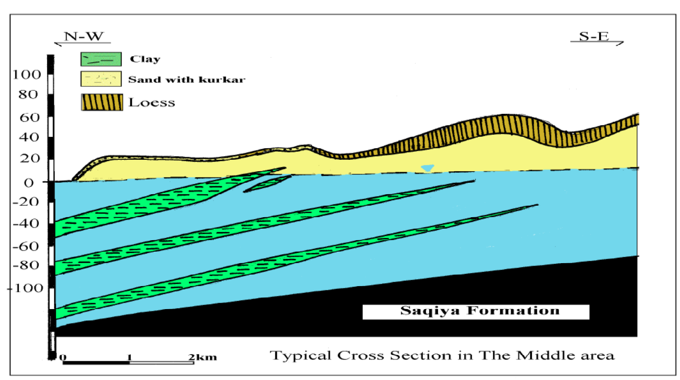


Figure 2. Typical hydrogeological cross section in the middle area of Gaza Strip

Water Balance

The water balance of the Gaza coastal aquifer has been developed based on an estimate of all water inputs and outputs to the aquifer system. The Gaza coastal aquifer is a dynamic system with continuously changing inflows and flows. The present net aquifer balance is negative; that is, there is a water deficit. Under defined average climatic conditions and total abstraction and return flows, the net deficit is about 40-50x10^6 m^3/y. Implications of the net deficit include:

- Lowering of water level (documented).
- Reduction in availability of fresh groundwater (documented).
- Seawater intrusion (documented), and potentially up-coning of deep brines (partly documented).

The net deficit has led to a lowering of the water table in the past 30-40 years and to the inland migration of seawater. Of these two factors, seawater intrusion accounts for a greater fraction of the volume loss, but it is less visible and thus tends to lessen the perception of the worsening aquifer evolution.

Demand Projections

Population growth and socio-economic development mainly determine water demand for the different uses (see following section for further detail). The annual population growth rate in Gaza was recorded at 5.9 and 6.8% between 1980 and 1996, by which time Gaza had a population of 963,000 inhabitants.

Based on PCBS (1997), Gaza population was recorded at 1,020,080. Using a conservative growth rate of about 3.5%, and assuming an influx of 50,000 returnees by 2010, the estimated population in 1999 was slightly over 1,100,000 and the forecast population for 2020 was 2,140,000. That means population is expected to double over the next 20 years.

In 2003, it was estimated that approximately 150x10^6 m^3/y of water was pumped from about 4100 wells. About 90x10^6 m^3/y of this water was used for irrigation and 60x$10^6$$m^3$/y was pumped for domestic and industrial uses from 100 municipal wells.

The World Health Organization (WHO) recommends an average of 100 liters per capita per day (l/c/d) as a minimum standard for individual water use. In 2003, it is estimated that 80 l/c/d were actually made available to consumers in the Gaza Strip. On the other end of the scale, only about 13 l/c/d meet WHO quality standards. As social development occurs, the demand for water will increase, as will the average WHO recommendation, which is expected to reach 150 l/c/d in future years.

These facts make it evident that the Gaza Coastal Aquifer is in extreme danger of becoming unusable for drinking water and irrigation. Exploitation of the aquifer has resulted in saltwater intrusion; as well, the continuous decline in groundwater levels has been observed in most of the areas of Gaza Strip since the mid-1970s. The ability of the aquifer to sustain life for the increasing population and a basic agriculture industry will be destroyed in twenty years if no action is taken.

Domestic and Industrial (D&I) Water Demand

The D&I demand includes net demand for domestic, industrial and public customers, as well as livestock water supply. Water losses through transmission pipelines and water distribution system are also included. Therefore, D&I demand represents the quantity of water at the water supply source that should be delivered to the D&I customers. It is clear that the total D&I water needs will reach to about 182x10^6 m^3/y by 2020 assuming an overall efficiency of 20% that includes both the level of leakage and uncounted for water.

Population growth, the increasing water needs of households and industry and the changing demands of agriculture will shape (D&I) water demand in the future.

Agricultural Water Demand

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 x10^6 m^3/y to 185x10^6 m^3/y by 2020. However, that figure is not a realistic projection for Gaza, because neither the water nor the land needed to support an increase in agricultural activity exists. Therefore, the estimated future demands for agriculture are, out of necessity, based on actual water amounts of today. Figure 3 illustrates the continuing trend in decreasing the agricultural water demand. This reflects the decreased use of both irrigated and rain fed agricultural land in Gaza.

This decrease is occurring as a result of the growth of urban areas, which expand onto agricultural land. This encourages farmers to bring what had been marginal land into production. It also means that farmers are turning to more intensive methods of agriculture, which require expensive inputs. In general, there is a trend to select crops that have lower water needs.

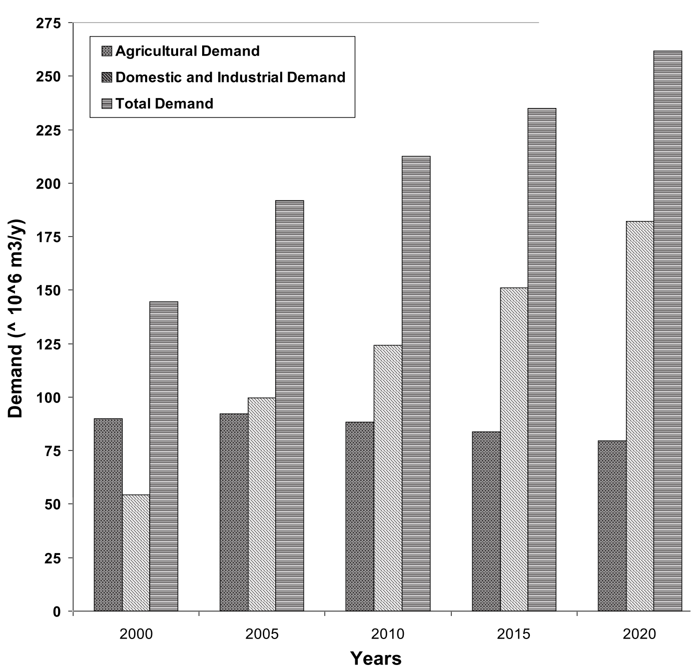


Figure 3. Overall water demand in Gaza Strip

Overall Water Demand

Generally, the overall water demand in Gaza Strip is estimated to increase from the present level of about 150x$10^6$$m^3$/y to about 260x$10^6$ m^3/y in 2020, as shown in Figure 3. This includes both D&I demand and agricultural demand (PWA, 2001).

Palestinian Water Resources Policy

Water resources must be developed and managed efficiently in order to meet present and future water needs in an environmentally sustainable way. Wastewater reclamation and reuse, desalination and storm water recharge together with renewable aquifer capacity will provide the quantity of water capable of satisfying Gaza Strip water demands for the next 20-years. However, comprehensive aquifer protection is also necessary to maintain its sustainable capacity. Certain strategies of water demand management and water quality management should be considered to support the maintenance of the aquifer at a sustainable level.

The Palestinian Water Authority (PWA) has considered three principal objectives for sustainable water resources management:

- Provide quantity and quality of water for domestic purpose in compliance with WHO standards.
- Supply adequate quality and sufficient quantity of water that is required for the planned agricultural production in Gaza Strip.
- Manage the Gaza Coastal Aquifer at its safe yield and prevent further deterioration of the aquifer

water quality.

The successful attainment of those principal objectives is based on the following fundamental promises:

- Reclamation of wastewater and maximum use of the reclaimed water for agriculture.
- Introduction of new water resource(s) into the Gaza Strip as soon as possible in order to meet the projected water demands.
- Improve pumped groundwater quality needed for domestic use by desalination facilities.

The implementation of these objectives will result in the maintenance of water balance and the prevention of further deterioration of the aquifer. In addition, clear and precise legislation and strict water sector implementation policies are necessary for successful implementation.

Groundwater Quality

The major documented water quality problems in the Gaza Strip are elevated salinity and nitrate concentrations in the aquifer. Chloride and nitrate concentrations in municipal wells in 1998/1999 are shown in Figures 4 and 5. The WHO drinking water standards for chloride (250 mg/L) and nitrate (50 mg/L) are exceeded in many areas.

Chloride (salinity)

Salinity in the Gaza coastal aquifer is most often described as the concentration of chloride in groundwater. Salinity affects both usability for irrigation and water supply. Intensive exploitation of groundwater in the Gaza Strip in the past 30-40 years has disturbed the natural equilibrium between fresh and saline water, and has resulted in increased salinity in most areas. Depending on location,rates of salinization may be gradual or sudden. In Gaza City/Jabalya, chloride values in several wells are increasing at rates up to 10 mg/L per year.

It is estimated from available data that less than 10 percent of the Gaza's aquifer resource contains groundwater that meets the WHO drinking water standard for chloride, which is 250 mg/L. This occurs primarily in the north and along the coastal dune sand areas of the southwest.

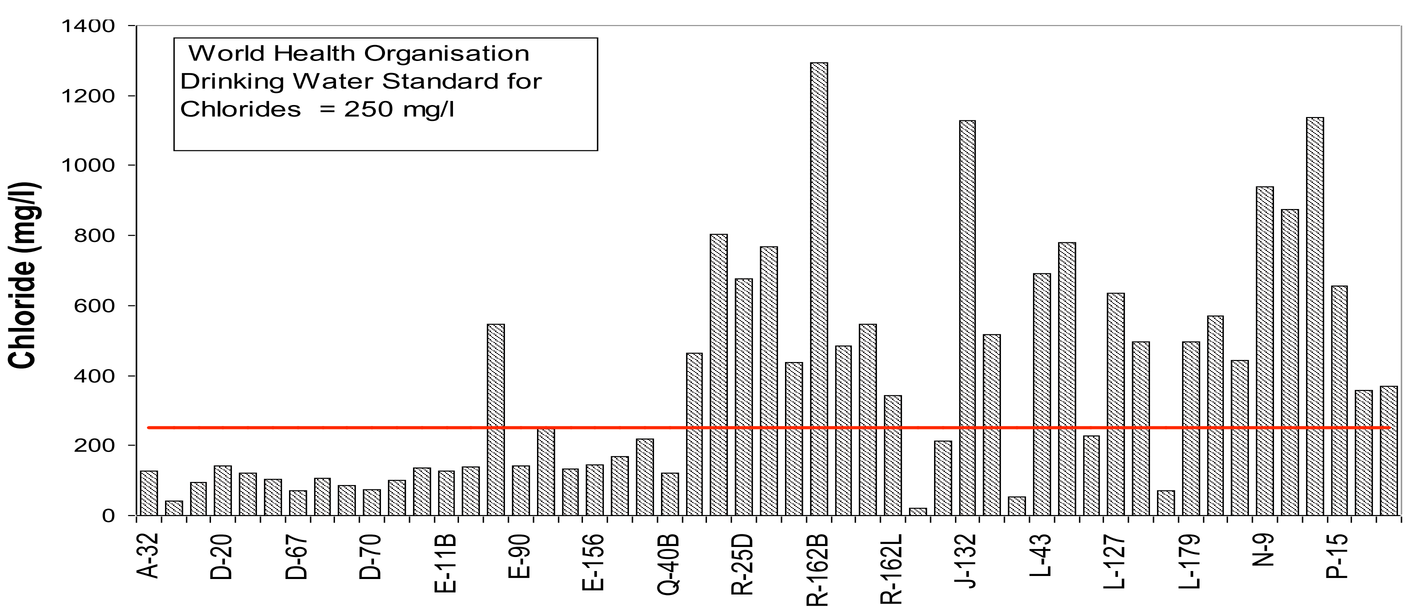


Figure 4. Chloride concentration of domestic municipal wells in Gaza Strip

Based upon existing data, sources of chloride that can be documented within the Gaza Strip include (Vengosh and Ben-Zvi, 1994; Vengosh and Rosenthal, 1994; Vengosh et al, 1999; Vengosh et al, 2005; Ghabayena et al, 2006):

- Seawater intrusion. Several shallow agricultural and municipal wells, primarily in coastal areas, have been abandoned in the past 10 years due to "breakthrough" of seawater.
- Lateral inflow of brackish water from Israel in the middle and southern areas of the Gaza Strip. The source is believed to be groundwater from the Eocene age rocks that underlie the coastal aquifer in the east, and is therefore of a natural origin.
- Presence of deep brines at the base of the coastal aquifer. Brines with chloride concentrations of 40,000 to 60,000 mg/L have been detected in a sub-aquifer between Rafah and the Netzarim.

Using geochemical data, Vengosh et al (2005) proved that most of the salinization process in the Gaza Strip is the result of the lateral flow of the Na-rich saline groundwater, superimposed with seawater intrusion and anthropogenic nitrate pollution. The above finding should be taken into account in future management scenarios since it could be the basis for strategies to reduce the eastern saline flux and thus slow down salinization in the Gaza Strip or even reverse the tendency and improve the overall quality of the groundwater resources.

In addition, there may be numerous anthropogenic sources of salinity such as agricultural return flows and the disposal of industrial waste. Despite the absence of data clearly quantifying anthropogenic contributions to this process, these are probably of secondary importance in the regional context of the Gaza coastal aquifer.

The natural, lateral inflow of brackish water from Israel (chloride concentrations vary from 800 to 2,000 mg/L) affects the water quality of a significant portion of the Gaza coastal aquifer. However, seawater intrusion, the potential mobilization of deep brines and the direct consequences of over pumping currently represent the greatest threats to municipal and agricultural water supplies in the Gaza Strip.

Localized shallow seawater intrusion has been documented, but in the Gaza Strip deep seawater intrusion is a bigger threat. Geophysical surveys conducted during the CAMP identified both deep and shallow seawater wedges along the coast. Current interpretations of these findings indicate that their inland extents generally range from 1.0 to 2.0 km in Gaza City/Jabalya and Khan Younis/Rafah. These areas correspond to the largest pumping centers in the

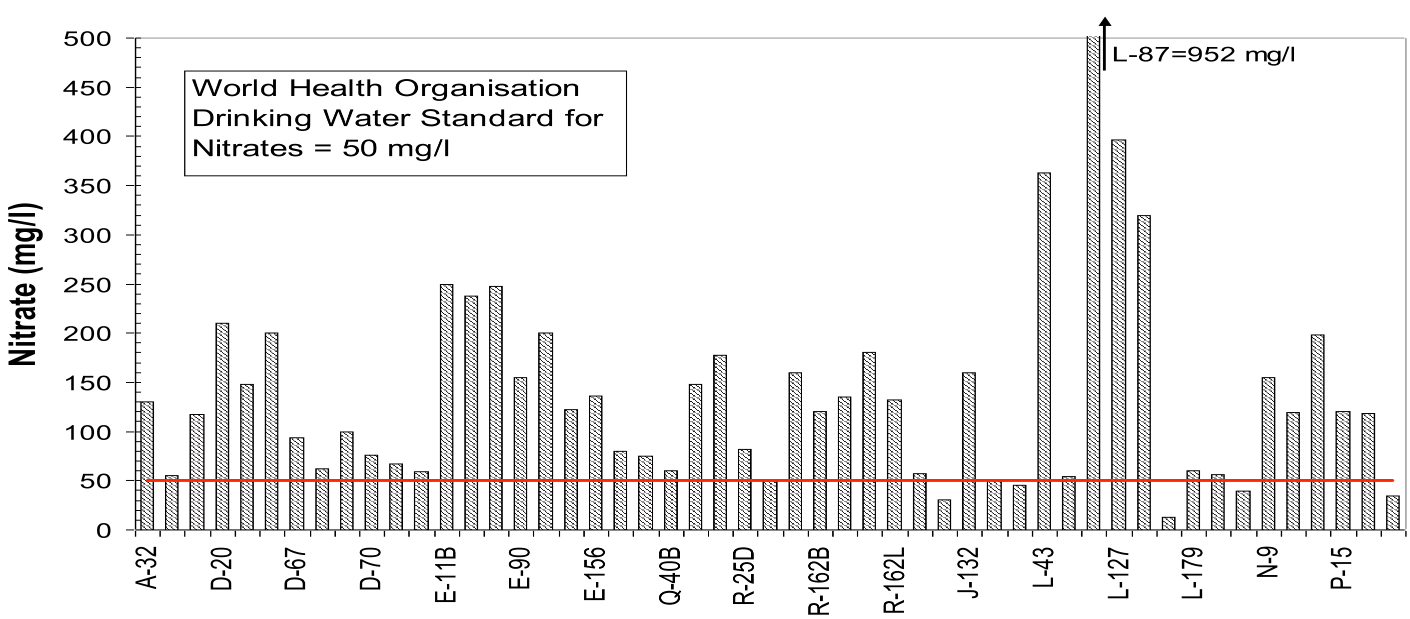


Figure 5. Nitrate concentration of domestic municipal wells in Gaza Strip

Gaza Strip, where groundwater levels are generally 1-2 m below sea level. Assuming that intrusion began in the late-1960s, the wedge has migrated inland at an estimated average rate of 30- 40 m/y.

Nitrates

Most municipal wells in Gaza show nitrate levels above the WHO drinking water standard of 50 mg/L. In the worst affected areas (urban centers), nitrate concentrations are increasingat rates of up to 10 mg/L per year, and in some cases even more rapidly.

The main sources of nitrates are fertilizers and domestic sewage effluent. The quantity of sewage that infiltrates the water table on an annual basis through cesspits and septic tanks is significant, about 12 Mm^3/y. In contrast to its salinity levels, groundwater flowing from the east has relatively low nitrate levels.

Water Quality Management

There are many promising ways to improve management of the Gaza aquifer on the basis of water quality. These include:

§ Selecting crops that tolerate high TDS concentrations. This would permit greater use of reclaimed wastewater and reduce pumping of aquifer for irrigation purposes.
§ Limiting pumping rates at individual wells to avoid or control the up-coning of salt water.
§ Landfill lining and leachate control.
§ Control and education on the use of agricultural fertilizers and chemicals that will reduce the quantity of nitrates and pesticides that reach the aquifer.

Potential of Brackish Groundwater Desalination

Presently, $5x10^6$ m^3/y of potable water for domestic use is purchased from Mekerot, an Israeli water supply company. The purchase of an additional $5x10^6$ m^3/y has been ratified by Oslo-II agreement and is considered a new water resource that will be introduced to the water supply system for domestic use after completing the North-South Gaza water carrier as proposed.

Two beach well seawater Reverse Osmosis (RO) desalination plants are also being constructed to ease the situation. These two plants are also considered new water resources that will provide, when completed, an additional $2.25x10^6$ m^3/y of fresh potable water to the Gaza Strip. This means that a total of 12.25 $x10^6$ m^3/y will be available for domestic use during the next 3-4 years from both Mekerot and beach well desalination plants.

As mentioned before, the total projected domestic demand will reach to about $182x10^6$ m^3/y by 2020. With the total of about $12.25x10^6$ m^3/y that will be supplied through Mekerot and beach well RO desalination plants, the remaining quantity required will be more or less $170x10^6 m^3$/y. Considering the water balance, as well as the groundwater yielding capacity, it has been assumed that by 2020 a total $128x10^6$ m^3/y can be produced from the groundwater aquifer for domestic use (Metcalf and Eddy et al., 2000). About 20% of total domestic water demand ($37x10^6$ m^3/y) can be satisfied from the aquifer and mixed directly with about $100x10^6$ m^3/y of treated or/desalinated groundwater through RO desalination facilities in order to fulfill domestic water compliance with WHO water quality standard (Metcalf and Eddy et al., 2000). Figure 6 shows the total domestic water demand projection to be produced from the aquifer and the groundwater desalinated quantity required (PWA and PEA, 2000).

Looking Ahead

In order to maintain the water balance in a positive condition and to fulfill the domestic water demand in terms of quality and quantity, new water resources should be introduced into the Gaza Strip as soon as possible. Those new water resources will relieve stress on the aquifer and prevent further deterioration of its water quality.

Assuming the implementation of an efficient comprehensive wastewater management in terms of reusing the reclaimed wastewater for agriculture and recharging the surplus wastewater into the aquifer, the proposed water balance will be improved relatively and the total water deficit will only be about $40x10^6$ m^3/y in 2020 (Figure 7).

Many alternatives have been examined to minimize the water deficit and fulfill domestic water

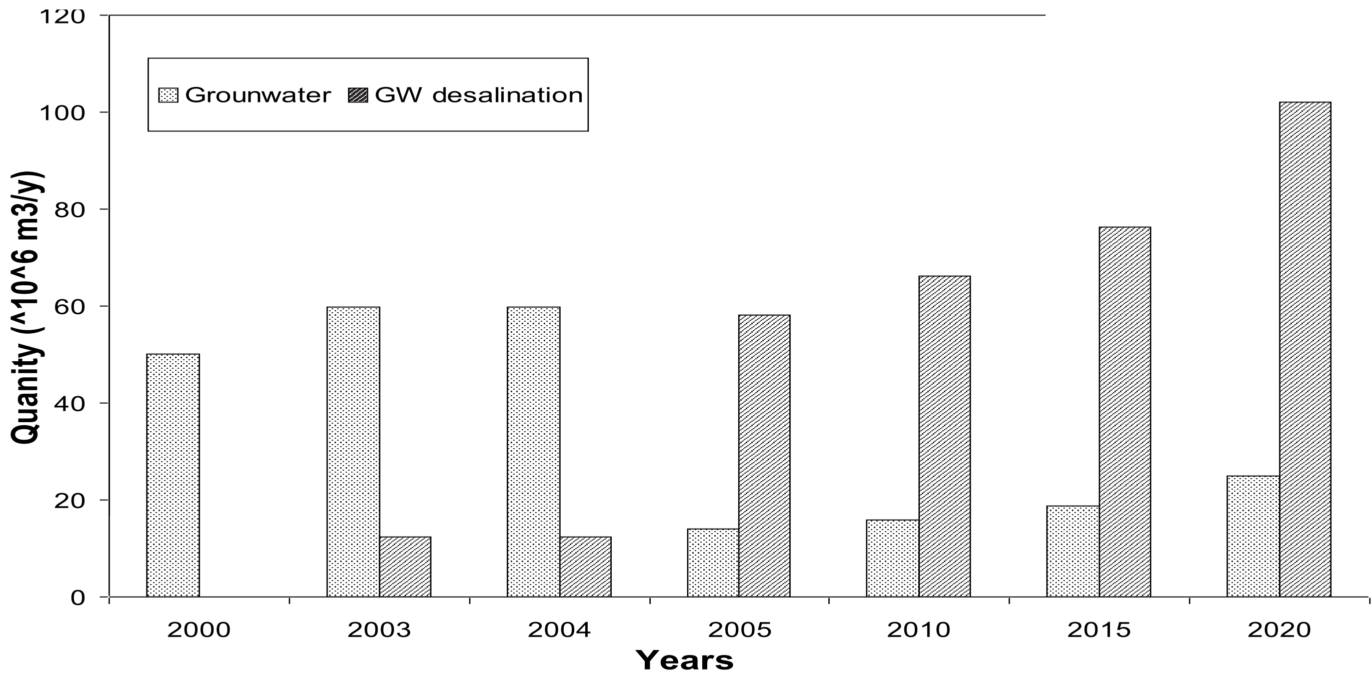


Figure 6. Originated water (fresh & desalinated brackish groundwater)

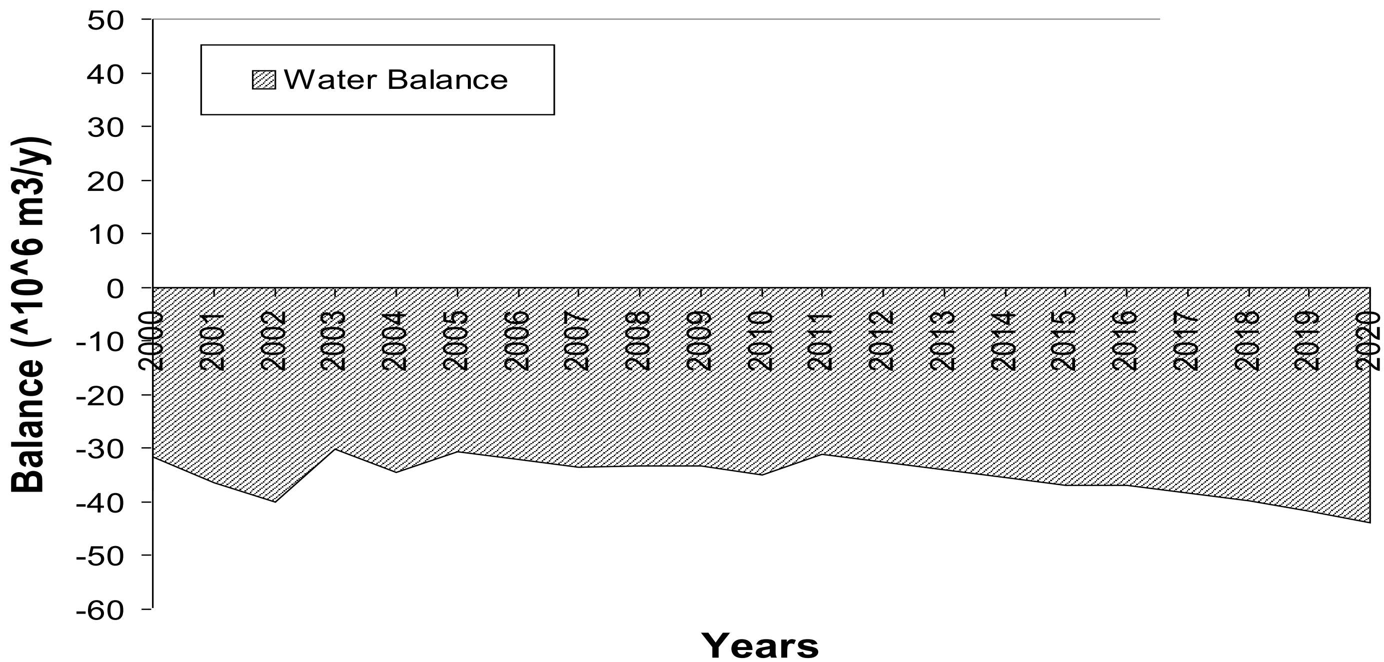


Figure 7. Water deficit with efficient reclaimed water reuse and without seawater desalination

demand, but seawater RO desalination has been identified as the most realistic option. In light of this recognition, a large scale RO seawater desalination plant with four different production phases is now being proposed (Al-Jamal and Al-Yaqubi, 2000):

- Phase-1: 60,000 m^3/d (21.9x10^6 m^3/y), in operation by 2005
- Phase-2: 60,000 m^3/d (21.9x10^6 m^3/y), in operation by 2008
- Phase-3: 20,000 m^3/d (7.3 x10^6 m^3/y), in operation by 2014
- Phase-4: 10,000 m^3/d (3.7 x10^6 m^3/y), in operation by 2017

Total desalination capacity will be by about 150,000 m^3/d (~55x10^6 m^3/y) by 2020.

The cost of desalinated water ranges widely, depending on the quality of the source water, the type of technology used in the desalination process, the type of plant selected, and the local cost of energy. The operation and maintenance costs of desalination facilities are relatively high, roughly US$ 0.5/m^3, of which electricity supply is the largest expense (US$0.35/$m^3$). The cost of the resulting desalinated water might be unacceptable to the general public. However, Metcalf and Eddy et al. (2000) studied different options to close the supply/domestic demand gap in Gaza using multi-criteria decision tools. Desalination of water was the first option.

The total seawater desalination quantity, in conjunction with the brackish groundwater desalination, Mekerot water supply and beach well desalination plants will be able to cover the D&I water demand compatible with WHO standard in terms of quantity and quality. Figure 8 shows the domestic water demand quantity that can be available from the different sources up to year 2020.

With the option and/or assumption of constructing a large seawater RO desalination plant as described earlier, the aquifer overdrafting will decrease. As a result, it is expected that seawater will be pushed back (transgression) toward the sea preventing further deterioration of the aquifer water quality. Ultimately, an acquifer water balance of approximately 10x10^6 m^3/y will be maintained starting by year 2008, as shown in Figure 9.

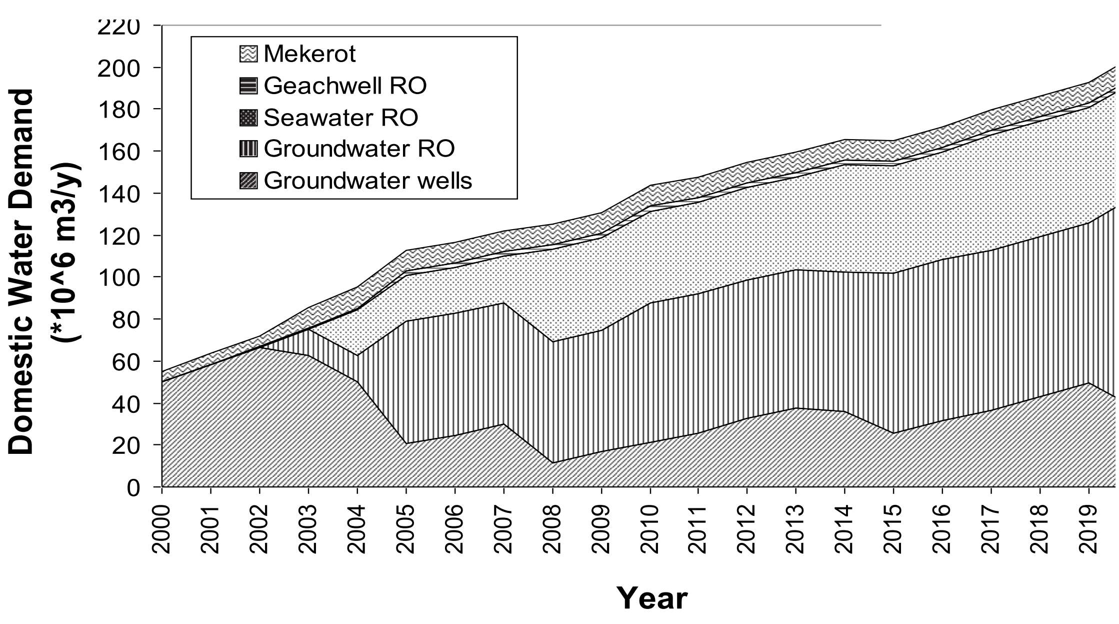
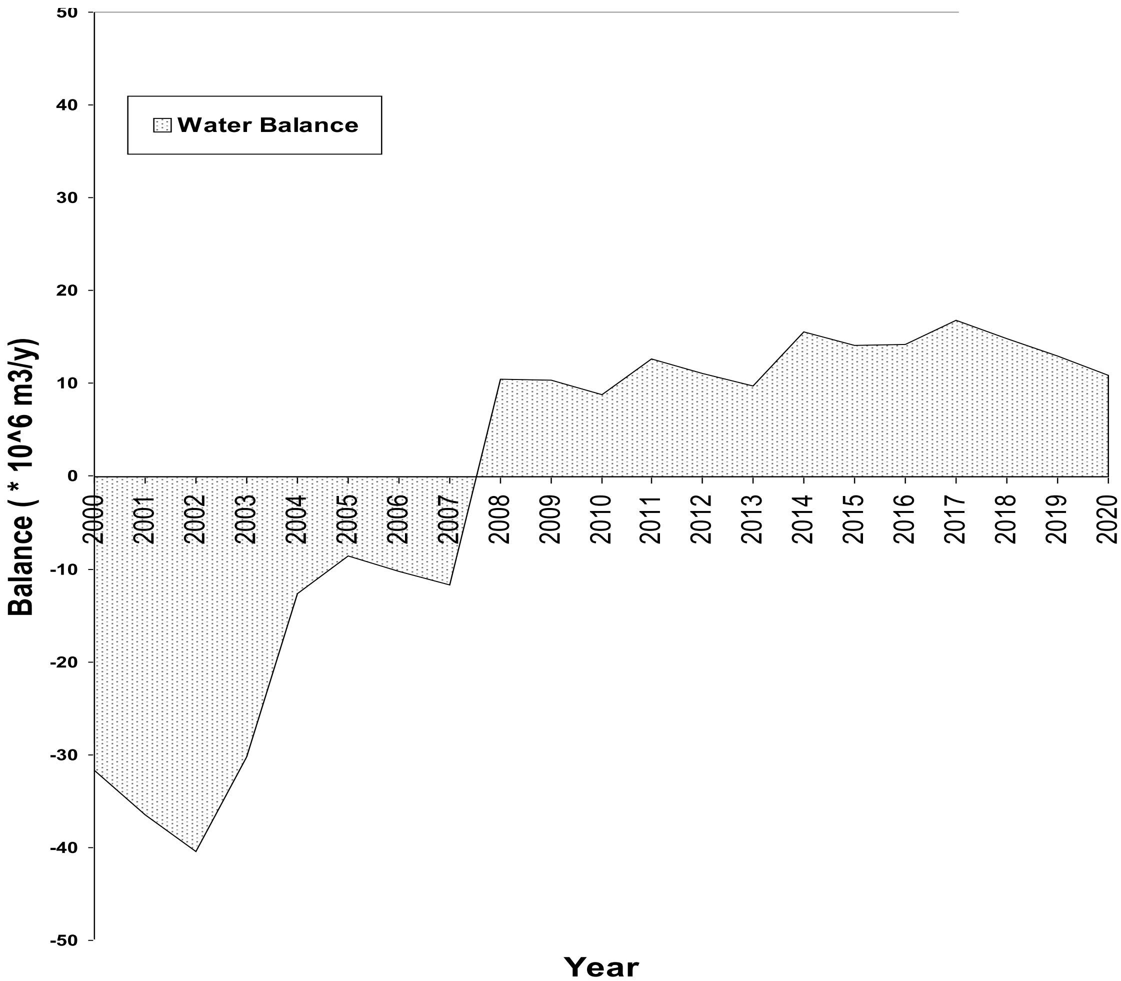


Figure 8. Projected water supplies for various demands in Gaza Strip

Figure 9. Water Balance with seawater Reverse Osmosis Desalination Plant and efficient reclaimed water reuse



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