

CASE STUDIES

Low Volume Water Desalination in the Gaza Strip – Al Salam Small Scale RO Water Desalination Plant Case Study

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The rapid deterioration of the water supply of the Gaza strip poses a difficult challenge for water planners and sustainable management of the coastal aquifer. The aquifer is currently overexploited, with total pumping exceeding total recharge. In addition, anthropogenic sources of pollution threaten the water supplies in major urban centres. Many water quality parameters presently exceed World Health Organisation (WHO) drinking water standards. The major documented water quality problems are elevated chloride (salinity) and nitrate concentrations in the aquifer. Up to 95 per cent of Gaza's population source their drinking water from public or private producers, whose production and supply chain result in the potential contamination of up to 68% of drinking water supplies, exposing nearly 60% of the population to severe public health risks.

Drinking water is being produced through 154 private and public desalination plants across the Gaza strip in addition to 10 MCM of drinking water received from Mekorot water company as a result of Oslo peace accord. To tackle the water crisis and the rapid deterioration of water resources, the PWA and water council have developed a national and strategic water plan. It has been reviewed and updated recently, via a water study conducted by PWA.¹ The national plan includes integrated water solutions such as water desalination, wastewater treatment and reuse, and storm water harvesting. This paper presents the details of the implementation of a medium scale brackish water desalination plant constructed in eastern Rafah – Gaza by Oxfam and its partner the Coastal Municipalities Water Utility to reduce the water stress in the Gaza strip and contribute to the provision of safe and clean drinking water.

Keywords: Desalination; Brackish water; sustainable management; coastal aquifer; pollution; over exploitation; water quality

Introduction/Background

Many countries around the world, especially developing countries and countries in the Middle East region and the Gaza strip in particular, suffer from a scarcity of fresh water. The population of the Gaza Strip is expected to increase to 2.1 million by 2020; with the UN reporting that Gaza will no longer be habitable if major reconstruction is further delayed (UNRWA, 2016).

One of the most affected service sectors is water, where poor water quality and high levels of water demand are increasingly leading to water scarcity, as highlighted by the Palestinian Water Authority (PWA) (Water Resources Status Report, 2015). The poor water quality, along with the deteriorating infrastructure and services, continues to negatively impact the quality of life in the Gaza Strip.

Ground water, or the coastal aquifer, is the only source of natural drinking and domestic water available to households and businesses in the Gaza strip. More than 43% of the available groundwater is being currently severely exploited for agricultural irrigation, while the remaining is used for domestic water supply and industry. Moreover, the coastal aquifer in the Gaza Strip receives an annual average recharge of 55 to 60 million cubic meters per year (MCM/year), mainly from rainfall in addition to 30 MCM/year from lateral ground water flow and leakages, while the annual intensive abstraction rates from the aquifer is about 200 MCM. As a result, it is estimated that there is an annual cumulative deficit of water of about 90 to 110 MCM/year. Meanwhile the groundwater quality is deteriorating rapidly compared to WHO standards for drinking water (**Figure 1**) with the high salinity of chloride concentrations which should not exceed 500 mg/l. The PWA/CMWU indicates an increase of nitrate concentrations with high salinity levels of 2000–10000 mg/l, high chloride concentrations of 500–3000 mg/l, and nitrate concentration of 100–800 mg/l especially in the northern part of Gaza as alerted by PWA water quality map (2016).

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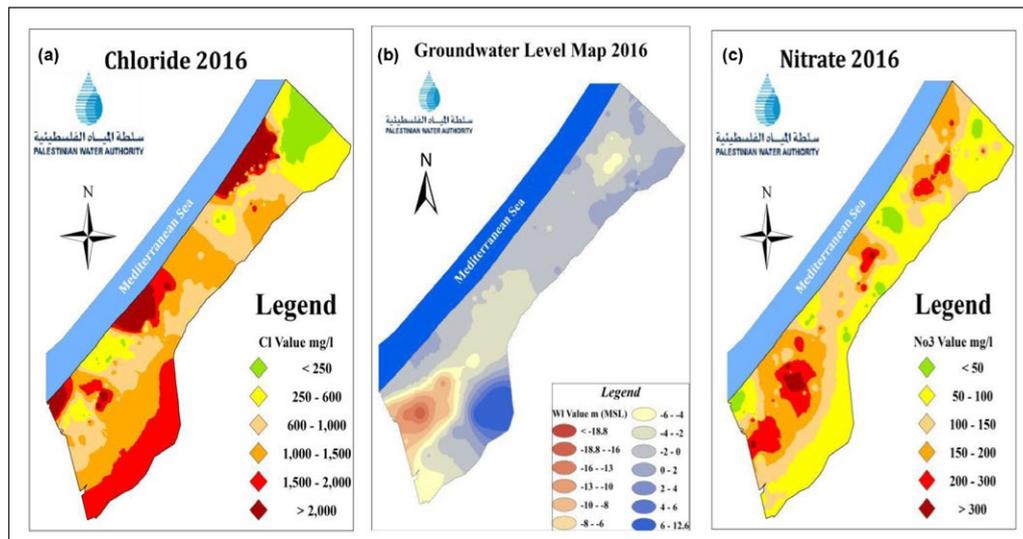


Figure 1: Quality of ground water in terms of Chloride (a) Nitrate (b) concentrations and Ground water level from main sea level (c) (PWA 2016).

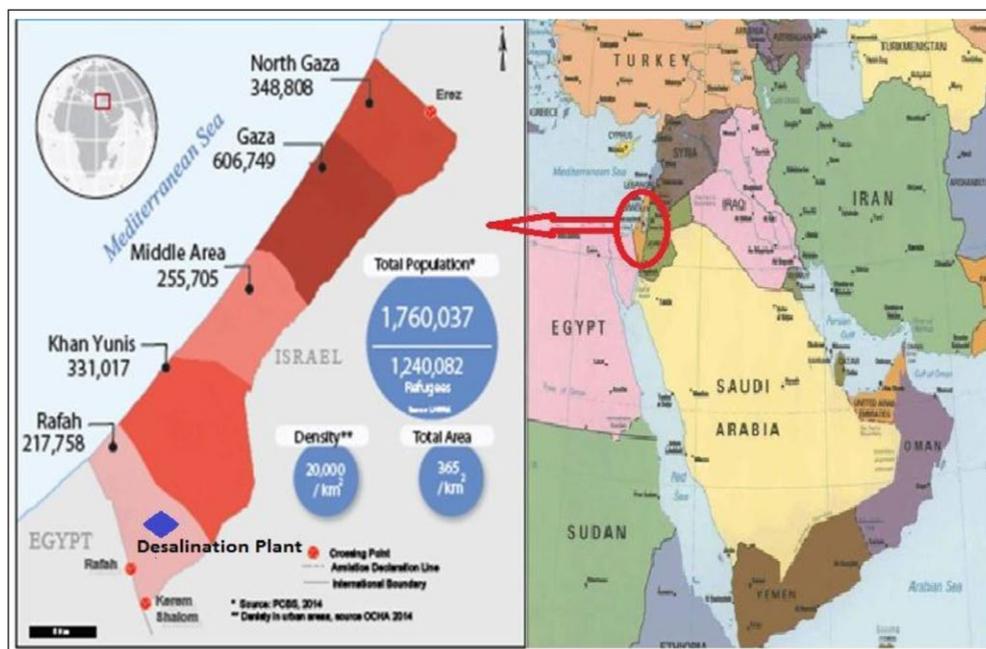


Figure 2: The Geographical location of the Gaza Strip and AL Salam Water Desalination Plant.

There is high salinity of chloride concentrations and total dissolved solids (TDS) exceed WHO recommended standards. The PWA’s recent water resources report reveals that there is a rapid and massive decline in the level of groundwater below the mean sea water level (MSL), causing seawater intrusion. The water measurements demonstrate that there is large cone of depression in Rafah city that reaches 19 m below mean sea level (MSL) as illustrated in **Figure 1**. This is considered the maximum groundwater level declination in the Gaza strip.

Geographical location and climatic situation

Study Area

The Al Salam brackish water desalination plant is located in the southern part of the Gaza Strip on the eastern coast of the Mediterranean Sea where it forms a long and nar-

row rectangle, approximately 45 km in length and 8 km wide, giving a total area of about 378 km² as shown in **Figure 2**. A desert area, it is bounded by the Negev Desert to the south east and the Sinai Desert to the south west.

It is one of the most densely populated areas in the world with an average density of approximately 4,300 inhabitants/km². Most of its people are refugees who fled their homes in areas now controlled by Israel in the 1948 and 1967 Arab–Israeli wars (The World Fact Book 2015). It is expected that the population density will exceed 5,835 inhabitants/km² by 2020 (UNCT, Gaza in 2020).

Climate, Rainfall and Environment

The Gaza Strip is located in the transitional zone between the arid desert climate of the Sinai Peninsula and the temperate and the semi-humid Mediterranean climate along

the coast. The average daily mean temperature ranges from 25°C in summer to 13°C in winter. Average daily maximum temperatures range from 29°C to 17°C and minimum temperatures from 21°C to 9°C in the summer and winter respectively.

The average annual rainfall varies from 450mm/year in the north to 200 mm/year in the south (EQA 1999). The major environmental problem in the Gaza Strip is deteriorating water quality through salinisation and pollution resulting from a deficit in the water balance. This problem covers the fresh groundwater in the shallow aquifer underlying the Gaza Strip. The major indicators for deterioration are increases in salinity (chloride) and nitrate concentration (Water Quality report).

Methodology

Authors have collected extensive project’s data during the implementation and post implementation and monitoring stages through project’s stakeholders including Oxfam GB, CMWU, and PWA. The water samples were collected from the existing water well, influent and effluent of AL Salam desalination plant by CMWU laboratory for all desalination stages. The feed water and product desalinated water were analyzed to evaluate the physical, chemical and bacteriological quality of desalinated water. Electrical conductivity and pH were measured directly in site. Chemical analyses have been done at the CMWU 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. The calcium and magnesium are determined with EDTA; while the titration with mercury nitrate is used to determine chloride. For alkalinity, a titration with 0.01N sulfuric acid is used and a turbidity method is employed for the sulfate analyses, Bacteriological analyses of water samples were analyzed for total coliform and fecal coliform. Further, the Operation and Maintenance scheme and staff training data at the desalination plant have been collected through site visits ad meeting with the operation and maintenance team at the desalination plant.

National strategic water plans

In the Gaza strip the total water supply for domestic water use is about 98 MCM in 2016 abstracted through 283 municipal water wells. While the drinking water is being

produced through 154 private and public desalination plants (Brackish and Seawater; public and private) spread over the Gaza strip as shown in **Figure 3** in addition to 10 MCM of drinking water received from Mekorot water company as a result of Oslo peace accord between Palestinians and Israel. The domestic and agricultural demand is outstripping the water supply, which will have long-term deleterious effects and requires immediate and urgent solutions to tackle these problems and challenges. To tackle the water crisis and the rapid deterioration of water resources, the PWA and water council alongside other ministries concerned with water and environmental issues have developed a national and strategic water plan. It has been reviewed and updated recently, via a comparative water study conducted by PWA. The national plan includes integrated water solutions such as water desalination, wastewater treatment and reuse, and storm water harvesting. Following this, in 2016, the PWA jointly with the water council conducted a comprehensive assessment to study the water desalination viability and feasibility has been conducted for the Gaza central desalination plant and short term low volume desalination plant (STLV) to cover the rapid drinking water demand in the Gaza Strip. These findings are reinforced by a rapid assessment undertaken by Oxfam and five international agencies jointly with PWA, CMWU and MoH in 2015 covering the whole Gaza strip, HHs can only access safe water by purchasing from unlicensed or unregulated private vendors which run a risk of being poor quality and contaminated. Where 84% of HHs are believed to purchase water from private vendors, spending an average of US\$ 7–10 per a month, approximate one third of the average income of those surveyed (UNICEF, 2010).

Contaminated drinking water poses a significant risk to public health, PWA baseline highlighted the correlation between poor water quality from municipal wells and the outbreaks of diarrhoea diseases. The most impacted were children between 0–5 years (59% of cases). Chlorination of commercial water provided by private vendors is inconsistent, and contamination present at all stages in the supply chain from RO desalination plant to household storage. According to the Surveying Private & Public Brackish Water Desalination Plants study conducted in 2015 at the Gaza Strip by the PWA, Oxfam and other INGO’s demonstrated that 45% of private desalination plants are not licensed and facilities are poorly managed ultimately contributing

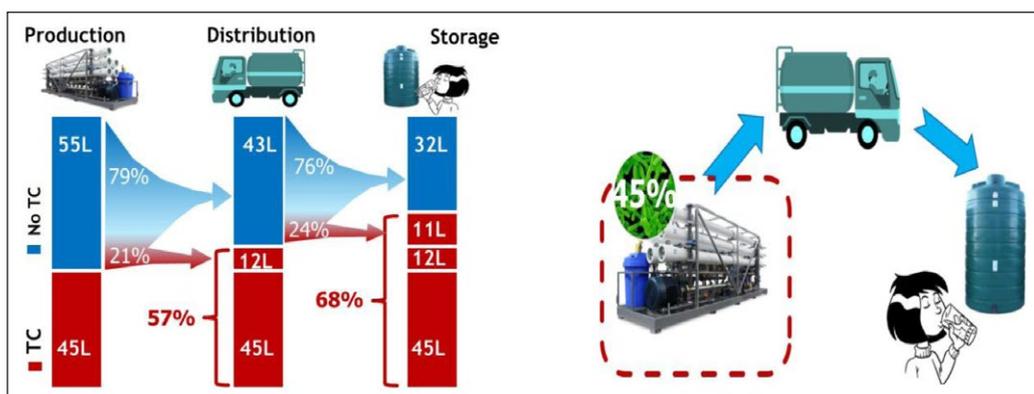


Figure 3: Contamination of water quality in the water chain distribution in the Gaza strip by private sector.

to the spread of water-borne diseases and total coliform (TC) contamination as shown in **Figure 3**. Over 68% of the water chain had bacterial contamination. 96 % of private desalination plants do not have post treatment (Mineralisation stage) and 43% of desalination plants lack proper operation and maintenance experience. Practices to regulate water supply effectively had remained weak and monitoring was inconsistent and ineffectively applied throughout the water chain supply.

Urgent measures to address the prevailing water crisis in the Gaza Strip are being considered by the PWA to secure safe water for the people of the Gaza Strip. Due to the high salinity of water wells close to the Mediterranean coastal line of the Gaza strip territory and the need to overcome both water scarcity and salinity a medium term solution of spot pointing the eastern water wells of Rafah has been initiated. A Reverse Osmoses (RO) brackish water desalination plant has been constructed in order to benefit 22,000 inhabitants of Al Salam District. Oxfam has worked with the Coastal Municipalities Water Utility (CMWU). The overall aim of the plant is to enhance the water quality and quantity supplied to eastern districts of Rafah city whilst reducing the very high levels of extraction from wells in the western region. The project included the drilling and equipping of the new reverse osmoses plant.

Rafah Water Supply System

The domestic municipal water supply and piped distribution system of Rafah served around 174,498 inhabitants in 2003. By 2016, it was serving around 213,124 inhabitants, using ground water extracted from the coastal aquifer. **Table 1** shows the historical and current abstracted water quantities in the Rafah governorates. It can be seen that water demand has significantly increased in Rafah governorate from 5.5 to 8.82 Mm³ within 13 years. Overall system efficiency has been about 65%. This dramatic increase in users has severely affected the quality of ground water, which will be discussed in the next section.

Water Quality

The aquifer water quality monitoring program and hydrological studies carried out by PWA water resources department shows less deterioration of water quality for water wells located at the eastern of the Gaza strip far away from the coastal line with mild brackish water. This

makes the construction of RO brackish water desalination plant more feasible. **Figure 4** shows the water quality of water wells in Rafah in addition to El Barazil water well highlighted in the circle which is being used to feed in Al Salam desalination plant.

The quality of the municipal water wells is also monitored through the Ministry of Health (MoH) laboratory by taking a water sample from each municipal well twice a year. **Figure 4** illustrates the TDS and chloride contaminants in the water well in Rafah; as it can be seen, the average TDS concentration in the water well is about 2,270 mg/l.

Selection of the Water Desalination Plant Location

The plan location was determined in collaboration with the Palestinian Water Authority according to the master plan and the equitable distribution plan issued by the Coastal Municipalities Water Utility (CMWU). Additional reasons considered are as follows:

- *The RO plant is located at eastern part of Rafah away from the other cluster of wells that suffer from high drawdown. The construction of this RO plant will offer the possibility of resizing the high discharge water wells and reducing the daily operating hours for each of them.*
- *No additional water network installations will be needed in addition to the RO plant.*
- *The location is close to an electricity utility and has drain facilities for brine rejection.*
- *The project will eliminate the need for carried lines to feed the eastern areas which will provide a positive impact in reducing pumping costs and reducing leakage from the main carrier lines.*

Project components and process

The project activities included water well drilling and plant construction along with all associated electro-mechanical and civil works. In addition to that, a local booster pump with a 30 m³ water tank was constructed to blend the desalinated pure water with a certain percentage of brackish water and to then to pump this water into the adjacent domestic water distribution network. **Figure 5** illustrates the different water desalination pro-

Table 1: Groundwater Extraction from the Coastal Aquifer in Rafah Governorate.

Items	2003	2004	2005	2016
Total Municipal Water Production (Mm ³)	5.5	6	6.4	8.82
Total Municipal Water Consumption (Mm ³)	3.6	3.8	4	5.78
Efficiency	65%	63%	62.5%	65.5%
Assumed Total Agricultural Water Production (Mm ³)	16.2	14.8	18	20
Total Water Abstracted (Mm ³)	21.7	20.8	24.4	28.82
Per Capita Per Day (L/C/D)	93 ⁽¹⁾ –60 ⁽²⁾	95 ⁽¹⁾ –61 ⁽²⁾	97 ⁽¹⁾ –61 ⁽²⁾	112 ⁽¹⁾ –73 ⁽²⁾

⁽¹⁾ Computed value according to abstracted water.

⁽²⁾ Computed value according to consumed water.

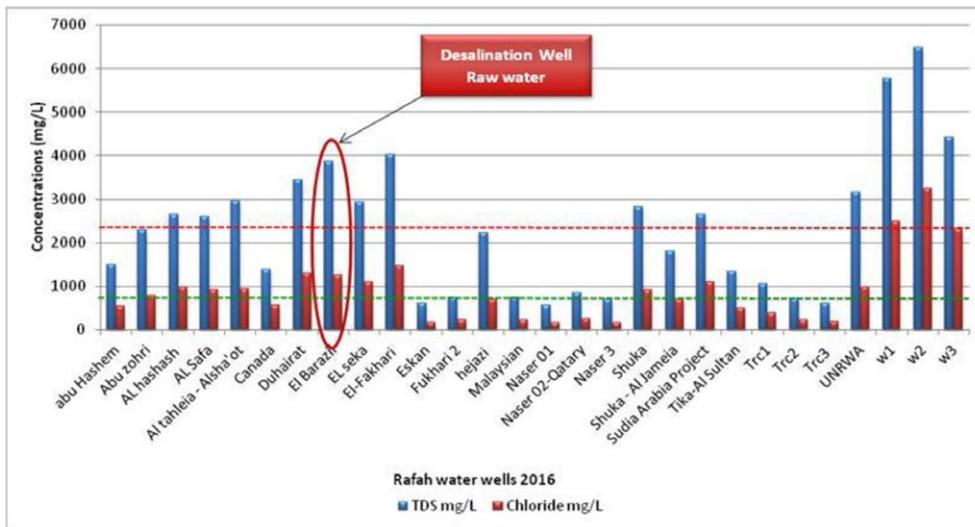


Figure 4: The water quality of Rafah water wells (Chloride and Nitrate).

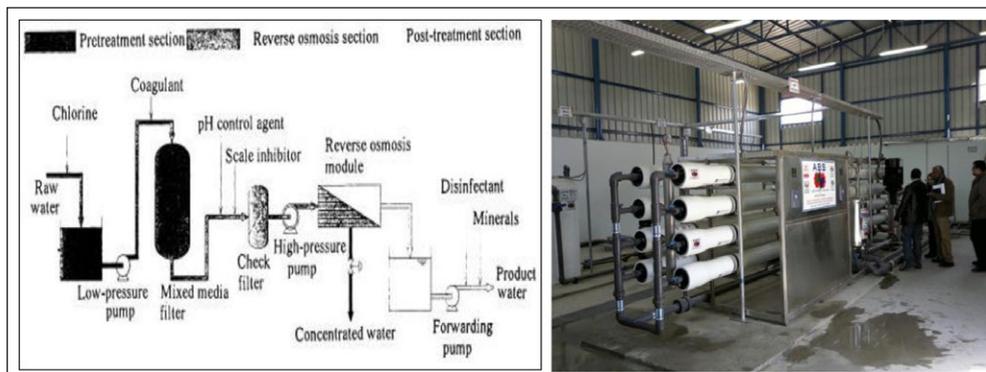


Figure 5: Schematic diagram for fully automated Containerized Skid Mounted Packaged RO Brackish Water Desalination Plant and its photo for Al Salam Unit.

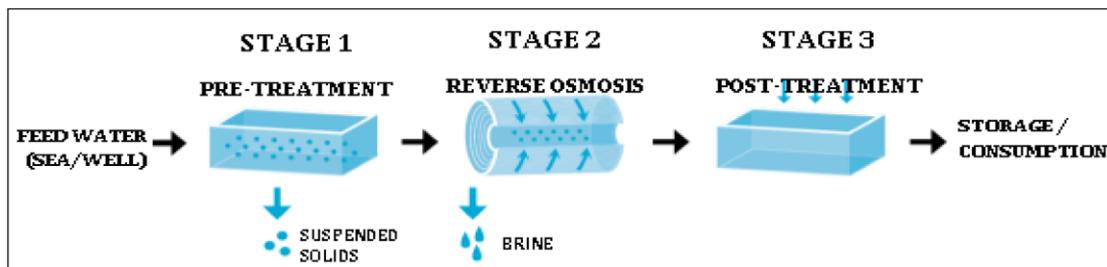


Figure 6: The three stages of the desalination process in a Reverse Osmosis plant.

cess and their components. This includes pre-treatment, the RO section and the post treatment process.

Raw water of total maximum TDS of around 3,000–4,000 p.p.m. and chloride concentration around 1,300 p.p.m. is drawn from the new brackish water well. This then passes through the raw water tank and is pumped through a multimedia filter by a raw water pump through to 4" diameter stainless steel mesh screen and 5-micron cylindrical cartridge filter as illustrated in Figure 5.

Chemical pre-treatment of the raw water to control the Alkalinity (pH) of the raw water is controlled by a fully

automated hydrochloric acid 33% dosing system linked with a pH monitoring meter.

Following the pre-treatment process the raw water is pumped through the RO membranes to generate the permeate water with 78% system efficiency, Brine from the treatment plant is discharged via a gravity system through a 6" UPVC pipeline from the desalination plant to the main manhole, and from there to the sea through the existing gravity pipeline. Meanwhile the desalination proves consists three stages of desalination as shown in Figure 6.

The quantity of permeate water from RO membrane is about 50 m³/hour.

The unit also is fully equipped with an anti-scaling chemical treatment and a controlled backwashing process, including residual chlorine monitoring program for both inflow and out flow water of the designated plant. **Figure 5** shows the installed RO desalination plant. Further desalination plant performance data parameters can be seen in **Table 2**.

Results and Discussions

Result of water quality tests for desalination plant (Raw Water from well, Permeate Water after RO and Feed Water after blending)

The Brackish Water Desalination Unit receives the feed water from a new municipal well named El Barazil (as circled and shown in **Figure 3**) with a total capacity of approximately 70 m³/h brackish water.

Table 3 shows the characteristics of the desalination plant including flow rates, quantities of feed water and distributed feed water. The mechanical and electromechanical equipment of the reverse osmosis unit itself has been designed for a maximum capacity of 50 m³/h.

The desalinated water (about 1,200 m³/d after a blending process with almost the same quantity of water supplied by another water scheme) is being pumped through the existing water networks, to supply drinking water to some 22,000 people (less than 500 p.p.m. Chlorides and nitrate concentration less than 70 p.p.m.).

Evaluation of Chemical water quality of effluent water from desalination plants

The constructed desalination plant consists of different filters (sand filter, carbon filter, Antecedents, RO filter). The main filter of the desalination plants is a Reverse Osmosis filter. This filter is very effective; purifying 99% of the contaminating elements found in the raw water supply (Toray, 2017). The most important factor determining the success of the

filters is the inlet water quality. However, as of March 2017, the quality of the water produced in the plant is within WHO limits for water quality as it can be seen in **Figures 7** and **8**.

The quality of the desalinated water and blended water has been laboratory tested. The RO plant is designed and constructed to produce fresh water and to distribute it through the water distribution network to the community. For this purpose the distributed water has been monitored and controlled to match WHO guidelines for drinking water and in particular to not exceed 250 p.p.m. for chloride and 50 p.p.m. for nitrate as it can be seen in **Figure 7**.

Microbiological water quality

An important aspect of drinking water is the microbiological quality. It is of particular significance because many types of disease can be transmitted to humans via pathogenic microorganisms or parasites in drinking water. Pathogenic organisms are highly dangerous to human health (Gray, N. F. 1994). The water quality analysis showed 100% of biological contaminant removal.

Financial aspects

The financial model and analysis for all incurred costs shows that the water produced costs no more than 1.6/m³ New Israel Shekel (NIS) = 0.44 US\$/m³ which is less than the unit price of water supplied by the Israel Mekorot water company (priced at NIS 2.9/m³ = 0.81 US\$/m³ (CMWU, 2017).

Operation and Maintenance and Staff Training

The operation, management and maintenance of the RO unit has been assigned to the CMWU, which is already managing all the medium-scale desalination units in the Gaza Strip and has the required expertise and

Table 2: Desalination plant parameters.

Desalination plant parameters	Performance
Plant production rate:	
per day	1200
per hour	50
Water recovery rate	77%
Membrane	Spiral wound Thin Film Composite RO membrane elements of 8 inch diameter and 40 inch length.
Osmotic Pressure	10–12 bar
Rejection ratio (High rejection)	≈99,50%

Table 3: Water Quantities.

Water Flow Rates											
Water Well	Feed Water	Permeate Water	Brine Water	Blending desalinated Water	Total Product Water	Efficiency of RO	Mobile Tankers	Public Taps	Flow Rate at HHS	Beneficiaries	
M ³ /hr	M ³ /hr	%	M ³ /day	M ³ /day	L/sec	People					
72,0	67,0	53,5	13,5	5,0	58,5	78	50,0	10,0	0,13–0,14	22000	

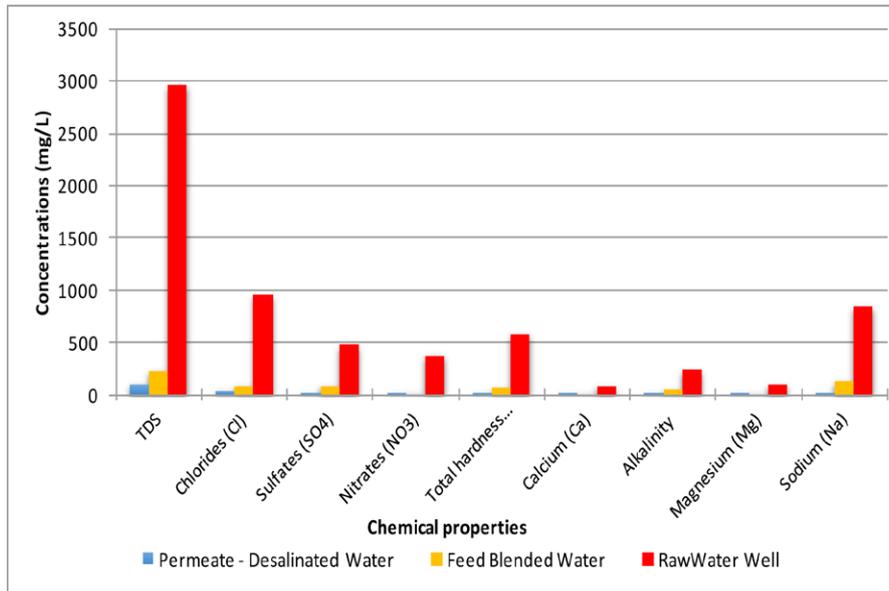


Figure 7: Water quality of desalinated, raw water and feed blended water.

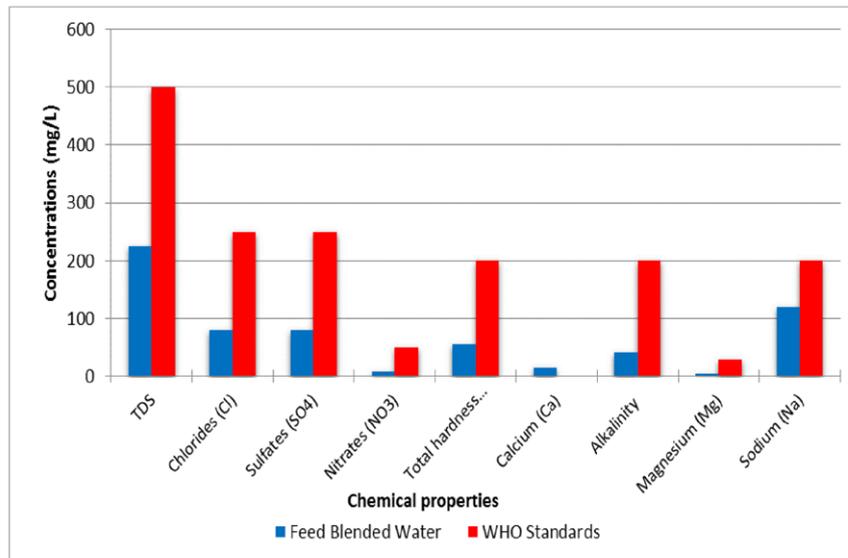


Figure 8: Water quality parameters of desalinated, water and WHO standards.

trained staff to keep the RO plant well-maintained and fully operational.

Sustainability

The desalination plant and its associated sustainability have been ensured through different aspects. The Brackish water RO unit has a lifespan of at least 20 years, if well-maintained and operated. The plants have so far been operated for 5 years by the CMWU, who have 20 years of experience of operating and managing such units.

The sustainability of a potable water supply for the target communities has also been enhanced by an extensive awareness raising programs. An increase consumption and utilization culture has been built among women, children and youth; creating a feeling of ownership for the water system and the infrastructure. This has helped promote keeping the RO units in good condition, both during and

after the programme intervention. In addition, the target youths, mothers and children were encouraged to share the information they receive with as many people as possible to raise their social responsibility in terms of water provision.

Conclusion

The desalination of saline water is proving to be an important source of fresh water and is contributing to tackling global water scarcity issues, especially in the Gaza strip. The rapid deterioration of the available water resources in the Gaza strip had encouraged the PWA and CMWU to adopt desalination as a non-conventional water resource in order to cover the massive shortfall in fresh water. The installation of Al-Salam desalination plant has achieved the following outcomes:

- Improved water supply quality to the Al-Salam

targeted communities (22,000 inhabitants) in terms of quality and quantity. The blended feed water is within WHO standards for drinking water.

- Reduction in the incidence of hygiene-related and water-borne diseases through integrating the RO unit's provision with hygiene and public health promotion, helping consumers to increase their awareness on water-borne diseases and how to prevent them.
- Reduction of malnutrition level, diarrhoea and anaemia by improving the quality of drinking water supply.
- Empowerment of women, youth and children role in promoting a better water culture. It was easier to create a new generation with a positive water culture than to modify an existing one.

Plans to enhance water availability and wastewater reuse in the Gaza Strip are highly dependent on political, economic and technical considerations, many of which have been postponed or suspended. A centralized Seawater desalination plant being the most effective in terms of the water quality and quantity provided is being hampered politically and financially. Meanwhile, many RO Brackish Water desalination units across the Gaza Strip, including Al Salam RO unit, are established and operated by the Coastal Municipalities Water Utility (CMWU).

Finally, a collective cooperation and coordination among PWA, CMWU, International agencies and local communities was established to promote the use of brackish water medium scale desalination plants in order to tackle the water crises in the Gaza strip for the short-term solution and until the central desalination plant has been constructed.

Abbreviations

MCM	Million Cubic Meter
PWA	Palestinian Water Authority
CMWU	Coastal Municipalities Water Authority
WSRC	Water Service Regulatory Council
WSRC	Water Service Regulatory Council
UNRWA	United Nations Refuge Work Agency for the Palestinians
WHO	World Health Organizations
TDS	Total Dissolved Solids
MSL	Mean Sea Level
MoH	Ministry of Health
HH	House Hold

TC Total Coliform

Note

- ¹ Comparative water study of options 2013 conducted by PWA.

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Competing Interests

Saffa Riffat is the Editor-in-Chief of Future Cities and Environment, with peer review completed as per the standard journal process. All other authors have no competing interests to declare.

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