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Desalination Processes for Drinking Water in Palestine: Optimization Using Decision Support System

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By

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Dedication

First, my heartfelt thanks to Allah the Almighty for giving me the energy to complete this thesis, for being my inspiration along the way.

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List of Abbreviations and Symbols

AC	Alternate Current
BW	Brackish Water
BWRO	Brackish Water Reverse Osmosis
CAPEX	Capital Cost
DC	Direct Current
ED	Electro Dialysis
ERT	Energy Recovery Turbine
F	Flux
FO	Forward Osmosis
GEC	Global Environmental Services
IX	Ion Exchange
MCDA	Multi Criteria Decision Analysis
MD	Membrane Distillation
MED	Multiple Effect Distillation
MEDRC	Middle East for Desalination Research Center
MSF	Multi Stage Flash
N	Number of Stages
NaCl	Sodium Chloride
N_E	Number of elements
N_{EPV}	Number of Element Pressure Vessels
NF	Nano Filtration
N_V	Number of Pressure Vessels
N_{V1}	Number of Pressure Vessels In Stage 1
N_{V2}	Number of Pressure Vessels In Stage 2
Ppm	Part per million
PV	Photovoltaic
PWA	Palestinian Water Authority
QP	Design Permeate Flow
R	Staging Ratio
RO	Reverse Osmosis
ROSA	Reverse Osmosis System Analysis
SDI	Silt Density Index
S_E	Area of Selected Element
SWRO	Sea Water Reverse Osmosis
TDS	Total Dissolved Solids
TFC	Thin Film Composite
TSS	Total Suspended Solids
WHO	World Health Organization

WTP	Water Treatment Plant
Y	Recovery

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Abstract

Palestine suffers from water shortage problem, there is a good potential for addressing the water shortage problem in rural and remote areas through sustainable saline water desalination technologies.

This study aims to investigate the Optimal Technique of Desalination Processes for Drinking Water in Palestine using the Multi-criteria decision analysis (MCDA), as a tool of Decision Support System, which is concerned with structuring and solving decision and planning problems involving multiple criteria. The purpose is to support decision-makers facing such problems. And ROSA software was used to evaluate some parameters like the energy required for desalination for both Nano filtration and Reverse Osmosis.

In MCDA the criteria and sub-criteria used in the assessment of optimal photovoltaic desalination technologies are summarized in terms of cost, efficiency and productivity. The study contains two types of water the Sea and Brackish water that varies in the TDS, and this variation cause a difference in the cost of desalination depending on the amount of energy required. The first case of the study shows that NF is the optimal technique for brackish water desalination in Zbaidat Village. That is, $1m^3$ of the

permeate water from brackish water with a TDS 2586 mg/l requires 1kWh, which can be obtained by using PV cells system, with which Palestine is highly enriched.

The results of the second case study show that RO is the optimal technique for seawater desalination in Gaza Strip, since this technique needs the lowest amount of energy than the thermal technologies (MSF and MED), in which $1m^3$ of the permeate water that produced from seawater with a TDS of 35230 mg/l requires 5 kWh.

Chapter One
Introduction and Background

1.1 General Background

Water has an indispensable role in our everyday life and its total utilization is increasing daily because of the growing structure of humankind living patterns (Gorjian & Ghobadian, 2015). The growing need for water puts more pressure on the water resources in Palestine in particular (Jone, 2015). Additionally, this rising concern may lead to scanty water resources and then to drought (Gampe, Ludwig, Qahman & Afifi, 2015).

Furthermore, in historical Palestine there are eight aquifers, four of which are located in the West bank and Gaza Strip. In the West Bank, the "Mountain Aquifer", includes the Western Aquifer, North-Eastern Aquifer, and Eastern Aquifer, whereas in Gaza strip there is the Coastal Aquifer, which is the only source of water. Unfortunately, Israel controls the aquifers, forbidding the Palestinians from more than 90% of the aquifers' water. Specifically speaking, Israel's water consumption average is 350 liter per capita per day, compared to 84 liter per capita per day for the Palestinians (Tal & Rabbo, 2010). Table (1.1) shows the Annual available water in the West bank and Gaza Strip (Average from year 2012-2016).

Table (1.1): Annual Available Water in the West bank and Gaza Strip.

Palestinian Central Bureau of Statistics (PCBS), 2012-2016).

	Population	Supplied	Consumed	Lost	use per capita
West Bank	2,435,338	93.9 MCM	67.9 MCM	26.0 MCM	76.4 lpcd
Gaza Strip	1,672,865	106.0 MCM	54.7 MCM	51.3 MCM	89.5 lpcd
Totals	4,108,203	199.9 MCM	122.6 MCM	77.3 MCM	81.7 lpcd

Palestine is going through a grave water shortage due to the Israeli domination of the water resources as per Oslo II Accords. In this study, Zbaidat in the West Bank and Gaza Strip will be the target cases of this study.

1.2 The Need for Desalination

The solution to water shortage is associated with diversifying the water sources, such as treating wastewater, harvesting rainwater, and desalinating seawater and brackish water (Miller.G, 2005).Mohsen & Jaber, 2001) [a].

Desalination is the process by which the saline water is converted into fresh water. Shatat (2013) classifies desalination into major and minor processes as shown in Figure (1.1).

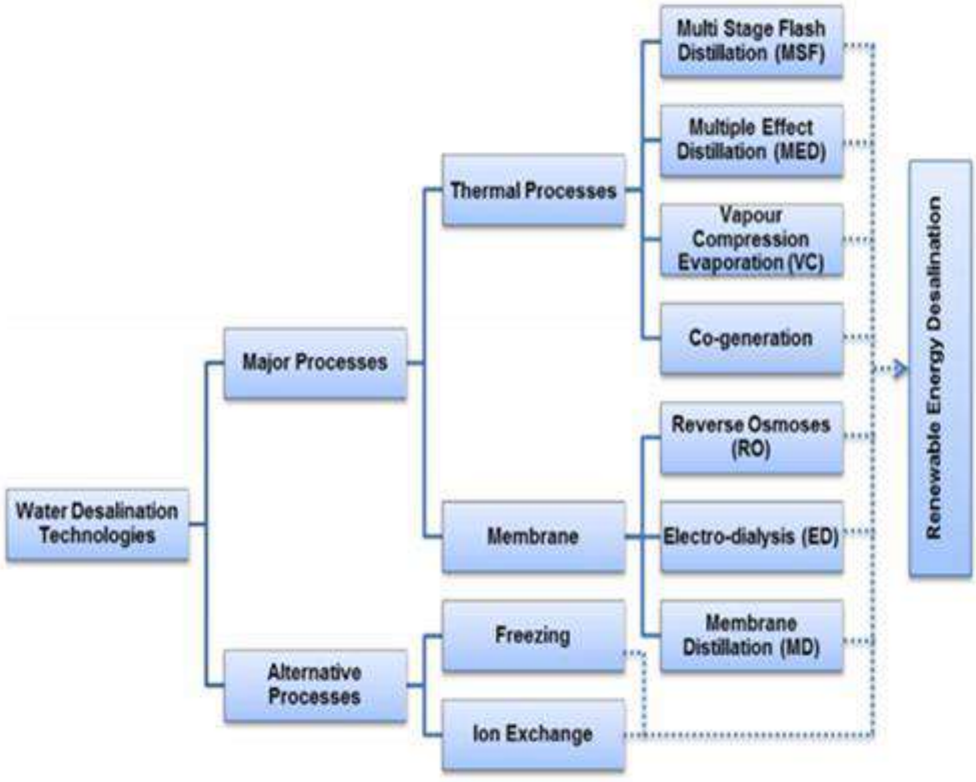


Figure (1.1) : Desalination Technologies (Source: Shatat, 2013)**.**

1.3 Obstacles Facing Desalination

At present, there are a number of barriers which impede desalinating the saline and brackish water in Palestine, such as the high cost, the lack of the technical expertise , inadequate electricity supply in addition to other environmental obstacles (Jone, 2015).

The environmental concern, for example, is represented by the disposal of brine , which is currently being pumped into the sea. This disposal pollutes the seawater and marine life (Miller et al., 2015). Therefore, there is a necessity for environmentally-friendly energy , which is derived from renewable natural resources , such as sunlight, wind, rain, tides, waves and geothermal heat (Stover, 2011).

As a potential solution, Loutatidou et al., (2014) invistigated the installation of Reverse Osmosis (RO) desalination plants as a major desalination technology that has been rising throughout the world. However, the major concern is still associated with Capital Expenditure (CAPEX),which is of major concern for the governments, potential investors and consulting engineers of the industry.

In addition, Loutatidou et al., (2014) discusses the major criteria for the selection of a desalination technology that include plant capacity, location, award year, feed salinity, and the cumulative installation capacity within a region.

Since the main requirements for the development of any country are energy and water, and in Palestine both of them are restricted, so alternatives should be find such as desalination using solar energy. Different technologies of desalination can be applied but the optimal one should be found to get water with high quality and less energy so the water reach the consumers with a reliable cost. To identify the optimal scenario for using different desalination techniques for both brackish and seawater the Multi Criteria Decision Analysis as a decision support system was used and Reverse Osmosis System Analysis (ROSA) was used for evaluating the energy required.

1.4 Research Objectives

1.4.1 General Objectives

1. To compare between different desalination technologies:

    - RO and NF for brackish water in Zbaidat village.
    - RO, MED and MSF for sea water in Gaza Strip.

1.4.2 Specific Objectives

1. Choose the best scenario of using different desalination technologies by MCDA as a tool of decision support system and ROSA software for evaluating the required parameters such as the energy required, considering:

    - Criteria: cost, efficiency and productivity.
    - Photovoltaic solar energy as an energy source.

1.4.3 Research Question and Identified Problems

The proposed research aims at giving a reliable answer to the following questions:

- Which desalination technology is the optimal one for desalinating BW in Zbaidat Village using PV as a source of energy?
- Which desalination technology is the optimal one for desalinating SW in Gaza Strip using PV as a source of energy?

1.4.4 Problem Definition

Due to the fact that the occupation controls the major water resources, the available natural water resources are already overexploited and water quality is threatened. The Jordan Valley is facing limited accessibility to water resources and quality deterioration challenges, due to the continuous rising in annual demand for agricultural, and over extraction of groundwater wells. All of these factors led to the increase in salinity levels ~1000 – 10000 ppm accord22ing to Bsharat (2014). On the other hand in Gaza Strip the only available water source is groundwater from the deteriorating Coastal Aquifer, the over-pumping of groundwater has led to damage of the trans-boundary aquifer due in part to a large increase in groundwater salinity following from seawater intrusion into the aquifer from the Mediterranean. Levels of salinity found in the aquifer under Gaza have risen continuously over the last two decades, and are now far in excess of the World Health Organization standards for drinking water.

Therefore, looking for unconventional water resources such as desalination of brackish water or seawater can be used to fulfill the gap. Desalination can be applied using different technologies such as thermal technologies (MSF, MED,..) and membrane technologies (NF, RO, ED) and others, so it's essential to study the optimal technology for both sea and brackish water using solar energy as a source of energy depending on different criteria such as cost, efficiency and productivity.

Chapter Two
Literature Review

2.1 Salinity Levels of Brackish Water and Seawater

Although salinity levels might be vague, there are some precise definitions for salty waters based on the total dissolved solids in the water as shown in Table (2.1).

Table (2.1): Water Classification Depending on TDS (Mahmoud, 2013).

Water Type	TDS (mg/L)
Fresh water	0-1000
Brackish water, mildly	1000-5000
Brackish water, moderately	5000-15000
Brackish water, heavily	15000-35000
Sea water	30000-50000 mg/L
Brine	Greater than 50000
Dead sea	330000

2.2 Environment and Energy

Fischetti (2007) realized that the conventional energy like fossil fuels is not only very expensive to run the desalination plants, but also it increases the environmental pollution and these desalinating plants are not feasible in the distant areas from the economic side unlike those that are close to the water source. In fact, fossil-fuel power-driven desalination systems are no longer capable to meet the water shortage, because of the costly and scarce energy resources, and the raise of greenhouse gas emissions (Gorjian &

Ghobadian, 2015). Shatat (2013) developed an Arrangement that shows the type of renewable energy and the possible technique of desalination that can be activated by it as shown in Figure (2.1).

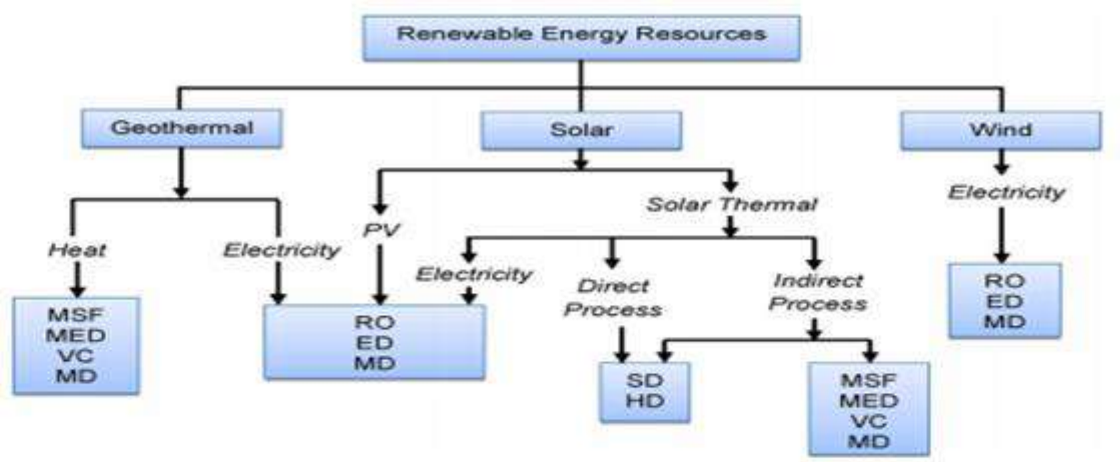


Figure (2.1): Arrangements of Renewable Energy Resources With Water Desalination Techniques (Shatat, 2013).

2.2.1 Solar Powered Desalination Technology

Solar cells generates solar power using solar energy through photovoltaic system, which uses an inverter to convert the electric current from direct to alternating current. For small scale systems the PV range from a few to several tens of kilowatts, while for large scale power plants it reaches to hundreds of megawatts. (Goodall, 2016).

There are two types of PV systems the grid-connected and the stand alone, but the most popular in the market is the grid connected system.

It should be noted that the solar powered desalination methods are promising ones because Palestine has an annual average of daily solar energy amounting to 5.4kWh/m^2 .day, that can efficiently be exploited to handle desalination techniques (Mahmoud, 2013).

Yousef (2013) investigate an economic analysis for Zbaidat BWRO, the cost of 1m^3 of permeate water produced from brackish water with a TDS 2681mg/L is 3.17$ with battery, and 2.33$ without battery.

2.2.2 Solar Energy Costs

To compare between solar costs and other fuels, ($/watt) should be converted to kWh. Firstly, convert the solar DC to AC power that can be used for home machines. For a solar energy system 10 % of the energy is lost when the DC is converted to AC power. Secondly, estimate the total output which equals the mean peak hours of sunlight (nearly 3.63 hr/day) multiplied by 365 days' multiplied by 20 years (assume the product lifetime 20 yr.).

As an example 5-kW solar energy system that costs $45000, can be converted to kWh as follows:

Conversion of DC to AC power = $5kW * 90\% = 4.5kW$

Daily energy = $4.5kW * 3.63hours = 16kWh/day$

Average Annual Output = $16kWh * 365day = 5962kWh$

Total output over 20 year lifespan = $5962kWh * 20year = 119246\ kWh$

Avg. cost= $\frac{\$45000}{119246kWh} = \$0.38/kWh$

2.2.3 Solar Powered Desalination Processes

Wang & Xie (2016) studied desalination via PV functioning. Nearly all types of membranes are mentioned, containing those relied on polymers, inorganic materials and their hybrids, all of which show reasonable functioning, with sufficient flux and excellent salt rejection.

Pugsley & Smyth (2016) view Reverse Osmosis driven by photovoltaic as the main technology since high scores were given to the countries in the Middle East, where fossil powered desalination is normal, and solar desalination has clear applicability. However, low scores were given to the countries with less applicable solar desalination like China. This indicates that the most governing factors of the performance are location, solar intensity, wind speed, ambient temperature, and water salinity.

2.3 Desalination Process

Buros (2000) gives the definition of the desalination as separating salts from the saline water, to produce potable water with low concentration of dissolved salts, and brine that has a very high concentration of dissolved salts, using different types of energy.

Buros (2000) reveal that there is no best technique of desalination, but usually for desalinating sea water, the distillation and the Reverse Osmosis are employed, whereas for desalinating the brackish water the Reverse Osmosis and electro dialysis are employed, so the selection of a process needs a careful study. In this study, the optimal technique will be chosen from these following techniques:

2.3.1 Multi-stage Flash (MSF)

In this technique, "seawater is purified by flashing a portion of the water into steam in several stages, of what are essentially countercurrent heat exchangers. This technique produces about 60% of all desalinated water in the world. An MSF distillation plant uses thermal power to evaporate the saline feed water and gather the distillate via a sequence of sections. Every following compartment functions at a lesser pressure than the prior one. MSF plants are expected to preserve a leading role in the desalination market, particularly in oil-rich countries, which obtain advantages from organizing the MSF plants with thermal co-generation" (Fthenakis & Sinha, 2015).

2.3.2 Multi-Effect Distillation (MED)

It is a form of solar energy comprised of diverse formations of MED used for seawater desalination. It goes through a number of phases or "effects". In each phase, the feed water is heated by vapor in tubes.

Nafey & Rodríguez, (2011) studied two various combined solar cycles, with various designs of multi effect distillation (MED) methods. The results have shown that the parallel feed design dominates the forward feed with feed heater design, and increases the number of effects to more than 12. This desalinating process is more attractive than desalination and power technique, due to the greater gain ratio, and the smaller area of the solar field required.

2.3.3 Reverse Osmosis RO

RO technology is used for purifying saline and brackish water. Lauren(2009). Tabieh et al (2015) assessed the value of desalinated brackish water of (JD 0.59/$m^{3)}$ while the steady desalination cost is (JD 0.28 m-^{3}). It should be noted that Reverse Osmosis system depends on pressure to separate the salts when the fresh water passes through a membrane; the pressurizing of the feed water consumes the major amount of energy (Mazlan, et al, 2015).

2.3.3.1 Pre-treatment advantages

- Produces a low concentrated suspended particles, that makes RO membranes operate at high flux.
- Extends the life span of the membranes.
- Lowers energy cost, chemicals, and labor.
- Needs less pressure vessels and needs RO membranes, so it causes additional savings (Bocci & Naso, 2013).

2.3.3.2 Membrane Process Terminologies

The main expressions used in the RO, NF processes include:

a) Recovery: the percentage of permeating flow to the feed flow that enters the system.

b) Rejection: the rate of solute concentration separated from the feed water by coating.

c) Passage: it is the proportion of dissolved pollutants in ××the feed water permitted to go through the membrane.

d) Permeate: produced fresh water, created by a membrane system.

e) Flow: the feed water percentage originated to the membrane system, it has a unit of m^3/h.

f) Concentrate flow: the feed water that doesn't pass through the membrane system.

(g) Flux: the percentage of permeate transported per unit area of the membrane, which has two units: (g/ft^2d) or (L/m^2h).

2.3.3.3 Feed water pre-treatment

The main purpose is to improve system functioning, stop the most important problems linked with RO membranes like scaling, fouling, and degradation.

2.3.3.4 Scaling

Scaling happens when soluble salt types (such as $CaSO_4$, $CaCO_3$, silica, etc.) are concentrated inside the element outside, their solubility boundary as the water is separated, and extra melted ions are strengthened in the system. This ,in turn, produces a precipitate on the surface of the membrane, which decreases the permeability, and causes damage to the membrane.

2.3.3.5 RO Cleaning

RO membranes need regular cleaning, from one to four times yearly depending on the quality of the feed water. This action is a must when a decrease in the normalized pressure or an increase in the passing of the normalized salt occurs by 15%, and if the flow of the standardized permeate has decreased by 15%. The membranes can be cleaned onsite or off site.

2.3.4 Nano Filtration (NF)

NF is regarded as the key factor in the reduction of rates involving the desalination process. In fact, cheaper seawater desalinating techniques had been established by combining NF with different kinds of these techniques, involving RO, ED, FO, MSF, MED, ion exchange (IX), and membrane distillation (MD) (Zhou et al., 2015).

Mazlan et al., (2015) made a simulation for FO and RO considering several circumstances and flow systems, by the “Aspen Plus environment”. As a result, there was nearly no change in the Specific Energy Consumed (SEC) by RO, and FO with (NF) DS recovery in addition to the benefit of the lower polluting tendency of FO, which may decrease the requirement of pre-treatment and chemicals (Mazlan et al., 2015).

Schäfer et al., (2007) examined NF in treating brackish water by NF/RO system powered by PV. In addition, function parameter mixtures like trans membrane pressure, feed flow were examined to obtain the most effective situations for the highest production of potable water, and the least consuming of specific energy. As a result, NF90 was capable of generating better water quality with the RO membrane BW30, but TFC-S membrane was not capable of satisfying the standards of the drinking water.

Mohsen & Jaber (2001)[b] investigated NF for brackish water treatment. Specifically, the water was gathered from Zarqa in Jordan. As a result, the NF was effective in reducing the organic and inorganic substances, and gave high water revival up to 95%.

2.4 Comparison Between Desalination Methods

Eshoul, Agnew, Al-Weshahi & Latrash (2016) investigated analysis for RO desalination system. As a result, the use of Energy Recovery Turbine (ERT) decreased the power used for SWRO by 30%, and the specific power used for $1m^3$ of SWRO, from 7.2 kW/m^3 to 5.0 kW/m^3.

McGinnis & Elimelech (2007) compared between different desalination technologies, a summary is shown in Table (2.2).

Table (2.2) Comparison between desalination processes (McGinnis & Elimelech, 2007)

Desalination process	**FO**	**MSF**	**MED**	**RO**	**MVC**	**NF**
Time	1924	1955	1959	1965	1969	1970
Situation of the Art	Commercial	Commercial	Commercial	Commercial	Commercial	Commercial
Plant Cost ($\$/m^3/d$)	-	1,500-2,000	900-1,700	900-1,500	1,500-2,000	-
Commissioning time (months)	-	24	18-24	18	12	-
Unit Production Capacity (m^3/d)	-	<76,000	<36,000	<20,000	<3,000	-
Conversion Freshwater-Seawater	-	10-25%	23-33%	20-50%	23-41%	-
Reliability	-	very high	very high	Moderate	High	-
Maintenance (Cleaning/ year)	-	0.5-1	1-2	More than 5	1-2	-
Pre- treatment	-	Simple	Simple	very simple	Demanding	
Operation requirement	-	Simple	Simple	Demanding	Simple	-
TDS (ppm)	-	<10	<10	200-500	<10	-
Electrical energy (kWh/m^3)	2.7-4	4–6	1.5–2.5	3–5.5	7–12	6-10
Thermal energy (kWh/m^3)	-	50–110	60–110	None	None	-
Electrical equivalent of thermal energy (kWh/m^3)	-	9.5–19.5	5–8.5	None	None	-
Total equivalent electrical energy (kWh/m^3)	-	13.5–25.5	6.5–11	3–5.5	7–12	-

2.5 Desalination Technologies and Environment

Brine is a type of water created from desalination with large amount of salt, which has negative effects on the environment when disposed. (Mogheir & Al Bohissi, 2015; Miller, et al, 2015). Poblete & Kamil (2016) discussed methods of brine disposal that include evaporation, on the contrary Hajbi & M'nif (2010) suggested that the best practice is to re-use the various kinds of salt, e.g. (NaCl, KCl, $CaSO_4{\cdot}2H_2O$, $MgSO_4{\cdot}7H_2O$) in the field of industry. Similarly, Abdulsalam & Ahsan (2016) proposed the evaporation ponds for filtering minerals from brine. On the other hand Ariono & Wenten (2016) investigated methods for brine disposal by recovering both brine and water or removing pollutant components to accommodate with environmental regulations when disposed. Abdul-Wahab & Al-Weshahi (2009) suggested seaside desalination, which is the least costly for brine disposal ,in which it is released into the sea, whereas Bresdin & Glenn (2016) discussed other options for wastewater when located at coastline regions. Those options are: using open waterways to carry wastewater and evaporation pools.

This study was conducted to find the optimal technique for both brackish and sea water in Palestine using solar energy. In fact, desalinated water can be used for drinking purposes after making sure that achieves the standards of WHO and the PWA.

Chapter Three
Methodology and Procedures

3.1 Methodology

The research highlights the current water and energy issues in both Zbaidat Village and Gaza Strip. The required data for the different desalination technologies was collected from the previous studies and using ROSA software. Then the collected data was analyzed using MCDA as a tool of Decision Support System to achieve the objective of the study.

The study consists of two scenarios the first one is desalinating the brackish water in Zbaidat Village, the data for both RO and NF were collected from literature review and the water specifications inserted to ROSA to get the required energy for the two desalination technologies, then the results were used in MCDA to optimize the desalination technique.

The second scenario is desalinating the sea water in Gaza Strip, the data were collected for RO, MED and MSF desalination technologies from literature review, then the MCDA was used to optimize the desalination technique. ROSA was used to evaluate the required energy for RO. The difference in the two scenarios was in desalination technologies used for the brackish and sea water. The NF and RO consume less energy and give a greater output, so these techniques are more suitable for brackish water. NF can be used as a pretreatment to another desalination technology for sea water to give potable water. Another difference was the sorting of the steps that was followed. On the contrary of sea water, for brackish water ROSA was used before the MCDA.

3.2 Variables of the Study

The study contained the following variables:

1- The independent Variables

The criteria and sub criteria used in the consideration of optimal photovoltaic desalination technologies were summarized in the Table (3.1):

Table (3.1): Criteria and sub criteria used in the MCDA(Snober, 2017)

Criteria	**Sub criteria**
Cost ($/m^3)	Capital cost
	Energy
	Skilled Labors
	O&M
Efficiency	Energy Required(kWh/m^3)
	Rejection %
Productivity	Fresh Water Recovery%

1. Cost: The price of desalinated water is the furthermost related values to associate desalination techniques with other methodical choices to provide water for different sectors and uses. Clearly, the cost of yielding desalinated water differs from service to service due to specific considerations, such as the position, service design, plant dimension and available scientific knowledge (Elazhar et al., 2015). The cost was given the largest weight**.**

2. Efficiency: the indicators for the effective performance of the desalinating system used is productivity in the form of flux and water recovery, desalinating effectiveness in the form of retention about TDS and some separate elements and energy necessities (Dach, 2008). In this study, efficiency contains the energy requirement (kWh/m^3) and the rejection rate of salts.

3. Productivity: The productivity was compared as fresh water recovery (%). The data collected from the literature review and from ROSA program.

2- Dependent Variables

The dependent variables are the desalination technologies as follows:

- For brackish water: RO and NF.
- For Sea Water: RO, MED and MSF.

3.3 Multi Criteria Decision Analysis

Multi-Criteria Decision Analysis has been one of the fastest growing problem areas in many disciplines. The central problem is how to evaluate a set of alternatives in terms of a number of criteria. Although this problem is very relevant in practice, there are few methods available and their quality is hard to determine. Thus, the question `Which is the best method for a given problem?' has become one of the most important and challenging ones.

MCDA was used to optimize the desalination technologies operated by photovoltaic system with seawater and brackish water. The steps used for MCDA were as follows (Yakowitz, Lane & Szidarovszky,1993):

1- Picking out the alternatives to be considered, which consisted of the desalination techniques basic options.

2- Defining the criteria and sub criteria.

3- Giving rates for the criteria of each desalination technique.

4- Giving weights for the different criteria and sub criteria, the weights should be normalized such that the sum of the weights equal one .

5- Combining the weights and the scores using the conventional linear additive model.

6- The evaluation measure (weighted sum) for each alternative is defined as:

Evaluation measure = $\sum$weights*values

The selection guideline is as follows: Choose the alternative with the largest value.

3.4 Reverse Osmosis System Analysis

Examining the RO, NF sections by ROSA software, which is used for the design of RO and NF membrane treats. The system pattern should first be determined and then included in the software. The input includes: water classification, individual solutes, system recovery rate, flow rates, pH, temperature, membrane configuration like the number of pressure vessels in each pass, and the type of membrane element used. To determine the membrane performance and the energy requirement for RO desalination systems, ROSA software is used (Gilau and Small, 2007).

After specifying the inputs, the software computes the power needed, the feed pressure, and the quantity of the produced water depending on the set recovery and the area of membrane required. The program has been run for multiple times. The required energy to yield fresh water is then determined (Gilau and Small, 2007). In order to get the best design decision in terms of energy and expense, the number and types of membrane elements should be varied (Niazi et al., 2009).

Chapter Four

4.1 Results and Discussion

The data for BW used in this study was taken from Zbaidat desalination plant. Zbaidat is a village which lies 35km north of Jericho City and bordered by the Jordan River to the east, Marj Na'ja village to the north, Tubas city to the west, and Marj al Ghazal village to the south (ARIJ, 2012). The location of Zbaidat village is shown in Figure (4.1).

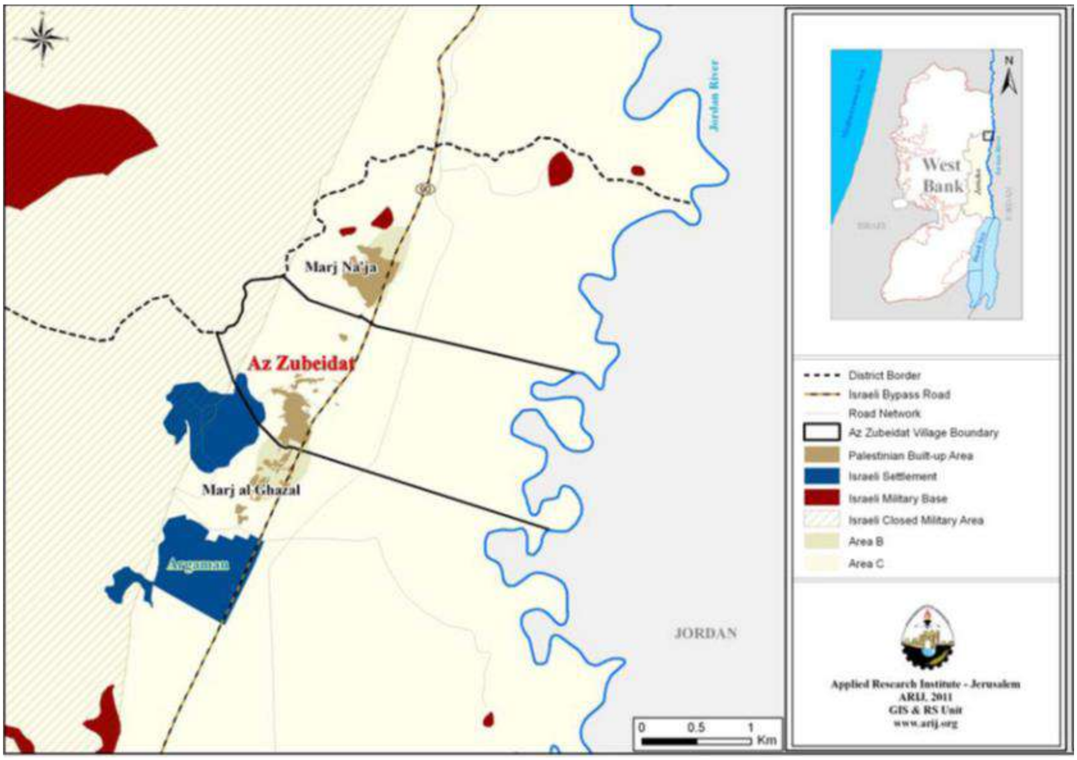


Figure (4.1): Zbaidat Village Location (ARIJ, 2012).

Zbaidat village has only three ground water wells with BW. The BW from one well is pumped to a concrete storage tank. The inhabitants of the village use the water from the tank for different purposes but not for drinking. Zbaidat desalination plant is the first Brackish Water Reverse

Osmosis system operated by solar energy (PV) in Palestine, the plant has a capacity of 10m^3/d, and it has been implemented by Al-Najah University in cooperation with local contractor (General Environment Services - GES) under the supervision of PWA. This project was donated by MEDRC (Shaieb, 2013). To know the water quality of the well and the tank, see Table (4.1).

Table (4.1): Water quality analysis Zbaidat storage tank (ANU-WESI, 2013).

Quality Parameter	Unit	Water Source
		Zbaidat Tank
TDS	mg/l	2636
TSS		10
PH		7.58
Chloride		1200
Sodium		483
Sulfate		157
Magnesium		146
Calcium		200
Potassium		13.1
Iron		0
Bicarbonate		305
Bromide		9.80
Silica		21.6
Boron		0.46
Nitrate		36
Hardness	mg/L as $CaCO_3$	1098.0
Turbidity	NTU	1.00

The whole information related to the existing Zbaidat desalination plant are in Table (4.2).

Table (4.2): Zbaidat Desalinating Pilot plant for Brackish water Source: (Bsharat, 2014).

1. General	
1.1 Location of the WTP	Zbaidat Village
1.2 Donor	MEDRC
1.3 Implementing Agency	PWA via Al-Najah University
1.4 Designer of the WTP	Global Environmental Services (GEC)
1.5 Manufacturer of the WTP	Different Manufacturer's
1.6 Operator of the WTP	Zbaidat Local Council
1.7 Operating hours	4-6 Hours/Day
1.8 Establishment year	2012
1.9 Capacity of WTP	10 m^3/day
1.10 Treatment technology	Pre-filtration- Multimedia filtration – RO
2. Status of Effluent	
1.9 Infflunet source	Ground water well – Main water tank
2.1 Infflunet Quality	TDS: 2636 mg/l Na: 483 mg/l Cl: 1200 mg/l HCO3: 305 mg/l
3. Specify the units included in WTP	
Equilizing tank	Not found Supplied directly from village tank
Intake pump	Found Q: 3 m^3/ hr H: 42.7 – 59.2 m
RO unit	Found Q: 3 m^3/ hr H: 192 m
Disifiction unit	Not found
Brine disposal method	Not found
PH adjustment method	Not found pH: 7-7.5
Unti-scalent unit	Found 100 lieter tank + Dosing pump
PV plant (Power Supply)	Found 28 Solar Module (each of 180 watt)
Others CIP unit (Clean in Place)	Found Washout of Pumps and Membranes
1.3 List any other chemical and their use	Unti-scalents
4. **Status of Effluent**	
4.1 Are there analyses for the Permate? If not Make your own	Yes
4.2 Permate analysis (Main parameter's) (mg/l)	TDS: 29 Na: 6.4 Cl: 20.9 HCO3: --

4.3 Do the results of the analysis comply with the palestininan standards?	Domestic use
4.4 What is the proceedure of disinfiction?	Sodium Hypochloride
4.5 Detemine the power source.	PV Plant 5 KW/Hr
4.6 Explane the brine disposal method	The treatment method for the brine is by plending with agricultural water
4.7 Determine the effluent reuse method	Other's, Please specify:Domestic use
5. Capital & Operational Cost	
5.1 Capital cost of the plant	$ 120 000 (USD)
5.2 Cost per cubic meter including operating and maintenance	$ 0.183 (USD)/m^3

4.2 The design of the system using ROSA program

1- Data about RO plant for the BW:

Enter the project data in ROSA program, such as the project title, units of temperature, flow and pressure as shown in Figure (4.2).

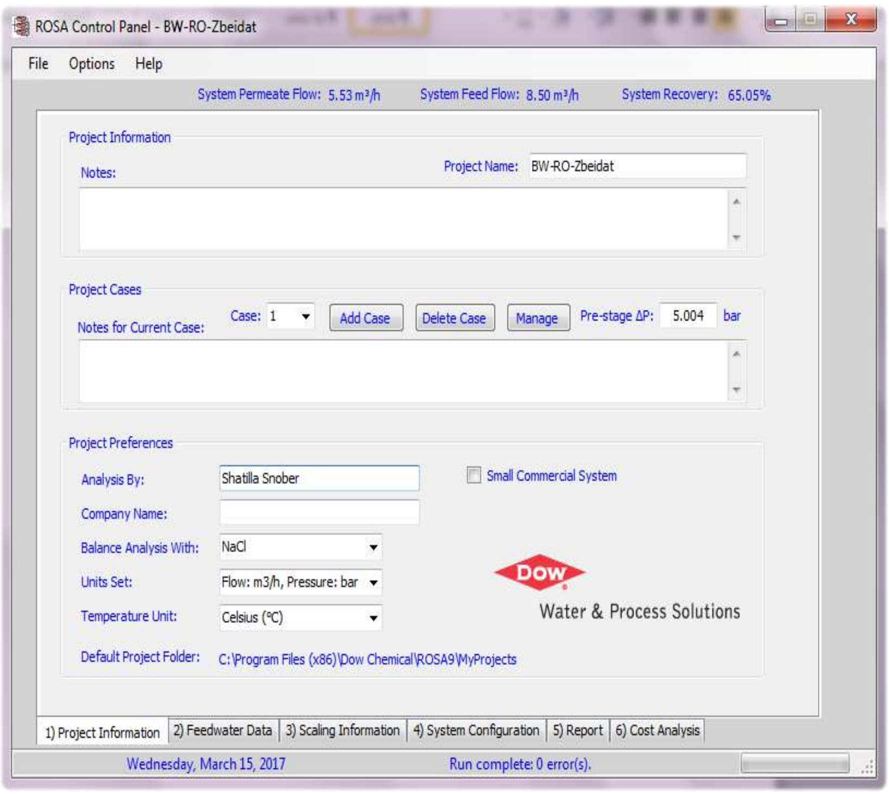


Figure (4.2): Project information at ROSA program.

2-Feed water information:

Enter the type of the feed water, the Silt Density Index which is a fouling measure when it has a value less than one the feed water has a high quality that would provide trouble free operation of the membrane for years and in this case the SDI<3 means the feed water has a low to moderate quality so the membrane operates for few months before it needs cleaning. Enter the concentration of Ions in the water (mg/l), temperature (°C) and pH as in Figure (4.3), the numbers in this figure differs than in Table(4.1) because an adjustment of the ions was made.

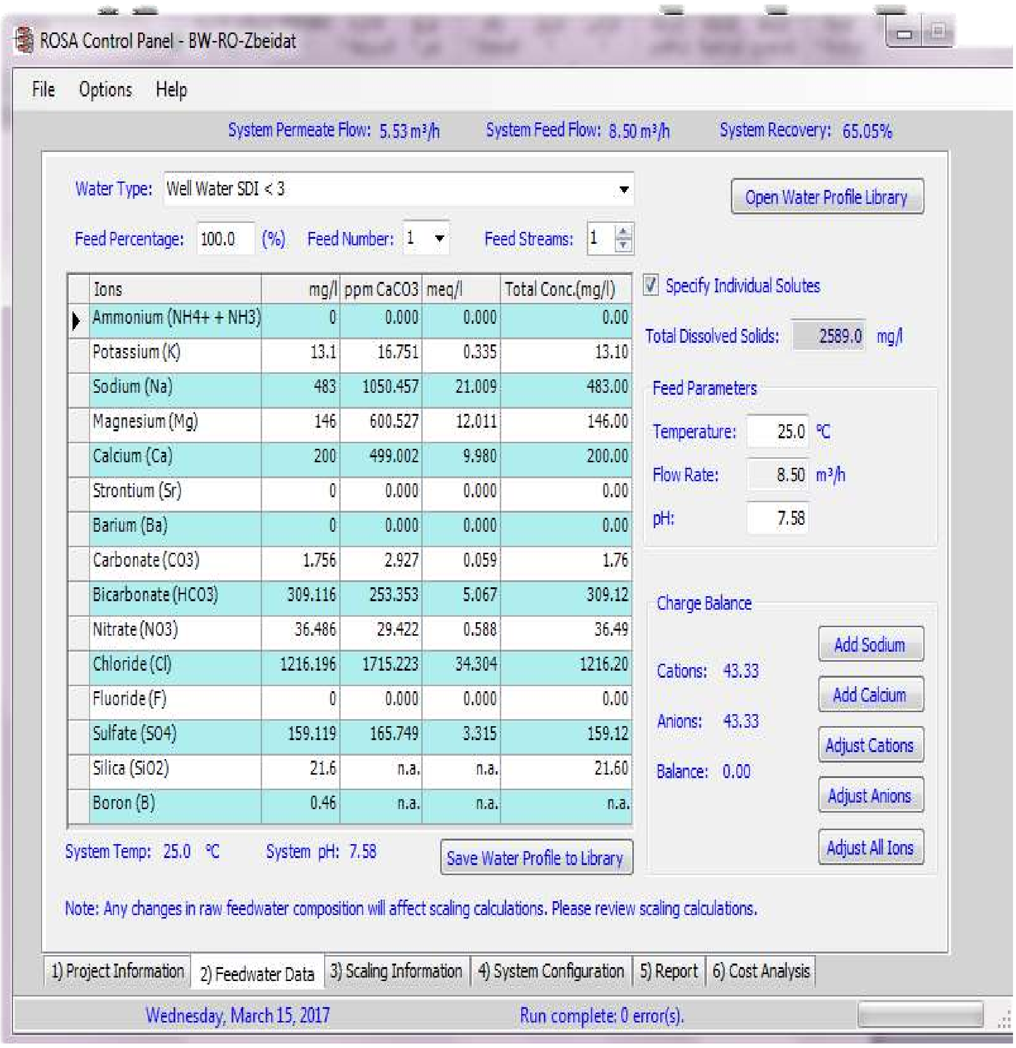


Figure (4.3): Feed water information at ROSA program.

3-Scaling information:

Enter the chemical dosing if it is used in the system, many methods can be used to minimize scaling like acid addition, H_2SO_4 is used as in the Figure (4.4).

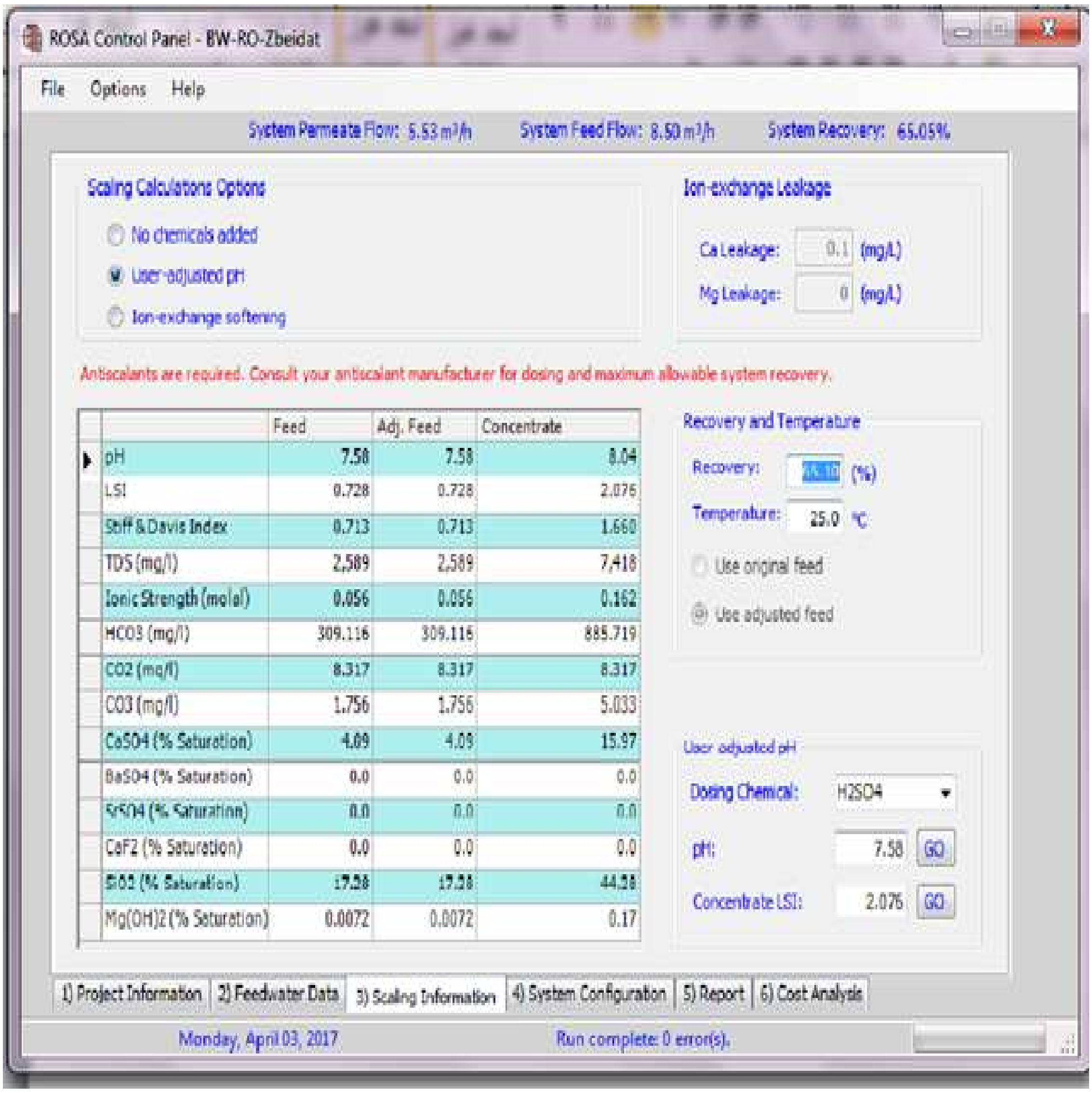


Figure (4.4): Enter the chemical dosing .

4- System Configuration

In this step calculate feed flow, recovery, permeate flow, and determine type of membrane, number of membranes, number of pressure vessels in each stage, number of elements in each vessel and many thing else, as shown in Figure (4.5)

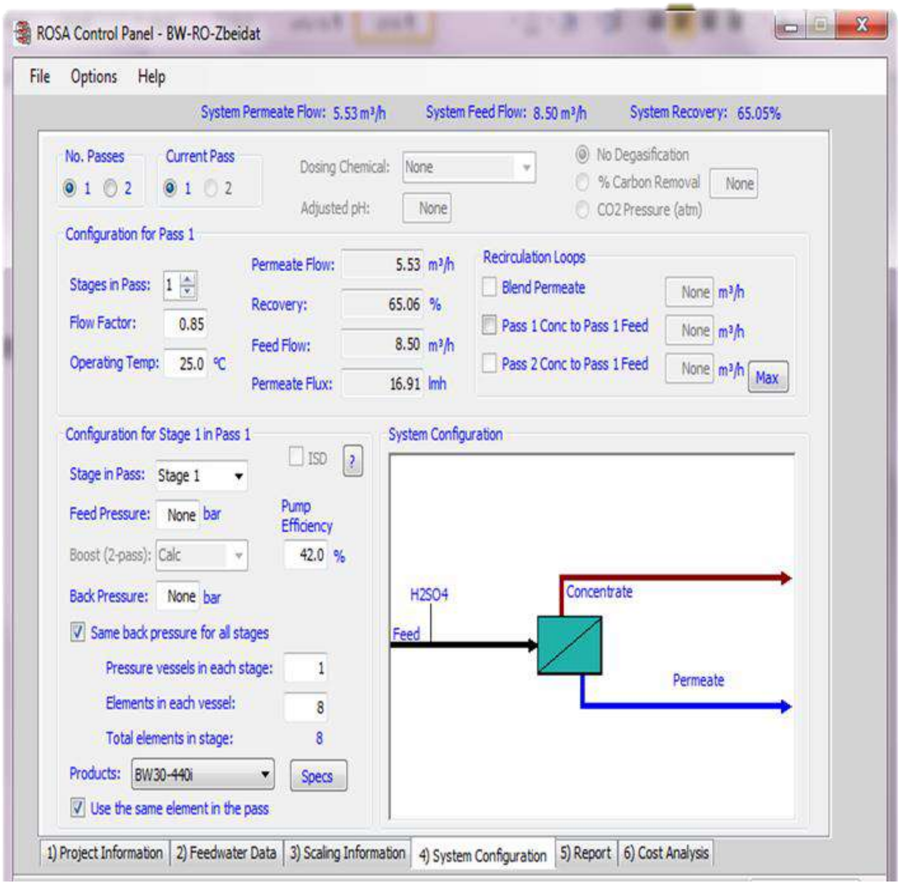


Figure (4.5): System configuration at ROSA program.

5- Report

The obtained report is shown in the Appendix (Report A). The main results of the RO are summarized in Table(4.3).

Table (4.3): Results of RO from ROSA for BW.

	RO
Element type	BW30-440i
Pressure Vessels/ Stage	1
Elements / Pressure Vessel	8
Total # of Elements	8
Feed Flow(m^3/h)	8.50
Feed Press(bar)	9.45
Conc. Flow(m^3/h)	2.97
Conc. Press (bar)	8.36
Perm Flow (m^3/h)	5.53
Perm Press(bar)	0
Stage Average Flux(lmh)	16.9
Permeate TDS(mg/l)	60.11
Energy (kWh/m^3)	1.47
Recovery	65.05

4.3 BW-NF-Zbaidat

The steps were followed as in RO using ROSA, but the element type was changed to NF 90-400 to take the results and compare it with RO under the same conditions to obtain the optimal one using MCDA. The results of Nano Filtration is in the Appendix (Report B). The main results are summarized in Table (4.4).

Table (4.4): NF results from ROSA.

	NF
Element type	NF90-400
Pressure Vessels/ Stage	1
Elements / Pressure Vessel	8
Total # of Elements	8
Feed Flow(m^3/h)	8.50
Feed Press(bar)	5.72
Conc. Flow(m^3/h)	2.97
Conc. Press (bar)	4.62
Perm Flow (m^3/h)	5.53
Perm Press(bar)	0
Stage Average Flux(lmh)	18.60
Permeate TDS(mg/l)	321.74
Energy (kWh/m^3)	1.09
Recovery	65.06

The required information for MCDA (for both RO and NF) as in Table (4.5) was taken from the results obtained using ROSA (report A, B in the Appendix), and the costs were taken from Table(4.6) at capacity<20m^3/day.

Table(4.5): Required data for MCDA (from literature and ROSA).

	Value of Alternative	Rating	
Criteria	Sub criteria	NF90-400	BW30-440i
Cost ($/m^3)	Capital cost	0.0004	7.42
	Energy	0.08	0.12
	Skilled labor	0.03	0.03
	O&M	1.19	1.33
Efficiency	Energy (kWh/m^3)	1.09	1.47
	Rejection %	0.88	0.98
Productivity	Fresh Water Recovery%	65.06	65.06

Table(4.6): Costs for NF and RO

Technologies	**Capacity of production (m^3/d)**	**Cost**	**Source**
NF	100,000	0.214 €/m^3	Costa and de Pinho (2006)
	20,000	(0.24-0.32) €/m^3	Wiesner et al (1994)
RO	<20	(4.50-10.33) $/m^3	E. Tzen (2006)
	20-1200	(0.78-1.33) $/m^3	Karagiannis and Soldatos(2007)
	40,000-46,000	(0.26-0.54) $ /m^3	Mohesn, Jaber and Afonso et al (2004)

The weights were given to the criteria and sub criteria depending on the importance (the weights for both criteria and sub criteria should be normalized, each weight divided by the total weights) and multiplied by the rates of the alternatives, the rating of each alternative for each criteria indicates how will the alternative perform as each criteria is considered. Rating as in Table (4.7) can be used:

Table(4.7): Rating Values (Yakowitz, Lane & Szidarovszky,1993).

very poor	(0-2)
Poor	(3-5)
Good	(6-8)
very good	(7-10)

Then the sum was taken for each of them (like total cost of RO and NF). Then the weights were given to the criteria, where the cost took the largest weight (wt.= 0.4) because it is the most important, then the efficiency (wt.= 0.3) and the productivity(wt.= 0.3). Multiplication and sum were made as in the Table (4.8).

As we can see from MCDA, that NF is more suitable for brackish water than RO in terms of cost, efficiency, and productivity. Nano filtration has a sum of (8), and RO sum was (6.8) as in Table (4.8).

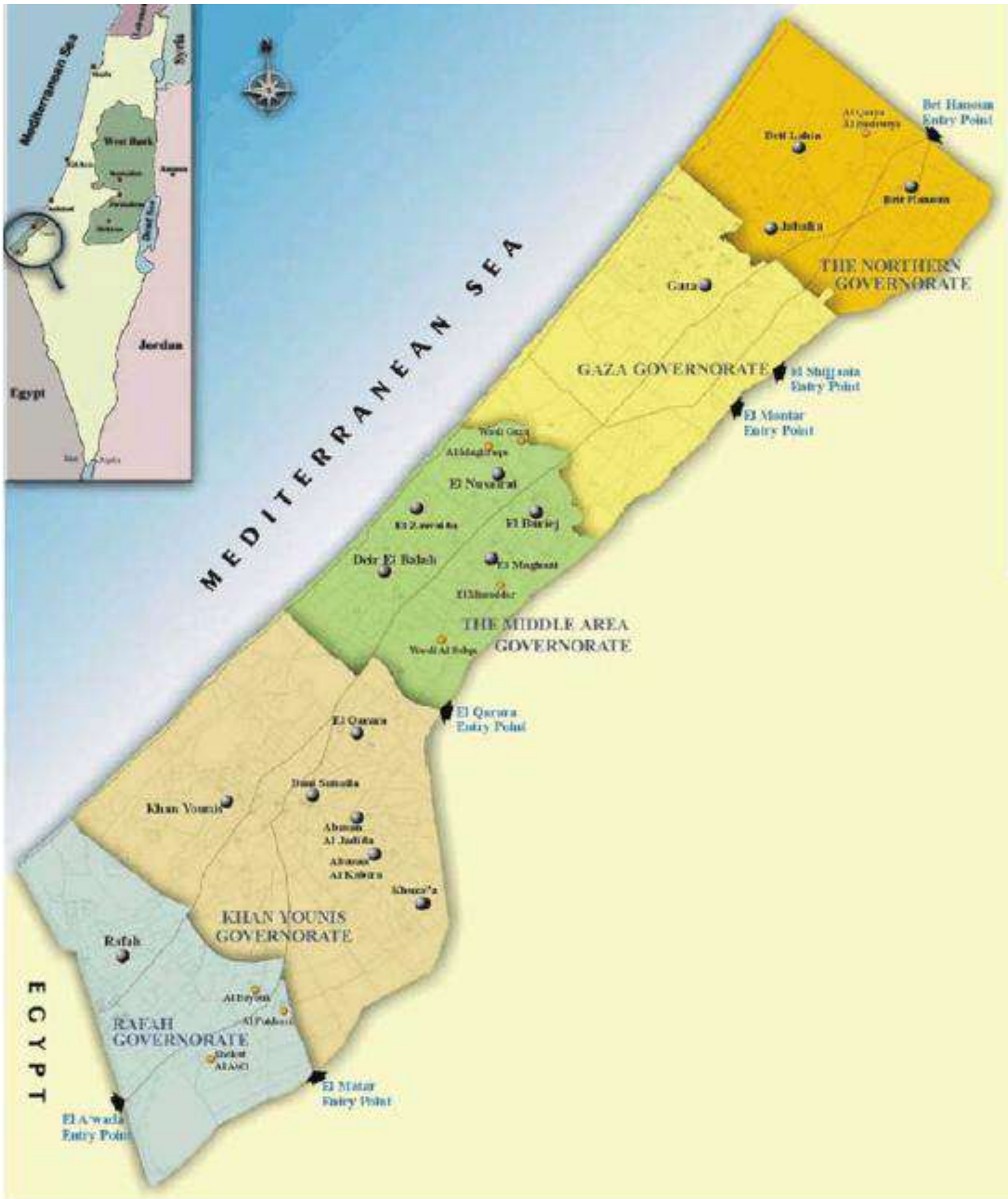
Table (4.8): Comparison between NF90-400, BW30-440i, RO desalination systems relating to cost, efficiency, and productivity.

Criteria	Sub criteria	Rated NF 90-400	Rated BW30-440i	Weight sub criteria	Weighted NF	Weighted RO	Weight of criteria	Wt. NF	Wt. RO
Cost ($\$/m^3$)	capital cost	7.00	5.00	0.40	2.80	2.00			
	Energy	8.00	6.00	0.18	1.44	1.08			
	labor(experienced)	7.00	7.00	0.02	0.14	0.14			
	O&M	9.00	7.00	0.40	3.60	2.80			
				Sum	7.98	6.02	0.40	3.20	2.41
Efficiency	Energy required(kWh/m^3)	10.00	6.00	0.50	5.00	3.00			
	Rejection %	8.00	9.00	0.50	4.00	4.50			
				Sum	9.00	7.50	0.30	2.70	2.25
Productivity	fresh water recovery%	7.00	7.00	1.00	7.00	7.00	0.30	2.10	2.10
							Sum	8.00	6.80

4.4 Optimization of seawater desalination in Gaza strip

Gaza Strip lies on the eastern coast of the Mediterranean Sea as in Figure (4.6). More than 90% of the population of the Gaza Strip depends on desalinated water for drinking purposes. About 90% of the groundwater is unacceptable for drinking as a result of contamination by nitrate and chloride. One of the major options for resolving the water problems is the utilization of desalination technology for both sea and brackish water (Al-Agha & Mortaja, 2005). Gaza's original desalinization plant in Deir al-Balah was started in 2014. It should be noted that this plant must by now be capable of produce 6,000 m^3/day of potable water.

The plant still needs to undertake rigorous testing of the pumps performance, filter and reverse osmosis membranes, which are accredited for purifying the water (Niazi, et al, 2009).



Figure(4.6): Gaza Strip Location Map (Al-Agha & Mortaja, 2005).

4.4.1 Optimal technique for seawater desalination

MED, MSF, RO is compared using MCDA, where the required data was collected from literature review Table (2.2), and the different costs from Table(4.9). Then rates and weights were given as in Table(4.10).

Table (4.9): Total costs of different desalination method (Frederick. J, 2010).

	Investment In plant capacity USD/m^3		Energy USD/m^3		Consumable USD/m^3		Labor USD/m^3		Operating and Mainte-nance USD/m^3		Total Running Cost USD/m^3	
Process	Low	high	Low	High	Low	High	low	High	low	high	low	High
MSF	1000	2000	0.6	1.8	0.03	0.09	0.03	0.2	0.7	2.21	1.36	4.3
MED	900	1800	0.38	1.12	0.02	0.15	0.03	0.2	0.47	1.59	0.9	3.06
VC	900	2500	0.56	2.4	0.02	0.15	0.03	0.2	0.65	2.91	1.26	5.66
SWRO	800	1600	0.32	1.28	0.09	0.25	0.03	0.2	0.48	1.83	0.92	3.56
BWRO	200	500	0.04	0.40	0.05	0.13	0.03	0.2	0.124	0.77	0.24	1.5
ED	266	328	0.06	0.40	0.05	0.13	0.03	0.2	0.156	0.749	0.3	1.48

Table (4.10): A Comparison between RO, MED, MSF desalination systems relating to cost, efficiency, productivity (for low capacity).

Criteria	Sub criteria	wt. sub criteria	Rate RO	Rate MED	Rate MSF	wt sub RO	Wt sub MED	wt. sub MSF	wt criteria	wt. RO	wt. MED	wt. MSF
Cost($/m^3)	capital cost	0.40	9.00	7.00	5.00	3.60	2.80	2.00				
	energy	0.18	3.00	4.00	2.00	0.54	0.72	0.36				
	Skilled labor	0.02	9.00	9.00	9.00	0.18	0.18	0.18				
	O&M	0.40	8.00	9.00	7.00	3.20	3.60	2.80				
					Sum	7.52	7.30	5.34	0.40	3.00	2.90	2.14
Efficiency	Energy req.(kWh/m^3)	0.50	10.00	5.00	2.00	5.00	2.50	1.00				
	Rejection %	0.50	8.00	9.00	9.00	4.00	4.50	4.50				
					Sum	9.00	7.00	5.50	0.30	2.70	2.10	1.65
Productivity	fresh water recovery%	1.00	9.00	7.00	5.00	9.00	7.00	5.00				
					Sum	45.00	33.00	25.00	0.30	13.50	9.90	7.50
									Sum	19.20	15.00	11.30

The RO has the largest sum(19), so it is the optimal technology for seawater desalination.

4.4.2 Steps for a membrane element design (RO plant in Gaza Strip)

The steps that were followed to design a Membrane System and the calculations (equations) were according to Baker (2000) :

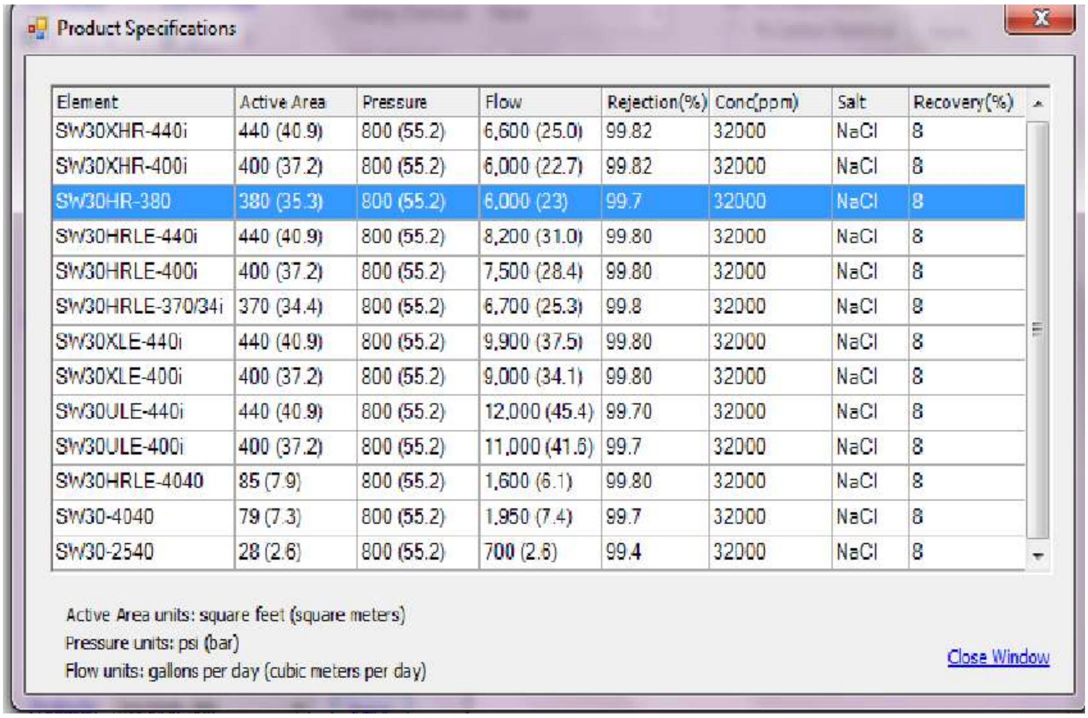
1. Specifying the feed source, feed quality, and required permeate quality. That is the feed water is the seawater, the quality of the permeate should abide by the PWA and WHO standards and the selection of the flow configuration and the passes number in the system.
2. Selecting the flow configuration and number of passes. In other words, the plug flow is the standard flow configuration for water desalination in which the feed volume passes once through the system. The recirculation of the concentrate is largely used for small commercial systems or for large ones with small number of elements when it's difficult to achieve high recovery rate with the plug flow.

The RO system have two types of operation: the first is continuous operation , in which the flow is continuous and the operation conditions for each element in the plant are constant with time, so RO is usually designed using this type. The second one is the batch operation in which the feed water discharged not continuously, so a tank is used to collect feed water and then treat it periodically, this type used for wastewater treatment and industries.

In a stage of RO system more or equal to two pressure vessels are placed in parallel, one stream of feed water go in the RO system, and exits as a concentrate and a permeate water. Where as in a double stage RO system the concentrate from the first stage is converted into feed water to the second stage. To increase the recovery rate ,the permeate water is collected from the first stage and blended with the permeate water from the second stage. Using a staging ratio of two to one for a typical double stage system.

3- Selecting membrane element type, considering the TDS

and fouling tendency of the feed water and the required rejection and the energy needed. For a system greater than 2.3 m^3/h, the standard element has a diameter of 8" and a length of 40". Smaller sizes for smaller systems are accessible. The typical membrane that was chosen for a single pass of seawater desalination is SW30HR-380 as shown in Figure (4.7) with high salt rejection and has the following specifications.



Element	Active Area	Pressure	Flow	Rejection(%)	Conc(ppm)	Salt	Recovery(%)
SW30XHR-440i	440 (40.9)	800 (55.2)	6,600 (25.0)	99.82	32000	NaCl	8
SW30XHR-400i	400 (37.2)	800 (55.2)	6,000 (22.7)	99.82	32000	NaCl	8
SW30HR-380	380 (35.3)	800 (55.2)	6,000 (23)	99.7	32000	NaCl	8
SW30HRLE-440i	440 (40.9)	800 (55.2)	8,200 (31.0)	99.80	32000	NaCl	8
SW30HRLE-400i	400 (37.2)	800 (55.2)	7,500 (28.4)	99.80	32000	NaCl	8
SW30HRLE-370/34i	370 (34.4)	800 (55.2)	6,700 (25.3)	99.8	32000	NaCl	8
SW30XLE-440i	440 (40.9)	800 (55.2)	9,900 (37.5)	99.80	32000	NaCl	8
SW30XLE-400i	400 (37.2)	800 (55.2)	9,000 (34.1)	99.80	32000	NaCl	8
SW30ULE-440i	440 (40.9)	800 (55.2)	12,000 (45.4)	99.70	32000	NaCl	8
SW30ULE-400i	400 (37.2)	800 (55.2)	11,000 (41.6)	99.7	32000	NaCl	8
SW30HRLE-4040	85 (7.9)	800 (55.2)	1,600 (6.1)	99.80	32000	NaCl	8
SW30-4040	79 (7.3)	800 (55.2)	1,950 (7.4)	99.7	32000	NaCl	8
SW30-2540	28 (2.6)	800 (55.2)	700 (2.6)	99.4	32000	NaCl	8

Active Area units: square feet (square meters)
Pressure units: psi (bar)
Flow units: gallons per day (cubic meters per day)

Figure (4.7): Membrane types in ROSA program**.**

4- Selecting an average membrane flux. Specifically, there is no specific value of flux for the elements chosen, but a range between (11-17) l/m^{2}h where specified by DOW Chemical Company for seawater SDI< 5. Here a flux of 14 l/m^{2}h is chosen.

5- Calculation of the number of required elements Recovery rate=60%

The design permeate=6000m^3/h**.**

$$NE = \frac{QP}{f}.SE = \frac{\frac{6000m^3}{h}}{\frac{14\,.\frac{l}{m^2}.h * 1m^3 * 35.3\,m^2}{1000l}} = 12141$$

N$_E$: Number of elements

$QP = design\ permeate\ flow = recovery * feed\ flow$

F: flux=14 l/m^{2}h

S_E: area of selected element(m^2 or ft^2)=35.3m^2

6- Calculate number of pressure vessels needed

$NV = NE/NEPV = 12141/6 = 2024$

N_{EPV}=6 element vessels are standard for large systems, 8 for smaller systems.

Nv: is round up to get the final value.

7- Select number of stages, From Table (4.11) depending on the recovery(60%), and 6 element in each vessel the number of stages=2

Table (4.11): Number of stages (Baker, 2000).

# of stages (8-element vessels)	# of stages (7-element vessels)	# of stages (6-element vessels)	# of serial element positions	System recovery (%)
–	1	1	6	35 – 40
1	1	2	7 – 12	45
1	2	2	8 – 12	50
–	2	2	12 – 14	55 – 60

8- Choosing the staging ratio, which can be defined as the relation between a number of pressure vessels in successive stages. For example a system that has eight vessels in the first stage and four in the second will have the staging ratio 2:1. The staging ratios for a brackish water system, between two successive stages are usually near to 2:1 for 6-element vessels, and less than that for shorter vessels. The typical staging ratio for a two-stage seawater systems with 6-element vessels, is 3:2. The ideal staging for a system is that each stage functions at the same recovery fraction, if all pressure vessels have the same number of elements (Lattemann & Höpner, 2008).

$R = (1/(1-Y))^{1/n} = (1/(1-0.6))^{1/2}$

$R = 1.58$

R:staging ratio

Y=recovery=60%

n:# stages=2

$Nv1 = Nv/(1 + R^{-1}) = 1240$

$Nv2 = Nv1/R = 785$

9- Balancing the permeate flow rate, which can be done before or after the system has been analyzed with ROSA.

10- Designing configuration on ROSA for Gaza Sea Water Desalination Plant:

a. Project Information:

Enter the project information as in Figure (4.8).

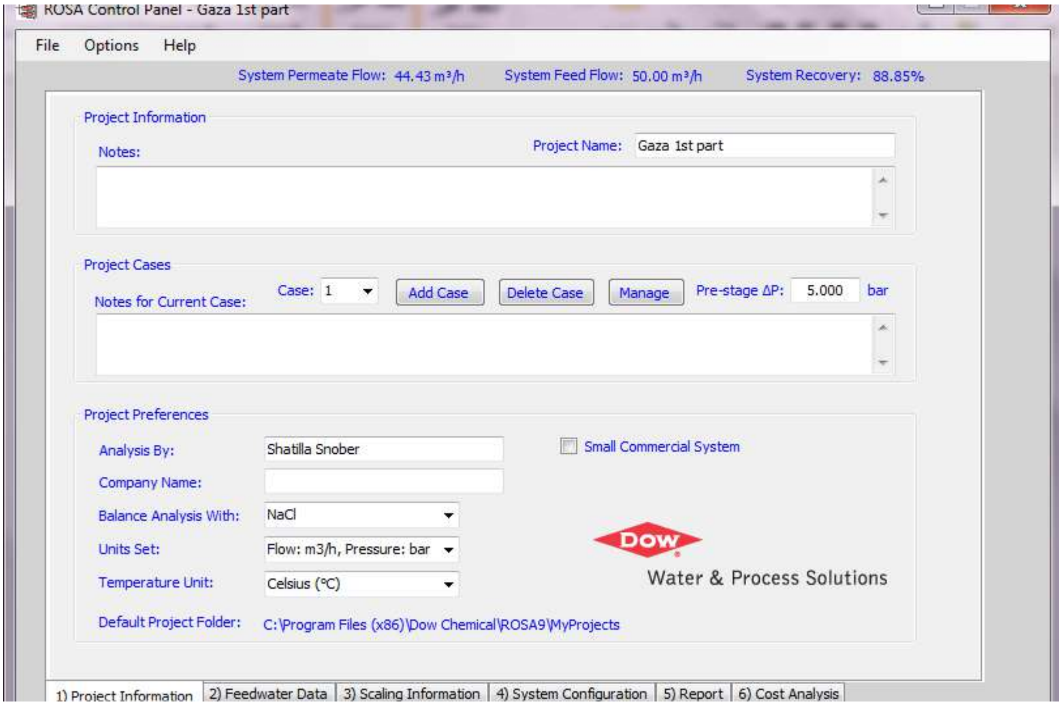


Figure (4.8): Project information at ROSA program

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b. Feed water Data

Enter feed water which contains the following elements as in Table (4.12), to obtain the figure (4.9).

Table (4.12): Feed water to Gaza desalination plant (Shedid & Elshokary, 2015).

Element	Concentration	Percent
CL^-	19.353	55.29
Na^+	10.781	30.80
$SO4^{-2}$	2.712	7.75
Mg^{+2}	1.284	3.67
Ca^{+2}	0.4119	1.18
K^+	0.399	1.14
$HCO3^-$	0.126	0.36
Br^-	0.0673	0.19
$B(OH)_3$	0.0257	0.07
Sr^{+2}	0.00794	0.02
F^-	0.00130	0.004

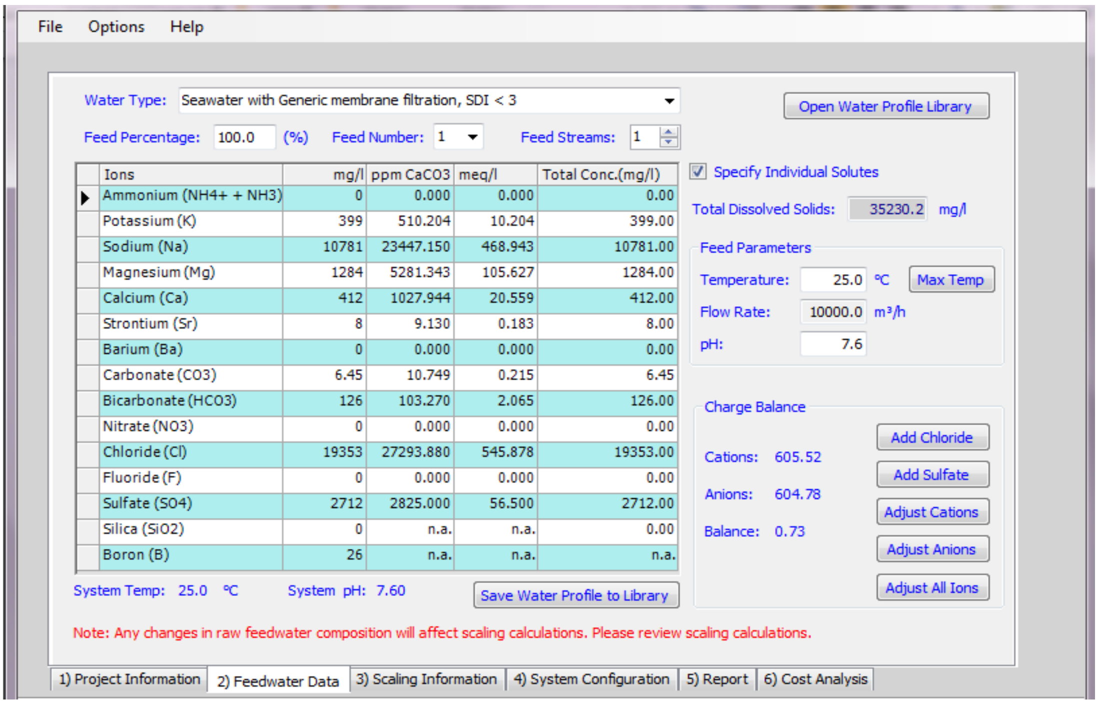

Figure (4.9): Insert the Feed water Data to ROSA software.

c. Scaling information

Enter the dosing chemical if it is used as in figure (4.10).

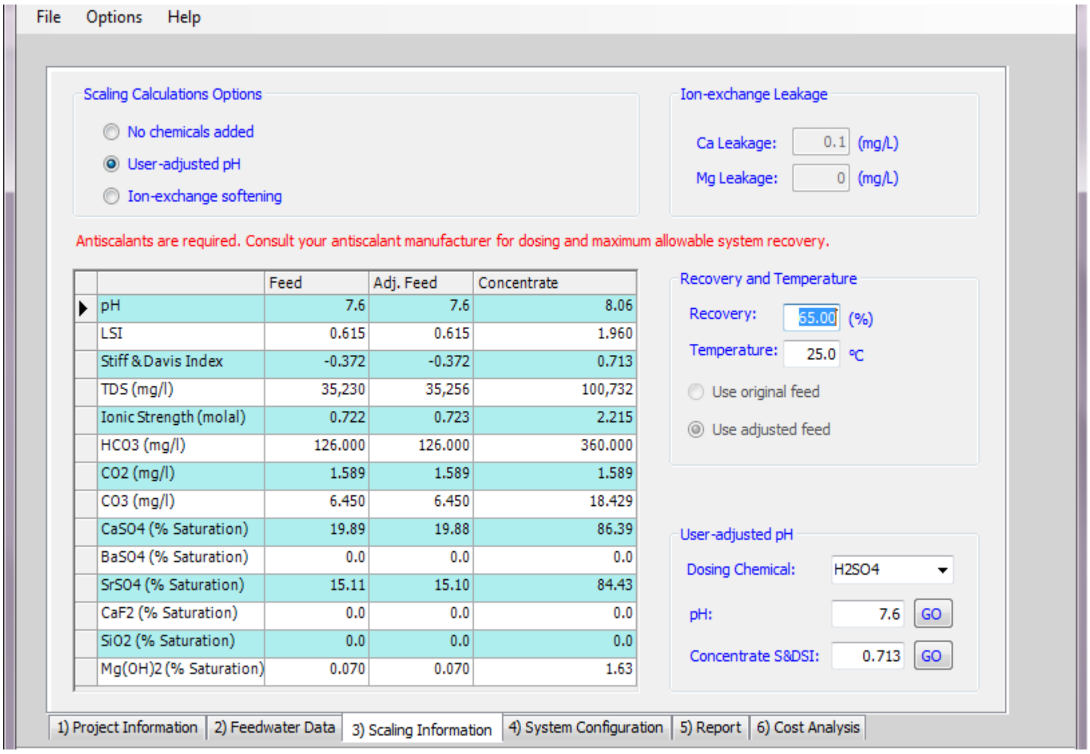

Figure (4.10): Scaling information in Rosa software.

d. System Configuration

Figure the feed flow, recovery, permeate flow, and decide the type and number of membranes, pressure vessels number in each stage, elements number in each vessel and many other things, as in figure(4.11).

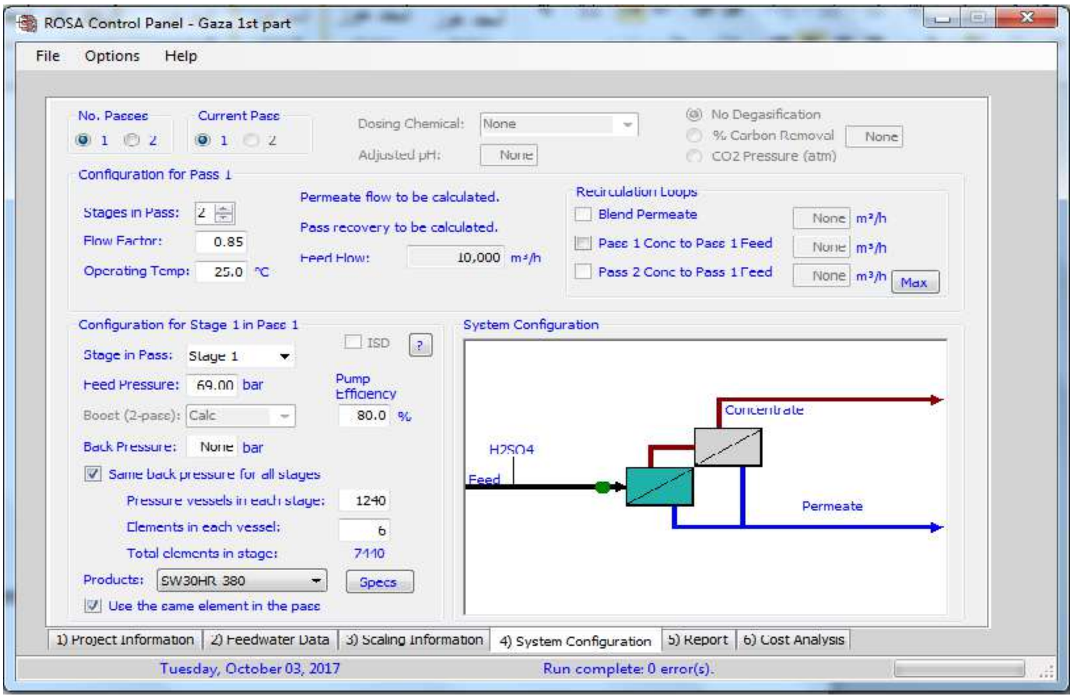

Figure (4.11): System Configuration in ROSA Program

e- Report

The report is shown in the Appendix (Report C), the main results obtained from ROSA are summarized as in Table(4.13).

Table (4.13): RO results using ROSA for Sea water.

	RO- Stage 1	RO- Stage 2
Element type	SW30HR-380	SW30HR-380
Pressure Vessels/ Stage	1240	785
Elements / Pressure Vessel	6	6
Total # of Elements	7440	4710
Feed Flow(m^3/h)	10000	6857.92
Feed Press(bar)	50	43.29
Conc. Flow(m^3/h)	6857.92	6377.40
Conc. Press (bar)	48.29	40.90
Perm Flow (m^3/h)	3142.08	480.52
Perm Press(bar)	0	0
Stage Average Flux(lmh)	18.31	3.23
Permeate TDS(mg/l)	206.84	1378.62
Energy (kWh/m^3)	9.63	
Recovery	53.47 %	

4.4.3 Comparison of The Permeate Quality of both BW and SW with the WHO and PWA Standards of Drinking Water

The permeate quality of both brackish and sea water conforms to the WHO and PWA standards of drinking water as shown in Table (4.14).

Table (4.14): Comparison of the permeate quality with WHO and PWA standards

Parameter	WHO (mg/l)	PWA (mg/l)	BWRO	BW-NF	SWRO
Potassium	5	12	3.02	8.27	4.28
Sodium	200	200	11.88	81.02	99.12
Magnesium	60	150	1.85	9.78	2.66
Calcium	100	100	2.48	13.15	0.85
Chloride	250	600	19.80	151.18	163.45
TDS	500-1000	1500	66.11	321.74	309.14

Chapter Five

5.1 Conclusions

- Many countries suffer from water shortage, especially Palestine due to the occupation that controls the water resources.

- As the NF desalination structures are considered to consume the lower quantity of energy than RO systems in desalinating BW, it is very suitable to be activated by solar electric power methods represented in PV, since Palestine enjoys a high solar energy potential.

- The RO is the optimal technique for SW desalination in Gaza Strip, since it needs the lowest amount of energy than thermal techniques, but the energy there is not sustainable.

- The permeate quality of both brackish and sea water conforms to the WHO and PWA standards of drinking water.

5.2 Recommendation

- Use the non-conventional resources of water as desalination to overcome the water shortage.

- Based on these outcomes, it is suggested to consider the PV powered NF desalination system for remote villages, which have brackish water only.

- Studying the possibility of increasing the recovery in order to increase the productivity of the systems.

- The option of combining power plant for energy generation to a large-scale desalination plants should be investigated, especially in Gaza Strip to keep the desalination plant in operation.

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Appendix

4.2 Report(A):

Report resulting from ROSA for BWRO for Zbaidat.

Project Information:

Feed Flow to Stage 1	8.50	m³/h	Pass 1 Permeate Flow	5.53	m³/h	Osmotic Pressure:		
Raw Water Flow to System	8.50	m³/h	Pass 1 Recovery	65.05	%	Feed	1.67	Bar
Feed Pressure	14.45	Bar	Feed Temperature	25.0	C	Concentrate	4.54	Bar
Flow Factor	0.85		Feed TDS	2589.01	mg/l	Average	3.10	Bar
Chem. Dose (100% H_2SO_4)	0.00	mg/l	Number of Elements	8		Average NDP	5.84	Bar
Total Active Area	327.01	M²	Average Pass 1 Flux	16.91	Lmh	Power	8.13	kW
Water Classification: Well Water SDI < 3						Specific Energy	1.47	kWh/m³

Stage	Element	#PV	#Ele	Feed Flow (m³/h)	Feed Press (bar)	Recirc Flow (m³/h)	Conc Flow (m³/h)	Conc Press (bar)	Perm Flow (m³/h)	Avg Flux (lmh)	Perm Press (bar)	Boost Press (bar)	Perm TDS (mg/l)
1	BW30-440i	1	8	8.50	9.45	0.00	2.97	8.36	5.53	16.91	0.00	0.00	60.11

Pass Streams

Pass Streams (mg/l as Ion)					
Name	Feed	Adjusted Feed	Concentrate	Permeate	
			Stage 1	Stage 1	Total
NH4+ + NH3	0.00	0.00	0.00	0.00	0.00
K	13.10	13.10	31.86	3.02	3.02
Na	483.00	483.00	1359.99	11.88	11.88
Mg	146.00	146.00	414.34	1.85	1.85
Ca	200.00	200.00	567.68	2.48	2.48
Sr	0.00	0.00	0.00	0.00	0.00
Ba	0.00	0.00	0.00	0.00	0.00
CO3	1.76	1.76	13.35	0.00	0.00
HCO3	309.12	309.12	854.41	7.17	7.17
NO3	36.49	36.49	84.79	10.53	10.53
Cl	1216.20	1216.20	3443.24	19.80	19.80
F	0.00	0.00	0.00	0.00	0.00
SO4	159.12	159.12	453.11	1.18	1.18
SiO2	21.60	21.60	61.28	0.29	0.29
Boron	0.46	0.46	0.69	0.33	0.33
CO2	8.32	8.32	12.60	9.24	9.24
TDS	2589.01	2589.01	7288.03	60.11	60.11
pH	7.58	7.58	7.75	6.07	6.07

Stage Details

Stage 1	Element	Recovery	Perm Flow (m³/h)	Perm TDS (mg/l)	Feed Flow (m³/h)	Feed TDS (mg/l)	Feed Press (bar)
	1	0.11	0.89	29.09	8.50	2589.01	9.45
	2	0.11	0.84	34.87	7.61	2889.23	9.22
	3	0.12	0.79	42.12	6.77	3243.10	9.02
	4	0.12	0.73	51.37	5.98	3663.26	8.85
	5	0.13	0.67	63.42	5.25	4164.96	8.71
	6	0.13	0.61	79.46	4.58	4765.11	8.60
	7	0.14	0.54	101.32	3.97	5480.26	8.50
	8	0.14	0.46	131.81	3.43	6321.77	8.43

Scaling Calculations

	Raw Water	Adjusted Feed	Concentrate
Ph	7.58	7.58	7.75
Langelier Saturation Index	0.73	0.73	1.76
Stiff & Davis Stability Index	0.71	0.71	1.35
Ionic Strength (Molal)	0.06	0.06	0.16
TDS (mg/l)	2589.01	2589.01	7288.03
HCO3	309.12	309.12	854.41
CO2	8.32	8.32	12.59
CO3	1.76	1.76	13.35
CaSO4 (% Saturation)	4.09	4.09	15.87
BaSO4 (% Saturation)	0.00	0.00	0.00
SrSO4 (% Saturation)	0.00	0.00	0.00
CaF2 (% Saturation)	0.00	0.00	0.00
SiO2 (% Saturation)	17.28	17.28	49.02
Mg(OH)2 (% Saturation)	0.01	0.01	0.04

To balance: 0.00 mg/l Na added to feed.

4.3 Report(B):

Report resulting from ROSA for NF.

Project Information:

Stage	Element	#PV	#Ele	Feed Flow (m^3/h)	Feed Press (bar)	Recirc Flow (m^3/h)	Conc Flow (m^3/h)	Conc Press (bar)	Perm Flow (m^3/h)	Avg Flux (lmh)	Perm Press (bar)	Boost Press (bar)	Perm TDS (mg/l)
1	NF90-400	1	8	8.50	5.72	0.00	2.97	4.62	5.53	18.60	0.00	0.00	321.74

Feed Flow to Stage 1	8.50	m^3/h	Pass 1 Permeate Flow	5.53	m^3/h	Osmotic Pressure:		
Raw Water Flow to System	8.50	m^3/h	Pass 1 Recovery	65.06	%	Feed	1.67	Bar
Feed Pressure	10.73	Bar	Feed Temperature	25.0	C	Concentrate	4.21	Bar
Flow Factor	0.85		Feed TDS	2586.43	mg/l	Average	2.94	Bar
Chem. Dose (100% H_2SO_4)	0.00	mg/l	Number of Elements	8		Average NDP	2.47	Bar
Total Active Area	297.28	M^2	Average Pass 1 Flux	18.60	Lmh	Power	6.03	kW
Water Classification: Well Water SDI < 3						Specific Energy	1.09	kWh/m^3

Pass Streams

Pass Streams (mg/l as Ion)					
Name	Feed	Adjusted Feed	Concentrate	Permeate	
			Stage 1	Stage 1	Total
NH4+ + NH3	0.00	0.00	0.00	0.00	0.00
K	13.10	13.10	22.09	8.27	8.27
Na	483.00	483.00	1231.41	81.02	81.02
Mg	146.00	146.00	399.62	9.78	9.78
Ca	200.00	200.00	547.88	13.15	13.15
Sr	0.00	0.00	0.00	0.00	0.00
Ba	0.00	0.00	0.00	0.00	0.00
CO3	1.76	1.76	12.51	0.01	0.01
HCO3	309.12	309.12	828.80	21.83	21.83
NO3	36.49	36.49	47.42	30.61	30.61
Cl	1216.20	1216.25	3199.19	151.18	151.18
F	0.00	0.00	0.00	0.00	0.00
SO4	159.12	159.12	448.15	3.88	3.88
SiO2	21.60	21.60	58.06	2.02	2.02
Boron	0.00	0.00	0.00	0.00	0.00
CO2	8.32	8.32	12.28	9.12	9.12
TDS	2586.38	2586.43	6795.15	321.74	321.74
pH	7.58	7.58	7.75	6.51	6.51

Design Warnings:

-None-

Solubility Warnings:

Langelier Saturation Index > 0

Stiff & Davis Stability Index > 0

Antiscalants may be required. Consult your antiscalant manufacturer for dosing and maximum allowable system recovery.

4.6.10 Report(C):

Report obtained from ROSA for SWRO.

Project Information:

Case-specific:

System Details

Pass Streams (mg/l as Ion)							
Name	Feed	Adjusted Feed	Concentrate		Permeate		
			Stage 1	Stage 2	Stage 1	Stage 2	Total
NH4+ + NH3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K	399.00	399.00	766.14	852.38	2.76	19.92	4.48
Na	10781.00	10781.00	20710.02	23050.44	64.98	457.61	104.46
Mg	1284.00	1284.00	2472.04	2756.31	1.79	12.21	2.84
Ca	412.00	412.00	793.22	884.43	0.56	3.91	0.90
Sr	8.00	8.00	15.40	17.17	0.01	0.08	0.02
Ba	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO3	6.45	6.45	15.62	17.64	0.00	0.00	0.00
HCO3	126.00	126.00	235.89	261.59	1.14	6.86	1.71
NO3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cl	19353.00	19379.05	37235.56	41451.38	107.20	754.70	172.31
F	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SO4	2712.00	2712.00	5223.42	5825.88	1.52	10.20	2.39
SiO2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Boron	26.02	26.02	45.78	48.78	4.70	19.78	6.22
CO2	1.59	1.59	3.15	3.59	1.89	2.86	1.99
TDS	35230.17	35256.22	67728.94	75395.98	206.84	1378.62	324.67
pH	7.60	7.60	7.64	7.67	5.93	6.45	6.07

Stage	Element	#PV	#Ele	Feed Flow (m^3/h)	Feed Press (bar)	Recirc Flow (m^3/h)	Conc Flow (m^3/h)	Conc Press (bar)	Perm Flow (m^3/h)	Avg Flux (lmh)	Perm Press (bar)	Boost Press (bar)	Perm TDS (mg/l)
1	SW30HR-380	1240	6	10000.00	64.00	0.00	5190.60	62.93	4809.40	18.31	0.00	69.00	206.84
2	SW30HR-380	785	6	5190.60	57.93	0.00	4652.90	56.73	537.70	3.23	0.00	0.00	1378.62

Feed Flow to Stage 1	10000.00	m^3/h	Pass 1 Permeate Flow	5347.10	m^3/h	Osmotic Pressure:		
Raw Water Flow to System	10000.00	m^3/h	Pass 1 Recovery	53.47	%	Feed	24.83	bar
Feed Pressure	69.00	Bar	Feed Temperature	25.0	C	Concentrate	55.46	bar
Flow Factor	0.85		Feed TDS	35256.22	mg/l	Average	40.15	bar
Chem. Dose (100% H2SO4)	0.00	mg/l	Number of Elements	12150		Average NDP	18.54	bar
Total Active Area	428919.30	M^2	Average Pass 1 Flux	12.47	lmh	Power	51487.09	kW
Water Classification: Seawater with Generic membrane filtration, SDI < 3						Specific Energy	9.63	kWh/m^3

Design Warnings

-None-

Solubility Warnings

Langelier Saturation Index > 0

Stiff & Davis Stability Index > 0

Antiscalants may be required. Consult your antiscalant manufacturer for dosing and maximum allowable system recovery.

Stage Details

Stage 1	Element	Recovery	Perm Flow (m^3/h)	Perm TDS (mg/l)	Feed Flow (m^3/h)	Feed TDS (mg/l)	Feed Press (bar)
	1	0.12	0.99	106.38	8.06	35256.22	64.00
	2	0.12	0.85	137.92	7.08	40156.14	63.74
	3	0.11	0.71	183.06	6.23	45613.19	63.52
	4	0.10	0.57	248.44	5.52	51429.03	63.34
	5	0.09	0.44	343.73	4.95	57288.80	63.18
	6	0.07	0.33	482.62	4.52	62826.75	63.05
Stage 2	Element	Recovery	Perm Flow (m^3/h)	Perm TDS (mg/l)	Feed Flow (m^3/h)	Feed TDS (mg/l)	Feed Press (bar)
	1	0.03	0.18	874.19	6.61	67728.94	57.93
	2	0.02	0.14	1085.45	6.43	69583.77	57.71
	3	0.02	0.12	1339.79	6.29	71161.59	57.51
	4	0.02	0.10	1637.55	6.17	72494.47	57.30
	5	0.01	0.08	1979.05	6.07	73619.64	57.11
	6	0.01	0.07	2328.97	5.99	74572.05	56.91

Scaling Calculations

	Raw Water	Adjusted Feed	Concentrate
pH	7.60	7.60	7.67
Langelier Saturation Index	0.62	0.62	1.32
Stiff & Davis Stability Index	-0.37	-0.37	0.10
Ionic Strength (Molal)	0.72	0.72	1.61
TDS (mg/l)	35230.17	35256.22	75395.98
HCO3	126.00	126.00	261.59
CO2	1.59	1.59	3.59
CO3	6.45	6.45	17.64
CaSO4 (% Saturation)	19.89	19.88	51.34
BaSO4 (% Saturation)	0.00	0.00	0.00
SrSO4 (% Saturation)	15.11	15.10	47.40
CaF2 (% Saturation)	0.00	0.00	0.00
SiO2 (% Saturation)	0.00	0.00	0.00
Mg(OH)2 (% Saturation)	0.07	0.07	0.21

To balance: 26.05 mg/l Cl added to feed.

جامعة النجاح الوطنية

كلية الدراسات العليا

عمليات التحلية لمياه الشرب في فلسطين: الحل الأمثل باستخدام نظام دعم القرار

إعداد

شتيلا عبد الباسط مصطفى صنوبر

إشراف

د. عبد الحليم خضر

قدمت هذه الأطروحة استكمالا لمتطلبات الحصول على درجة الماجستير في هندسة المياه والبيئة بكلية الدراسات العليا، في جامعة النجاح الوطنية، نابلس– فلسطين.

2017

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الملخص

تعاني فلسطين من مشكلة نقص المياه، وهناك إمكانيات جيدة لمعالجة مشكلة نقص المياه في المناطق الريفية والنائية من خلال التقنيات المستدامة لتحلية المياه المالحة.

تهدف هذه الدراسة إلى البحث عن التقنية المثلى لعمليات تحلية المياه الصالحة للشرب في فلسطين باستخدام تحليل القرار المتعدد المعايير كأداة لنظام دعم القرار الذي يهتم بتنظيم وحل مشاكل التخطيط التي تحتوي على معايير متعددة. والغرض من ذلك هو دعم صناع القرار الذين يواجهون هذه المشاكل. واستخدم برنامج ROSA لإيجاد قيم بعض المتغيرات مثل الطاقة المطلوبة لتحلية المياه لكل من تقنيات الترشيح الدقيق والتناضح العكسي .

في تحليل القرار المتعدد المعايير تم تلخيص المعايير والمعايير الفرعية, المستخدمة لتقييم طرق التحلية المثلى باستخدام الطاقة الشمسية, في التكلفة والكفاءة والقدرة الإنتاجية. تحتوي الدراسة على نوعين من المياه, مياه البحر والمياه المالحة (Brackish) التي تختلف في محتواها للأملاح الذائبة الكلية، وهذا الاختلاف يسبب فرقا في تكلفة تحلية المياه اعتمادا على كمية الطاقة المطلوبة. وقد أظهرت هذه الدراسة في الحالة الأولى التي تم تطبيقها في قرية الزبيدات, أن تقنية الترشيح الدقيق (النانو فلتريشن) هو الأسلوب الأمثل لتحلية المياه هناك، حيث أن 1م^3 من المياه العذبة الناتج من تحلية مياه الزبيدات بمحتوى كلي من الأملاح الذائبة 2586ملغم / لتر، يتطلب 1 كيلوواط ساعة، ويمكن الحصول على ذلك باستخدام نظام الخلايا الكهروضوئية وفلسطين لديها قدرة عالية من الإشعاع الشمسي.

وتشير نتائج دراسة الحالة الثانية إلى أن التناضح العكسي هو التقنية الأمثل لتحلية مياه البحر في غزة، حيث أنها تحتاج إلى كمية أقل من الطاقة مقارنة بالتقنيات الحرارية، حيث أن 1م^3 من المياه العذبة الناتج من تحلية مياه البحر بمحتوى كلي من الأملاح الذائبة 35230 ملغم/ لتر، يتطلب 5 كيلو واط ساعة.