DESALINATION IN WATER TREATMENT AND SUSTAINABILITY

HÄMEEN AMMATTIKORKEAKOULU
HÄME UNIVERSITY OF APPLIED SCIENCES

Bachelor's thesis

Construction Engineering

Visamäki/autumn 2016

TOLUMO DESMOND OYOH

HÄMEEN AMMATTIKORKEAKOULU
HÄME UNIVERSITY OF APPLIED SCIENCES

Hämeenlinna
Degree Programme in Construction Engineering
Environmental Technology

ABSTRACT

Author Tolumo Desmond Oyoh **Year** 2016

Subject of Bachelor's thesis Desalination In Water Treatment

ABSTRACT

The purpose of this Bachelor's thesis was to introduce different desalination technologies in solving water scarcity in countries where access to safe drinking water is limited, due to increasing population growth, industrial activities and agriculture. This thesis covers and explains different desalination technologies in dealing with water problems in different countries and the best suitable methods. The thesis was commissioned by HAMK University of Applied Sciences.

The thesis also focuses on the Economic and Social Commission for West Asia (ESCWA) member countries were access to water is limited due to scanty rainfall and dry lands. Desalination technology has played a significant role in solving their water scarcity in the region leading to sustainable development. A case study of Taweelah power and desalination plant in Abu Dhabi was explained providing detailed information.

As a conclusion, it can be stated that desalination in water treatment and sustainability is a significant factor in the world today, because the future of water supply requires adequate sustainability to be able to effectively supply and support the world's increasing population. For the Taweelah power and desalination plant project, a suitable re-design of the intakes and outfall layout should be adjusted. The outfall can be an offshore pipeline instead of its location onshore.

Keywords Desalination, Groundwater, Water resources, Sustainability, Wastewater.

Pages 82 p. + appendices 4 p.

CONTENT

1 INTRODUCTION

Desalination technologies have been used rapidly over the past few decades throughout the globe to produce clean drinking water from groundwater, seawater and brackish, to improve the quality of already existing supplies of fresh water for human consumption, commercial applications or to treat industrial and municipal wastewater prior to reuse or discharge. Water consumption rate in the world today is no doubt an increasing factor outweighing the population growth two times more than its availability. The access or ease of use to good quality water is on the turn down and demand rate is on the increase. The availability of fresh water for human consumption and commercial application in the world today is limited, especially in the Economic and Social Commission for Western Asia (ESCWA) member countries. In recent times different industrial and developmental activities have resulted in increasing the population level and deteriorating the water quality. The shortage of water supply and poor water quality are considered the main problems to accomplish sustainable development and improvement in the quality of life. The increase in population growth as well as the increase in the tourist, industrialization activities and improving life standards have led to an increase in the demand for water and have created an acute shortage of potable water.

Globally, the total installed capacity of desalination plants was 61 million m3 per day in 2008. Seawater desalination is the most common, accounting for 67 percent of production, followed by brackish water, at 19 percent, river water, at 8 percent and wastewater, at 6 percent. Figure 1 below shows the percentage of worldwide feedwater used in desalination.

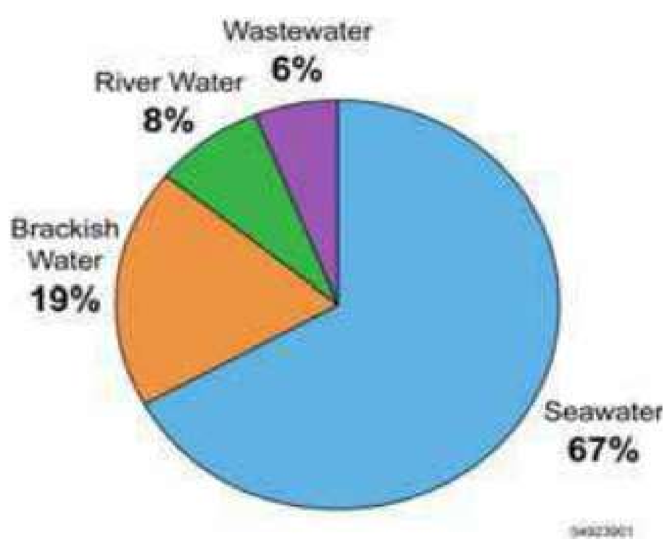


Figure 1 Worldwide feedwater used in desalination (https://www.researchgate.net)

The most users of desalinated water are located in the Arab region, namely Saudi Arabia, Kuwait, United Arab Emirates, Qatar, Oman and Bahrain, which uses more than 40 percent of worldwide capacity. There are different levels of salinity in seawater, brackish water and fresh water, that is often expressed by the total dissolved solids (TDS) concentration. When the TDS of water is below 500mg/L, water is considered portable. Seawater has a TDS of about 35,000mg/L and brackish water has a TDS between that of potable water and seawater. Another category that contains dissolved salts mostly in the low brackish level is the wastewater. The water retrieved from wastewater can be used for cooling, irrigation and for other industrial application purposes. Since th requirements for irrigation and industrial project has so far exceeded that of domestic requirements, recycle and reuse of waste effluents apart from desalination makes enormous sense for future management. Tables 1-2 below show the classification of water according to its concentration of solids and the palatability of water according to its concentration of total dissolved solids

Table 1 The classification of water according to its concentration of solids (Sources: http://www.fwr.org/desal.pdf)

Description	Dissolved Solids (mg/l)
Drinking water	Less than 1,000
Mildly brackish	1,000 to 5,000
Moderately brackish	5,000 to 15,000
Heavily brackish	15,000 to 35,000
Average seawater	35,000

Table 2 The palatability of water according to its concentration of total dissolved solids. (Sources: http://www.fwr.org/desal.pdf)

Palatability	Dissolved solids (mg/l)
Excellent	Less than 300
Good	300 to 600
Fair	600 to 900
Poor	900 to 1,200
Unacceptable	More than 1,200

Sea water has an average concentration of dissolved solids of 35,000 mg/l (3.5%) , but this can vary quite considerably as shown below in table 3.

Table 3 Variation of seawater salinity. (Sources: http://www.fwr.org/desal.pdf)

Sea	Approximate salinity in mg/l
Red sea	40,000
Mediterranean sea	38,000
Average seawater	35,000
Black sea	18,000
Baltic sea	8,000

The range of concentration of dissolved solids in the water to which different processes can be applied economically as shown in table 4.

Table 4 Range of concentration to which different desalination processes can be applied (Sources: http://www.fwr.org/desal.pdf)

Process	Concentration range in mg/l
Ion exchange	10 - 800
Reverse osmosis	50 – 50,000
Electrodialysis	200 – 10,000
Distillation processes	20,000 – 100,000

1.1 Background History

In the early centuries, humans thought that the taste of water is determined by its purity. The ancient Greek are said to have used evaporation from sea water to obtain drinking water. The Greeks and Romans are well known for their elaborate water systems. It is said that the first desalination plant in America turned sea water to drinking water at Fort Zachary Taylor in Key West Florida as early as 1861, but the use of modern desalination technology dates from the beginning of the last century.

During World War II, desalination technology was then called as desalting, and was said to be developed in order to convert saline water into usable water, where supplies for fresh water were limited. In 1952, the congress passed the ''Saline Water Act'' to provide federal support for desalination. During the 1950s and 60s fund was provided by the U.S. Department of the interior, through the Office of Saline Water (OSW) for the initial development of desalination technology and for construction of demonstration plants. Desalination is absolutely a new technology that has developed to reach a very large point during the latter half of the 20th century, and still continues to undergo technological improvements at the present time.

By the year 1999, desalination plants have spread throughout the world, with over more than 11,000 desalination plants in operation, producing over 20 million cubic meters (approximately six billion US gallons) of water per day. In Western Asia and Middle East Asia exists about 63% of the capacity, North America has about 11% and Europe and North Africa account for about 7% each of the capacity. The sizes of plants and designs range from more than 500,000m^3/day down to 100m^3/day, and low pressure products can produce as little as a few liters per day for home point-of-use application. By the end of the year 2001 a total of 15,233 large desalting units had been installed, providing a total capacity of 32.4 million m3/day.

1.2 Water Usage

The society today cannot function without fresh water. There is only 0.5% - 1% of fresh water available for all plants, animal and human needs. About 97% of the water in the world is in the oceans and approximately 2% - 2.5% of the water is in the ice stored in glacier and in polar ice, but global warming is reducing this reservoir of fresh water. The misuse of existing fresh water supplies has become a problem in different parts of the world today. There are issues resulting to these causes, the principal ones being higher living standard, population growth, growth of both agriculture and industry and climate change. In Europe on average 24% of total water abstraction is used for agriculture, 11% for industry, 44% for energy production (mainly for cooling purposes) and 21% for public water supply (European Environmental Agency, 2009).

In the world today, the main water consumption sectors are urban, irrigation and manufacturing industry. Agriculture is a major user of water resources, especially in countries which already suffer from increasing water shortages such as Greece, Spain, Southern Europe in general and the Middle East and North Africa. Water shortage and drought are already affecting countries around the world from China, Sri Lanka, Syria, Iraq, Australia, up to USA and even part of the UK. Already, approximately 70% of the water abstracted around the world is used for irrigation with this figure rising to 80% in some countries (European Environmental Agency 2010).

1.3 Water supply for Future Purposes

The future of water supply requires adequate sustainability to be able to effectively supply and support the world's increasing population. Our global economy needs a continuous growth. Water is significant to the future, but also one of the major limiting factor to growth, due to the fast increasing population growth and economic development. Water resources in many parts of the world are been pushed to their natural limits. In return, the possibilities of countries and cities to grow, attract investment, meet the primary needs of populations and ensure environmental protection will be extremely threatened, if there is no adequate or proper water resource management. Water is a significant resource that enables life's growth and increases all human activities. It is now important that every industry, public and policymakers understand, identify, prioritize and act.

1.4 Objectives and Research Questions

The aim and target of this thesis is to introduce different desalination technologies in solving water scarcity in the globe, especially in countries where access to clean drinking water is limited, like the ESCWA member countries and also adopting suitable desalination technologies in those countries that face water problems.

Desalination is one of the main significant factors in substituting water shortage in different countries. The scope of this thesis is detailed in explaining different desalination technologies in water treatment from seawater, brackish water and wastewater in general level. Then it goes into a more detailed level in introducing desalination technology in Kuwait and the United Arab Emirates (UAE). At the same time different desalination technologies will be introduced. A case study of seawater desalination in the Arabian Gulf and Taweelah power and desalination plant located in the city of Abu Dhabi will be conducted and suitable technology will be suggested.

The objectives and study of this thesis seek to examine the various measures that have been taken by ESCWA countries to upgrade their water resource management and derive therefrom relevant lessons and specialized knowledge that may be of benefit to the other countries. Another objective is to contribute to the enhancement of the capacity of member countries to analyse and evaluate the effectiveness of their water resource management and identify weaknesses and any measures that should be reformed or strengthened

The research questions to be answered and studied are the following:

- Where desalination is feasible and best suitable technology
- What are the different and common features of desalination technologies used in the ESCWA member countries
- What impact desalination have in the environment
- What are the benefits of desalination in water treatment

1.5 Methodology

This thesis is a literature based text on all aspects of the ESCWA member countries. To begin with, establishing an analytical framework that would be enabled to determine, in a systematic and orderly way, the various rationalization and reform measures taken by the ESCWA States in the area of their water resource management and facilities. Those measures could then be assigned to two main categories: measures designed to manage demand for water, and measures designed to manage water supply.

2 WORLDWIDE WATER PROBLEMS

In many countries, population and industrial activity continue to grow rapidly at an alarming rate. These changes have both direct and indirect effects on water resources. Water is a significant factor to human life, environment and development, but it is a finite and vulnerable resource which has quantitative limitations and quantitative vulnerability. Water is a regional resource, but its scarcity has become a global problem due to economic growth, climate change and increasing population. An increasing population requires water not only for domestic use, but also for sewage disposal, if not properly handled, may cause serious water quality problems. Development of new sources of water beside its efficient use, together with conservation measures, should be an important component of any country's national plan. According to People Action International (PAI, 1997) estimate, there were 31 countries with a total population of 458 million which faced water stress in 1995. More critically, over 2.8 billion people in 48 countries will face water stress in 2025, based on the United Nation medium population projections. In these 48 countries, 40 are in the middle East and North Africa. Hinrichsen (1999, 6) predicts that an increase in population alone will drive all of the Middle East into water stress over the next two decades.

There are major driving forces demanding a huge expansion of water resources in the 20th century: industrial development, population growth, massive urbanization, expansion of irrigation and rising standards of living (Gleick 2000, 6). The world population has grown from 1600 million to more than 6000 million over the past century. Land under irrigation increased from around 50 million hectares to over 267 million hectares. All of these factors have led to more than six-fold increase in freshwater withdrawals, from 580x109 m^3/y estimated for 1900 to 3700x109 m^3/y in 2000 as shown in figure 2 and 3.

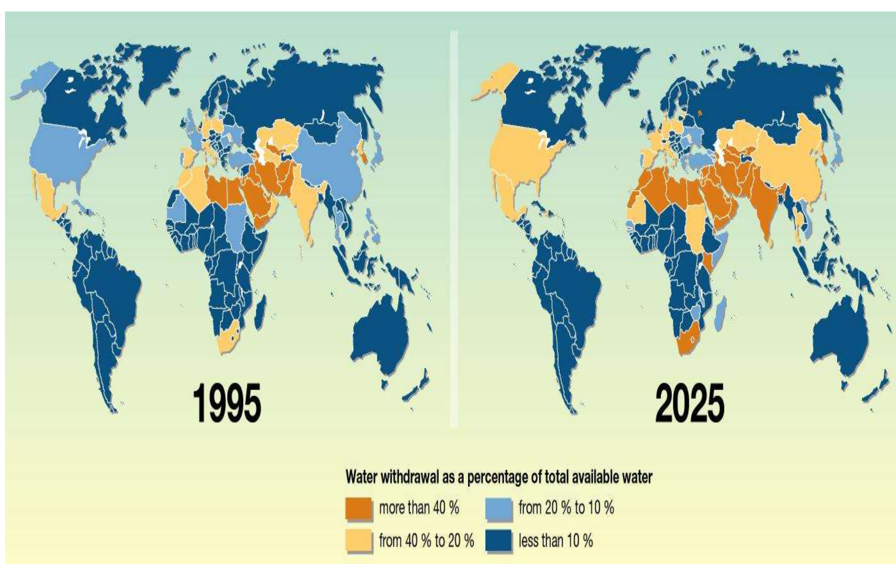


Figure 2 The world's fresh water supplies – annual renewable supplies in 1995 and the projection for 2025, (UNEP, 2002)

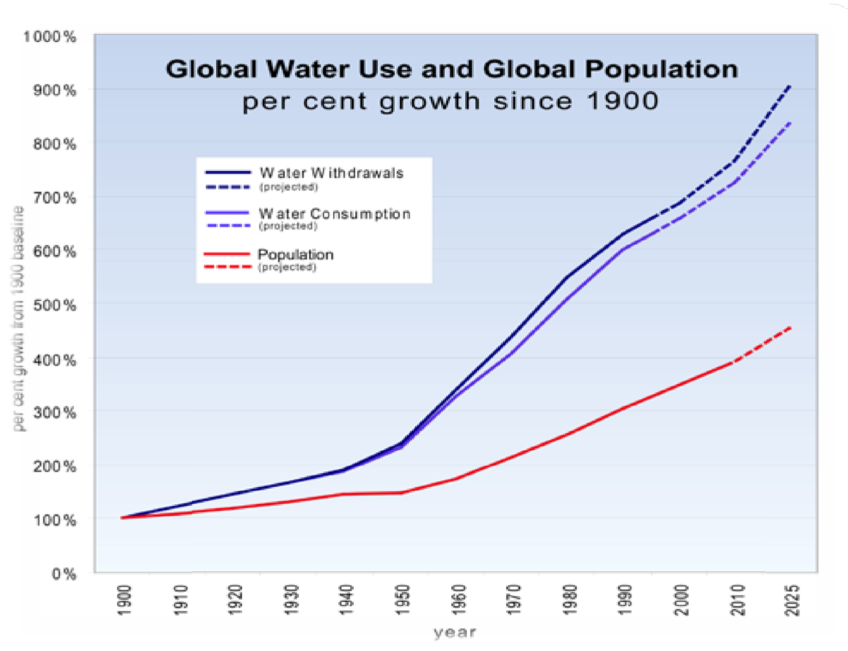


Figure 3 World population water use and irrigated area, (Gleick, 2000)

From the discussion above and a broad analysis of the literature, it maybe said that the world is already facing critical water related problems. These resulting problems maybe identified as follows:

- 20% of the world's population or more than 1 billion people lack access to safe drinking water, (Simonovic, 2000), see Figures 3 and 4. Figure 3 shows the population without access to safe drinking water and Figure 4 shows the distribution of unserved population in water supply and sanitation.
- About 50% of the world's population or more than 3 billion people lack access to sanitation, (Cosgrove, 2000), as shown in Figure 4.
- Around 80% of all illnesses and more than one third of all deaths in developing countries are related to water. It is estimated worldwide that around 7 million die yearly from diseases related to water. Every eight seconds a child dies from a water-related illness, that is about 4 million a year, (UNEP, 1999 and Serageldin, 1999).
- Half of the lakes and rivers in the world are seriously polluted. Pollution of the waterways and surrounding river basins have created millions of environmental refugees, (Serageldin, 1999).
- Main rivers from the yellow river in China to the Colorado in North America are drying up and barely reaching the sea, (Serageldin 1999).
- Almost half a billion people in 31 countries face water shortage problems. This figure is said to rise to nearly two-thirds of the world population by 2025. The worst areas comprise the entire Mediterranean region, including parts of southern Europe, North Africa and Middle East, Northwest and south India, Mongolia, northern China, most of Sub-Sahara Africa and major regions in North and South America, especially the western United States. They will face severe water shortages in the coming years. Europe

as a whole also faces severe problems, because half of its lakes have already atrophied, (Cosgrove, 2000 and Serageldin, 1999).

- Aquifers are being extracted at an unusual rate, 10% of the world's agricultural food production depends on using extracted groundwater. As a result, groundwater tables fall by up to several metres a year with the risk of a collapse of agricultural systems based on groundwater irrigation in the north China plain, the USA high plains and some major regions depending on aquifers in India, Mexico, Yemen and elsewhere, (Serageldin, 2000). Some of the world's biggest cities, including Beijing, Buenos Aires, Dhaka, Lima and Mexico City, depend heavily on groundwater for their water supply. The current over use is not sustainable, because it takes many years to fill aquifers.

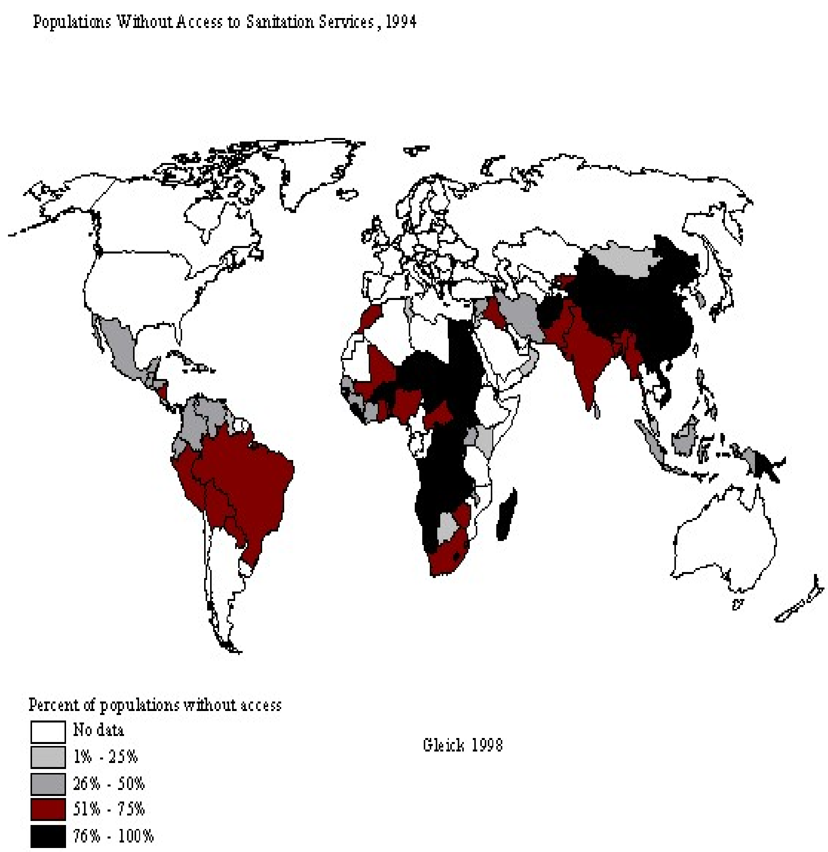


Figure 4 Population without access to safe drinking water, (Gleick, 1998)

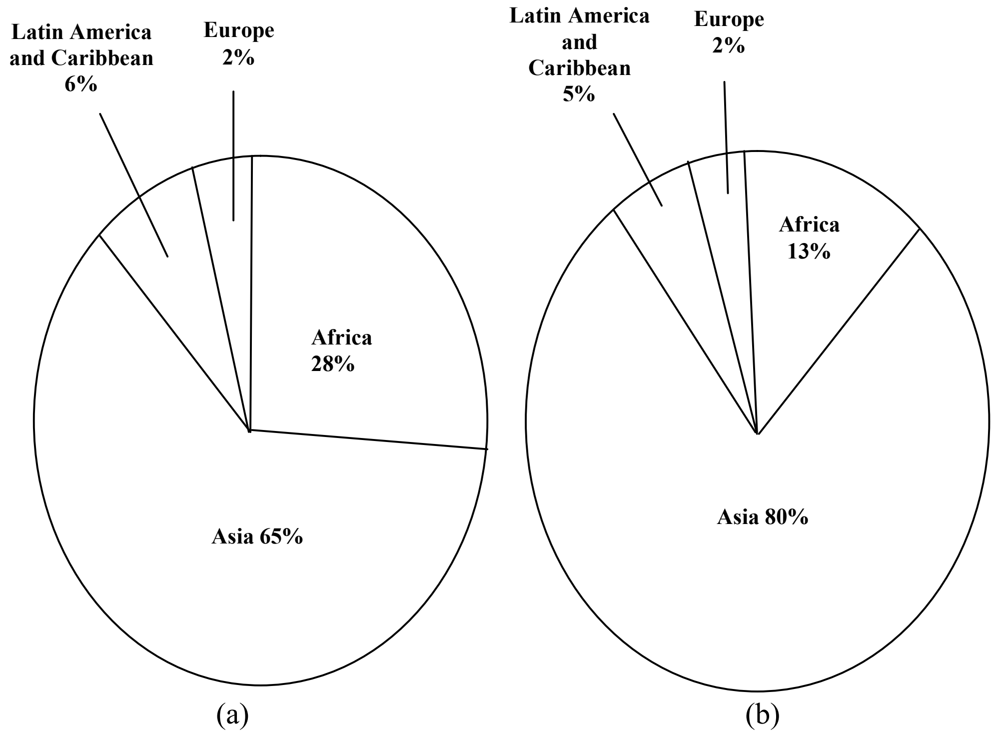


Figure 5 Distribution of unserved populations in (a) Water supply and (b) Sanitation (UNESCO, 2003).

- Diverting water for irrigation in Central Asia has caused devastating effects. A notorious case is the Aral Sea. This has shrunk to a fraction of its original size and badly degraded in water quality. The latter has caused hundreds of thousands of people to suffer from anaemia and other diseases due to the consumption of water saturated with salts and other chemicals coming from the cotton fields, (Serageldin, 2000).
- Transmission of water itself causes severe problems. The supply system of large European cities, for example, can lose up to 80% of the water transported because of pipe damage; with some Mexican cities losing up to 60% through leakage from their old supply systems, (Dossier, 1997). Countries like Bangladesh, the Philippines and Thailand experience water losses of 50%. In Middle East countries like Jordan, Yemen and others with rising water scarcity, more than 40% of the available water cannot be traced, (Chaturvedi, 2000).

The amount of water used in a country, however, does not depend only on minimum needs and/or how much water is available. It also depends on the levels of economic development and urbanisation. In fact, the amounts for personal use (drinking, cooking and sanitation) are small compared with other uses. As mentioned earlier, on a worldwide basis, agriculture accounts for about 70% of all annual water withdrawals; industry about 20% and domestic use about 10%, (Cosgrove, 2000 and Serageldin, 2000). Because world development varies so broadly, according to Hinrichsen (1999) there are large regional differences. In Africa, for example, an estimated 88% of all freshwater use is for agriculture, 7% for domestic purposes and 5% for industry. In Asia water is used mostly for agriculture, estimated at 86% of total use, while industry accounts for 8% and domestic use, 6%. In Europe, however, most water use is for industry, at 54%, while agriculture accounts for 33% and domestic use, 13%. While the analysis above gives percentage breakdowns of the various uses of water, in absolute terms, a country's level of water use strongly depends on its level of economic development. Furthermore, in developing regions, people use far less water per capita for personal use than in developed regions. According to UNDP (1994), in Africa annual per capita water withdrawals for personal use is only 47 litres of water per day and in Asia, 85 litres per day. In contrast, comparable water use in the UK is estimated at 334 l/pd and in the USA, 578-700 l/pd, (PAI, 1999). As to be expected, around the world freshwater demand per capita is rising as countries develop economically. These increasing withdrawals of water are reflected in all three major categories of use: rising industrial demand, rising domestic demand and increasing reliance on irrigation to produce food.

Again, as might be expected, the amount of water use also indicates the extent of urbanisation in a country. Low levels of water use in several developing countries indicate difficulty in obtaining freshwater, partly because piped water systems are uncommon in rural areas. According to PAI (1999) two-thirds of the world's population in developing countries get their water from public standpipes, community wells, rivers and lakes or rainfall collected off roofs. Often rural people, usually women and girls, walk several kilometres and spend several hours to bring water for their households and in Africa, for instance, such activity consumes 40 billion person-hours annually. This depresses the possibility of economic advancement as shown in the figure below:

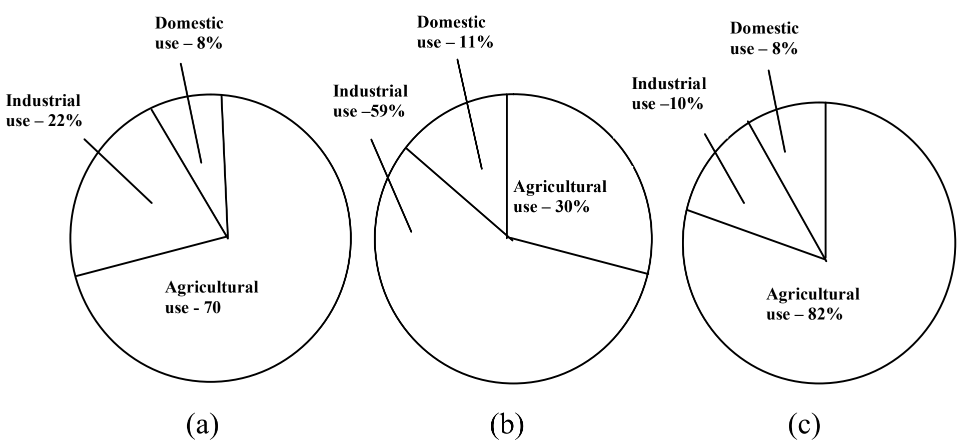


Figure 6 Competing water use for (a) world, (b) high income countries and, (c) low and medium income countries, (UNESCO, 2003).

2.1 Desalination in Solving Water Scarcity

Desalination plays a very important role in solving water scarcity globally, especially in the ESCWA region. Almost half of the global desalination capacity is concentrated within the region and many other countries rely almost completely on desalinated water for their freshwater supply in order to meet their growing water demand in the face of increasingly scarce water resources.Water scarcity and growing water demands have driven the region to become a global leader in water desalination.

Desalination capacity has grown significantly since 2001. While investments in desalination continue to increase in the Gulf region, other ESCWA and member countries have also practiced desalination as a means of balancing existing conventional water resources. Desalination capacity is focused on the middle to high-income Gulf Cooperation Council (GCC) countries as a result of different conditions, namely, severe water shortage coupled with an abundant endowment of fossil fuels. These conditions have encouraged decision makers to support investment in desalination. Particularly, Qatar, Kuwait and the United Arab Emirates are producing more desalinated water per annum than its availability from their national renewable water resources. Non GCC countries in the ESCWA and Arab regions are also increasing their desalination capacity as water scarcity increases and desalination technologies becomes more efficient and less expensive. For example, Algeria, Jordan, Tunisia and Yemen have incorporated desalination into their water resource management strategies in order to satisfy growing water demand as shown in table 5 below

Table 5 The countries with the world's worst and best Water Exploitation Index (Source: http://www.fwr.org/desal.pdf)

Countries with the fewest resources	**m3/person per year**	**Percentage withdrawal**
Kuwait	6.9	2,075
United Arab Emirates	18.5	1,867
Saudi Arabia	83.6	936
Jordan	145	99.4
Countries with the most resources	**m3/person per year**	**Percentage withdrawal**
Canada	88,691	1.5
Norway	77,016	0.77
Russia	34,590	1.47
Finland	20,359	1.49
Sweden	18,325	1.5
Latvia	15,861	1.18
Ireland	11,356	1.5
UK	2,332	8.8

2.2 Feasibility of Water Desalination

Desalination has been practised on a very large scale for more than 50 years in the world. Desalination is feasible in countries were water resource is scarce, especially in the ESCWA region where a renewable freshwater source is extremely limited. During this period, there have been continuous improvements in the desalination technology, and the most frequently used technologies are now, mature, efficient and reliable. Desalination represents the largest source of non-conventional water for ESCWA member countries, especially where limitation for renewable freshwater is extreme. Population growth, climate change and industrial development have led to an increase in water demand, and desalination constitutes one way for countries to close the gap between water demand and supply. Without desalination, many of these regions would be uninhabitable.

The availability of conventional water resources is affected by growing water demands and the decline of surface and groundwater quality. Studies have also indicated that climate change pressures are further exacerbating the situation. In order to meet this deficit, ESCWA member countries have to manage their existing water resources more efficiently by increasing their supply of freshwater through the development of conventional and non-conventional water resources. Due to the limitation in conventional freshwater reserves in the region, a number of non-conventional water resources have been developed to balance the water gap. These include desalination, agricultural runoff reuse and wastewater treatment and reuse. Investments in desalination and the reuse of treated wastewater in the region have become so widespread in some countries that there is even some doubt as to whether they can still be considered nonconventional water supply options.

The Gulf Cooperation Council (GCC) countries produce approximately half of the world’s desalinated water; and Jordan, Palestine and Yemen are incorporating the desalination of seawater and brackish in their water strategies in order to expand their water supplies. Large-scale investments are already under way in Jordan and Yemen, and small household desalination units can be found in the Gaza Strip.

For example in Abu Dhabi the capital city of the United Arab Emirates, green energy was a requirement to power desalination plants using solar energy. There is no lack of sunlight in Abu Dhabi and solar power has overcome the usual high cost of energy for operating the plants, and most importantly it has no environmental impact. Harnessing the energy of the sun makes it possible to supply the power needed to run the desalination plants in each of the designated protected areas, thereby providing a stable supply of clean drinking water for the Arabian Oryx and other animals, plus water to irrigate the area where they live.

3 OPTIMIZATION OF DESALINATION IN WATER RESOURCE MANAGENENT IN THE ESCWA COUNTRIES

In the ESCWA member countries, water resources are in limited supply, while the demand for water continues to grow. Given this situation, the question of the optimal management of water resources is clearly of crucial importance, with implications not only for the future development of those countries, but also for the sustainability of their past economic and social achievements. The problem arises from the continuing growth in demand, which is as a result of population increase and other social factors, in conjunction with the fact that the region is already exploiting all its annual surface water resources, while its aquifers are becoming depleted.

In brief, the ESCWA countries are facing a water crisis that is becoming more critical year by year. It is imperative for them to adopt realistic policies and institutional arrangements that will enable them to control demand for water, apportion the available quantities along economically efficient lines, and ensure that water is used more efficiently in various sectors. The essential purpose of this study is to shed light on the measures that the ESCWA member countries have taken to upgrade their water resource management and their water facilities.

3.1 Desalination Role and Water Resource Management in Kuwait

Kuwait is an arid country located in the Middle East, rich in oil but poor in water resources. The state of Kuwait lies at the northeast edge of the Arabian Peninsula at the head of the Arabian Gulf and occupies a total area of 17,000km^2 of mostly desert land. The hot dry climate results in a very low rainfall with an annual average rainfall of around 110 mm, with a variation of 31mm to 242mm. Surface runoff and groundwater recharge from rainfall are rare, this is primarily due to factors such as the high potential evapotranspiration rate. Fresh water streams do not exist. The fresh water resources are limited to groundwater, desalinated seawater and brackish groundwater and treated wastewater effluents.

The total of conventional fresh water resources available in Kuwait are 6 million m3/y while the total water demand has exceeded 350 million m3/y in the year 2000. With the continued deterioration of existing groundwater resources, almost 90% of the water demand is currently satisfied through seawater desalination plants. Currently the desalination capacity in Kuwait is 1.65 million m3/d of which 1.47 million m3/d is provided by multi-stage flash desalination (MSF) and 0.17 million m3/d is supplied by reverse osmosis (RO). The tertiary treated wastewater effluents of about 0.4 million m3/d are produced by three major municipal wastewater treatment plants, which is currently utilized in irrigation as shown in figure 7 and 8 below.

Figure 7 Aerial photo for Kuwait and neighboring countries

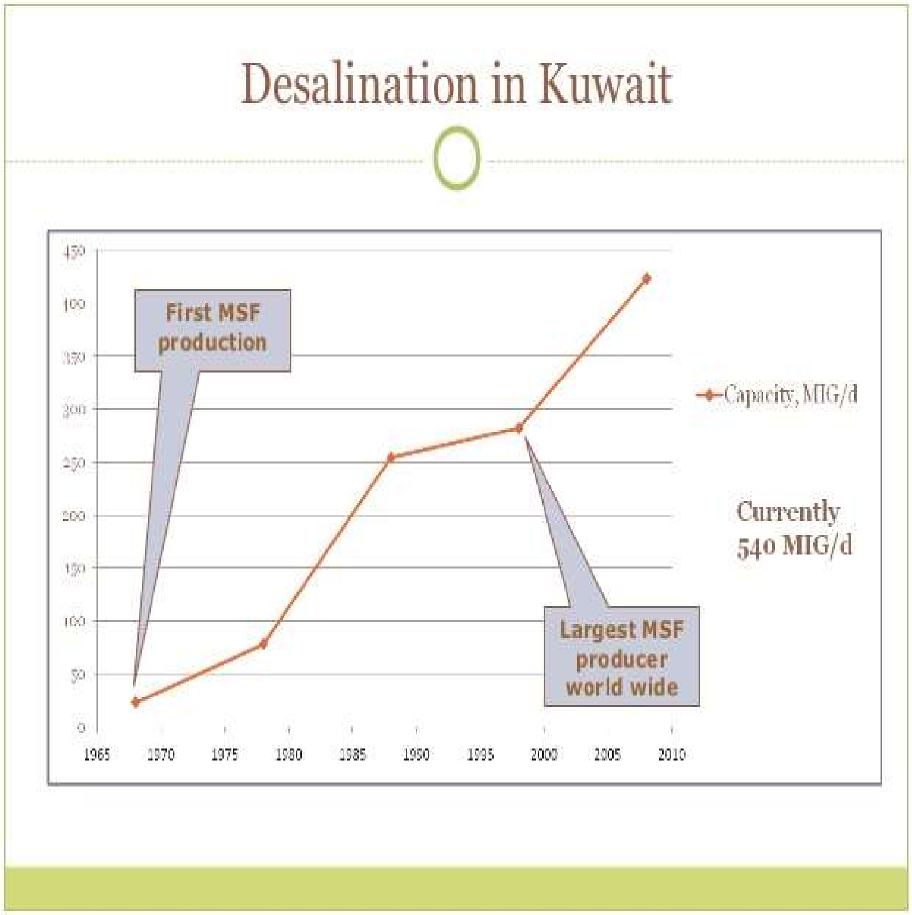


Figure 8 Desalination capacity in Kuwait (Source: PPT Desalination role in Kuwait's water sector. - Arab Climate Resilience ...)

3.1.1 Components of the Water Balance of Kuwait

The purpose of the water balance component of this assessment is to characterize the climatic, surface water, and groundwater components of the watershed. The water balance is intended for use as a screening tool to further evaluate water resources allocations within the watershed and to identify water balance components that may require further analysis during the next levels of watershed planning. Figure 9 shows the water balance of Kuwait

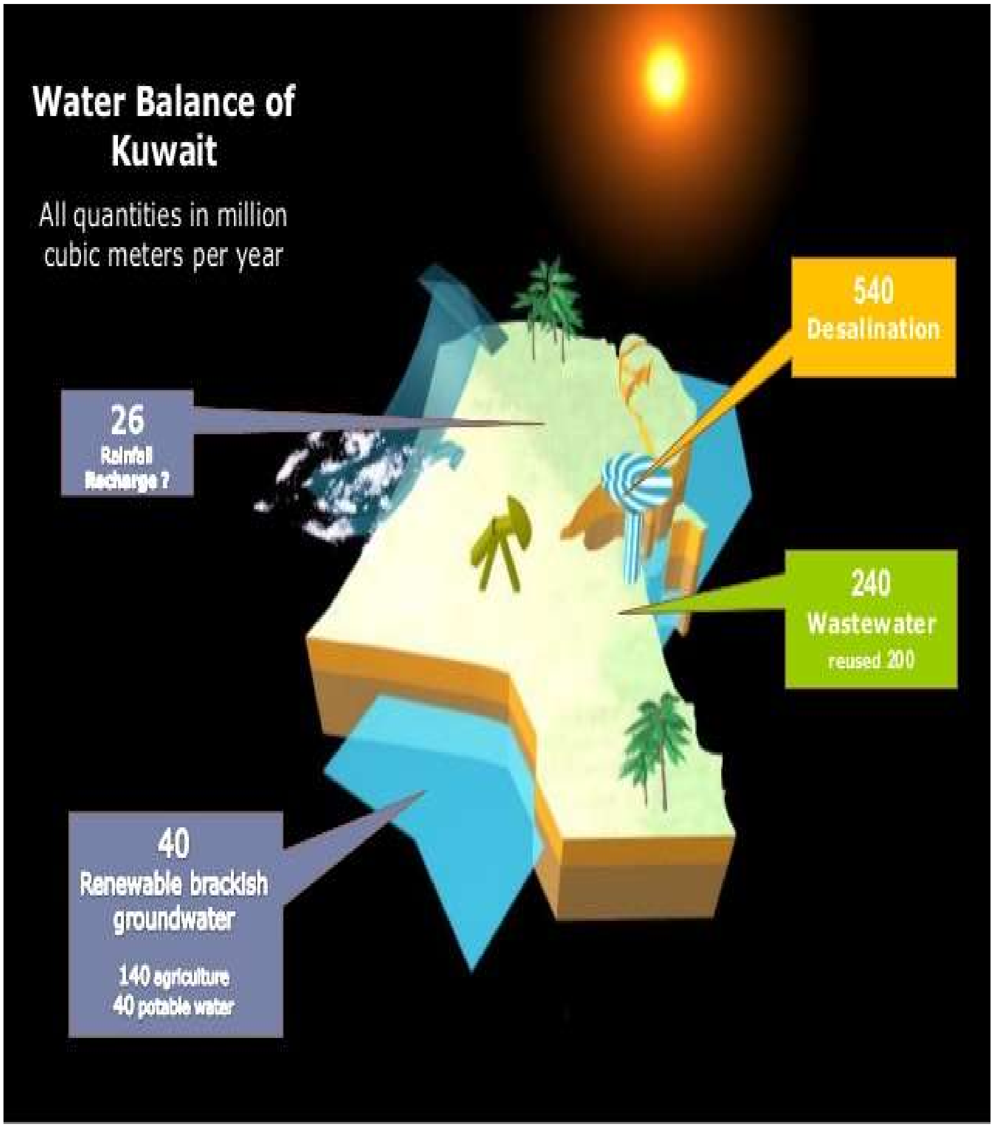


Figure 9 Water balance of Kuwait (Source: (PPT Desalination role in Kuwait's water sector. - Arab Climate Resilience ...)

3.1.2 Desalination of Seawater and Brackish Groundwater in Kuwait

Seawater and brackish groundwater are considered the main water resources in Kuwait. Currently the desalination of seawater is accomplished in five distillation and power plants. The distillation units in the power stations use the multi stage flash (MSF) evaporation method. Each of the distillation unit consists of anumber of stages ranging from 24-26 stages and the capacity of the units is between 0.023 to 0.027 Mm^3/d for each unit according to each station. Moreover, the total capacity of the distillation units in the power and water distillation stations is 1.175 Mm^3/d, which can possibly be raised to 1.291 Mm^3/d at high temperature operation of some distiller units in Doha West and Az-Zour South stations.

Brackish groundwater existence in Kuwait has a total output capacity of 0.55Mm^3 from wells at present, with a TDS ranging between 4000-9000mg/L, which is used for (1) blending with distilled water, (2) irrigation and landscaping, (3) household purposes, (4) livestock watering, and (5) construction works. Brackish water is conveyed to consumers through a separate pipe network parallel to the fresh water distribution network. The total production of brackish water has increased from 47.4Mm^3 to 127.3Mm^3 per year during the period of 1975 to 2000. The availability of unconventional fresh water resources in Kuwait at present includes; (1) desalinated seawater, (2) desalinated brackish water, and (3) treated wastewater effluents. Figure 8 shows the production of brackish groundwater during the years 1975-2000

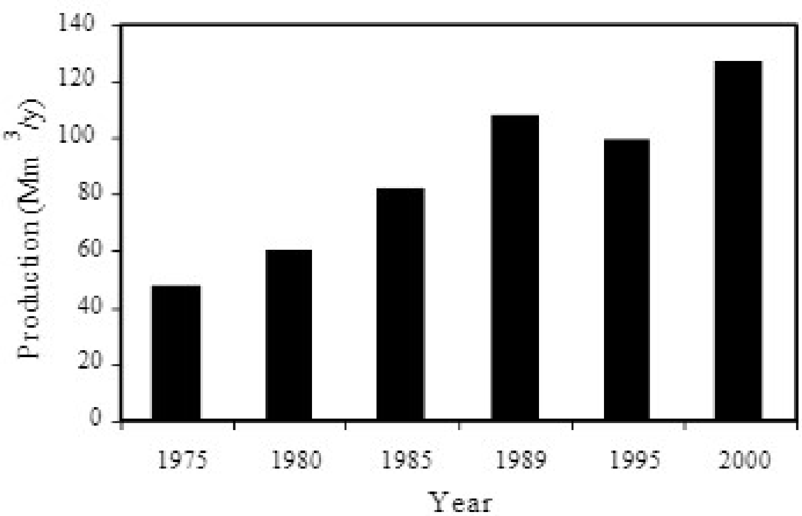


Figure 10 Production of brackish groundwater during the years 1975-2000 (Source: https://www.researchgate.net)

In order to produce fresh (potable) water for human use, distilled water collected from the five distillation plants is being mixed with underground water pumped from the brackish water wells in the blending plants. The disinfection of the blend is being done by injecting chlorine solution, then adding caustic soda solution to maintain the OH value of the water within the required limits according to the specification of the World Health Organization (WHO). Table 6 shows the capacity of seawater MSF distillation plants in Kuwait.

Table 6 Capacity of seawater MSF distillation plants in Kuwait for the year 1999 (Source: https://www.researchgate.net)

Station	Shuwaikh	Shuaiba South	Doha East	Doha West	Az-Zour South	Total
Year of first commissioning	1960	1971	1978	1983	1988	
No. of units (distiller)	3	6	7	16	12	44
Installed capacity at normal temp., Mm^3/d	0.082	0.136	0.437	0.192	0.328	1.175
Installed capacity at high temp., Mm^3/d	0.082	0.136	0.503	0.192	0.378	1.291

Desalination of brackish water is accomplished using the RO process. In 1987, the first stage plant of RO was carried out by installing 14 RO units each of $1100m^3/d$ capacity. By the year 1993, the plants were expanded to produce a total of $37,600m^3/d$ of desalinated brackish water. The encouraging results of RO desalination and the significant improvements in the membrane materials and equipment has led to the present consideration of installing RO plants to desalinate seawater in Kuwait.

3.1.3 Desalinated Water Used in Kuwait

The production capacity of Kuwait's desalination plants amounted to around 1.5 MCM/d in 2000, as shown in figure 11. Fresh water is provided for municipal use, industrial activities, power plants and agriculture. Although a number of desalination technologies are applied in Kuwait. The MSF process is the most widely used for the supply of fresh water for urban and industrial applications. Figure 11 shows the cumulative growth in desalination capacity in Kuwait (Millions of cubic metres per day)

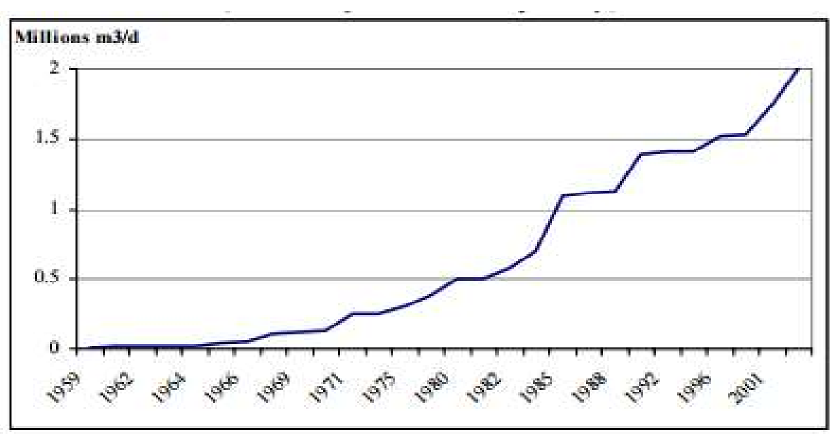


Figure 11 Cumulative growth in desalination capacity in Kuwait (Millions of cubic metres per day)

The country's first MSF unit, installed in Shuwaikh in 1960, had 19 stages, a capacity of 4,546 m3 /d, and a performance ratio of 4. The designs on which MSF plants in Kuwait are based were developed by Westinghouse of the United States and Weir Westgarth of the United Kingdom of Great Britain and Northern Ireland; these and subsequent units had a performance ratio of 8 and included between 24 and 30 stages.

3.1.4 Wastewater Treatment and Water Re-use in Kuwait

There are three wastewater treatment plants that treat municipal wastewater collected from urban areas of Kuwait. The largest treatment plant is located in Ardhiya, with a design capacity of 100,000 m^3/d which was commissioned in 1970, and was later expanded in 1984 to a design capacity of 150,000 m^3/d. In 1993 the plant was commissioned for the second time and was expanded to increase its design capacity to 190,000 m^3/d. The second largest wastewater treatment plant in Kuwait is located in Rekka and was commissioned in 1981 with a design capacity of 85,000 m^3/d which was later expanded 1995 to a capacity of 120,000 m^3/d . The third wastewater treatment plant located in Jahra was commissioned in 1981 with a design capacity of 70,000 m^3/d. All these three plants provide tertiary treatment of wastewater which reached an average total flow of 388,000 m^3/d in the year 1999.

Reuse of wastewater for irrigation purposes has proved to be one of the best ways to recycle nutrients and water and thus protect the environment and the public health. It contributes directly to the environmental sustainability by increasing crop production and decreasing amounts of pollutants discharged into the environment. The prime goal of these plans is to utilize 100% of the reclaimed municipal wastewater mainly in restricted agricultural irrigation (e.g. fodder crops irrigation), greenery landscaping (grass, plants, trees and bushes) and in the development of a forestation areas. Figure 12 shows the wastewater reused in Kuwait.

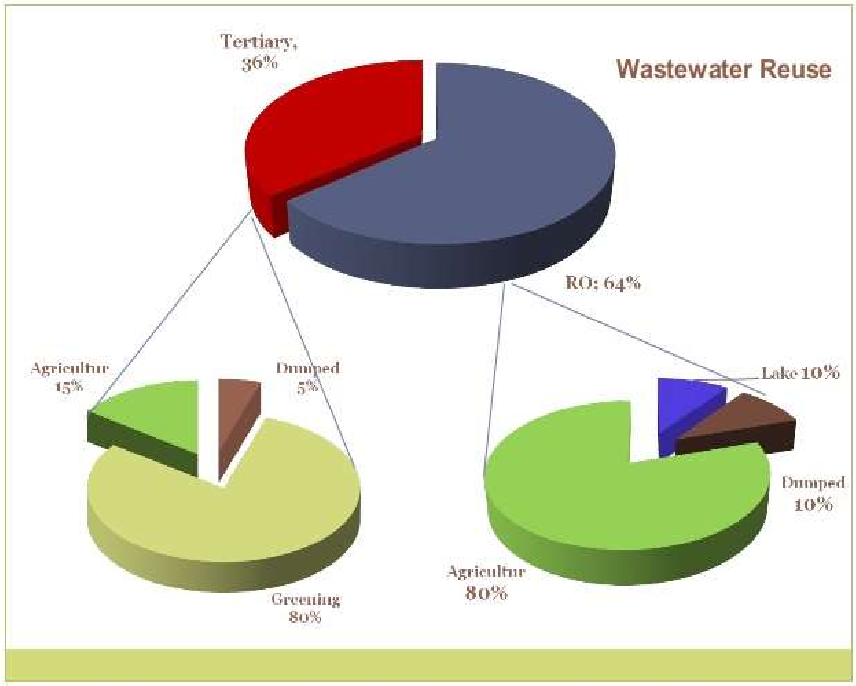


Figure 12 Wastewater reuse in Kuwait (Source: PPT Desalination role in Kuwait's water sector. - Arab Climate Resilience..)

The treated wastewater effluent generated in Kuwait has increased significantly during the last three decades due to, increase in population, construction and expansion of wastewater collection system and development of wastewater treatment plants. The wastewater effluent account for only 40% of the total water consumption at present due to the lack of wastewater facilities in some areas, prohibition of industrial effluent discharges into the municipal wastewater collection system and disposal of parts of untreated wastewater into the sea. Figure 13 shows the generation of treated wastewater effluents during the years 1975-2000

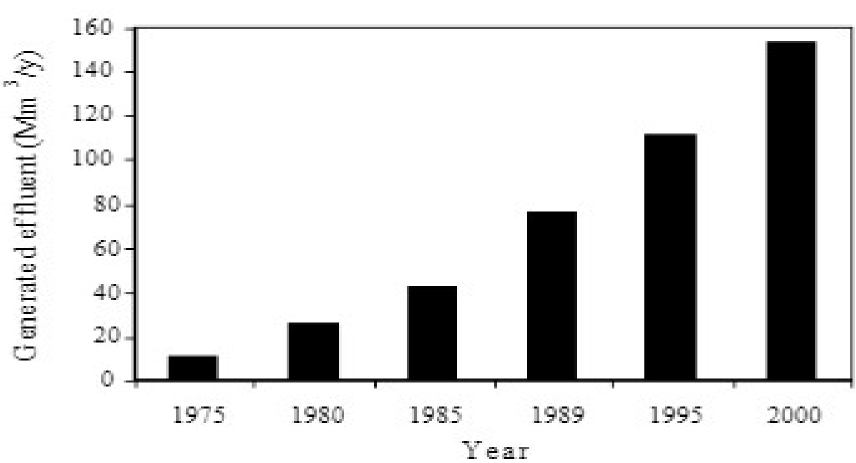


Figure 13 Generation of treated wastewater effluents during the years 1975-2000 (https://www.researchgate.net)

The tertiary treatment effluents are stored in series of reservoirs with an overall storage capacity of 400,000 m^3, making water available for irrigation and providing the microbiological quality of the stored water. These reservoirs are located at the Data Monitoring Centre (DMC) in Sulaibiya, from which water is pumped to farms and landscape area for irrigation. A total of 155,000m^3 of tertiary treated wastewater was used for irrigation in the year 1999, representing about 40% of the total treated effluents produced from the treatment plants. This percentage is decreased to about 24% in the winter season. Treated effluents that are not used for irrigation are disposed of to the sea. Table 7 shows the operating data of municipal wastewater treatment plants in Kuwait in 1999.

Table 7 Operating data of municipal wastewater treatment plants in Kuwait in 1999 (Source:https://www.researchgate.net)

	Plant		
Location	Ardhiya	Rekka	Jahra
District Servid	Kuwait city and district	Ahmadi	Jahra
Design flow, m^3/d	190,000	120,000	70,000
Actual flow, m^3/d	240,000	95,000	53,000
Secondary treatment processes	Two-stage activated sludge	Expanded aeration	Expanded aeration
Tertiary treatment processes	Granular media Filteration and chlorination	Granular media Filteration and chlorination	Granular media Filteration and Chlorination

3.2 Suggestion or Suitable Desalination Technology for the Region

- Limited scale RO of brackish groundwater units could be used for remote areas for drinking water and agriculture.
- Large scale desalination plants for major coastal cities could be used for drinking water to free the natural water for use in ag.
- Privatization of the desalination industry is key

3.3 Desalination Role and Water Resource Management in the United Arab Emirates

The United Arab Emirates is located within the arid zone to the southeastern part of Arabian Peninsula. The arid zone is characterized by a low amount of rainfall and high rate of evaporation. Based on rainfall statistics of different emirates from 2000 to 2006, the lowest and highest amount of rainfall received in Abu Dhabi Emirate was 2.8 mm in 2001 and 153 mm in 2006, respectively. However, in Dubai, the lowest and highest amount of received rainfall was 8.8 in 2001 and 112.2 mm in 2004, respectively. The lowest and highest amount of received rainfall in Sharajah Emirate was 9 mm in 2001 and 168.21 mm in 2006, respectively. The eastern and northern parts of the country received the highest amount of rainfall during the period of 2001 to 2006 due to its location near the recharge areas. The amount of rainfall in the northern and eastern parts of the country varies from 31 mm in 2001 to 145.5 mm in 2006.

The United Arab Emirates rely on non-conventional water resources, in addition to conventional water resources, to meet the increasing demands for water. Conventional water resources include seasonal floods, springs, falajes and groundwater. Non-conventional water resources are the desalinated water and treated sewage water. The existing conventional water resources in the United Arab Emirates include 125 Mm^3/yr (million cubic meter per year) from seasonal floods, 3 Mm^3/yr from permanent springs, 22 Mm^3/yr from seasonal springs, 20 Mm^3/yr of falaj discharges, 109 Mm^3/y of aquifer recharge. The existing non-conventional water resources include 475 Mm^3/yr of desalinated water and 150 Mm^3 of reclaimed water. Figure 14 shows the location of the United Arab Emirates in the Arabian Peninsula.

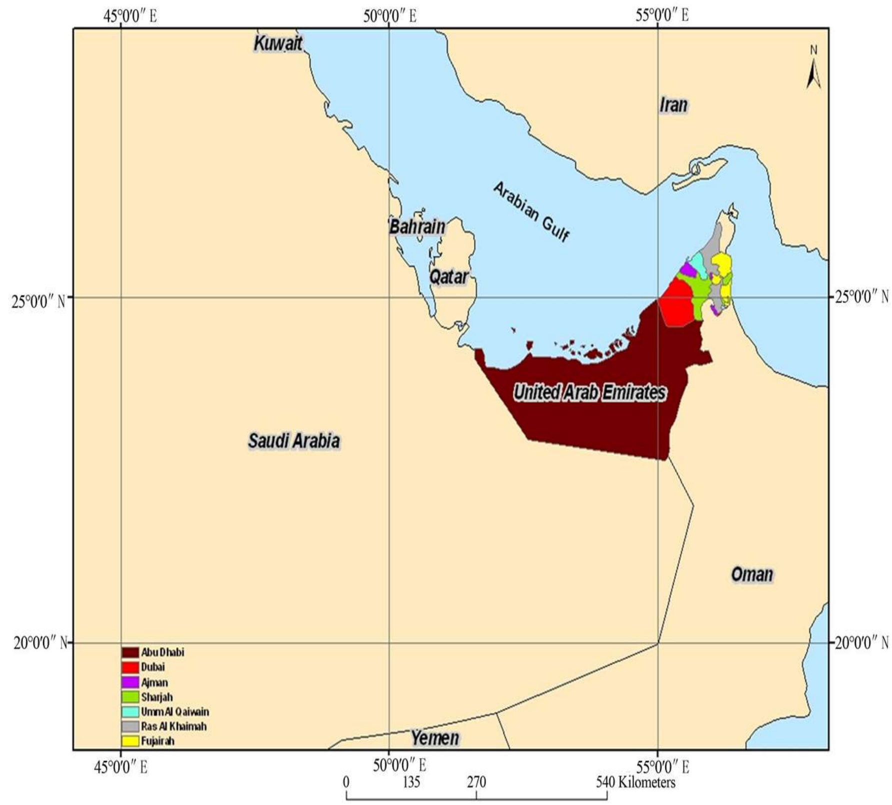


Figure 14 Map showing location of the United Arab Emirates in the Arabian Peninsula.

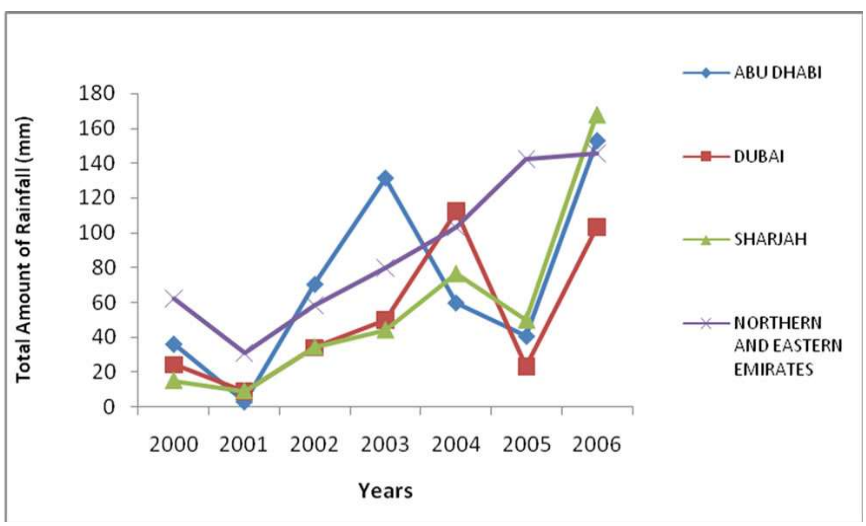


Figure 15 Total amount of rainfall for the UAE in mm for the period of 2000 to 2006 (Ministry of Economics 2007)

Water resources in the United Arab Emirates have been threatened by population growth, agriculture and industrial activities. In UAE, groundwater quantity is reduced and its quality is also deteriorated due to very little rainfall and over pumping for different uses. The shortage of groundwater is met by desalinated water and reused of treated wastewater. Agricultural activities have negative impacts on water resources and this causes reduction of groundwater quality as the agriculture the main land use in the UAE and it accounts for more than 70% of groundwater use. The treated wastewater is an alternative source for agricultural activities. The most important water related problems in the UAE are the depletion of aquifers in several areas, such as at Al Ain and Al Dhaid; saline-water intrusion, and water quality degradation, such as that associated with the oil industry and agricultural activities.

3.3.1 Desalination of Seawater and Brackish Groundwater in UAE

The UAE with Saudi Arabia and Kuwait is considered one of the largest users of desalinated water in the region, and these three countries account for 77% of the total of the region. Desalinated water represents one of the most important water sources in the UAE at the present time, and needs to expand in order to meet the increasing demand of water. The desalination technology started in UAE in 1976, when the first plant was established in Abu Dhabi with a capacity of 66000 gallons/day. Over the time, the water demand for domestic, agricultural and industrial uses is increasing, so new desalination plants are being constructed in the country. The number of desalinated plants in the UAE rose from one station in Abu Dhabi, during 1976, to 65 in 1995, with each Emirate having at least one desalination plant. Most of the plants are on the coast or on islands, although a small number were built inland, where brackish groundwater is desalinated. The daily production of desalinated water in the Abu Dhabi Emirate, for example increased from 12,500 m^3 in 1969 to 590,000 m^3 in 1989 (Alsharhan et al., 2001). The total production of desalinated water in UAE was 134412.8 million gallons in 2000 and it increased to 277942.14 million gallons in 2006. The desalinated water that was produced by ADWEA, DEWA, SEWA and FEWA was 76015, 41703, 11075, 5619.77 million gallons respectively in the year 2000. In 2006, the production of ADWEA, DEWA, SEWA and FEWA was increased to 176457.1, 71703, 18438.54 and 11343.5 million gallons respectively. Figure 16 shows the production of desalinated water in UAE by different water authorities from 2000 to 2006

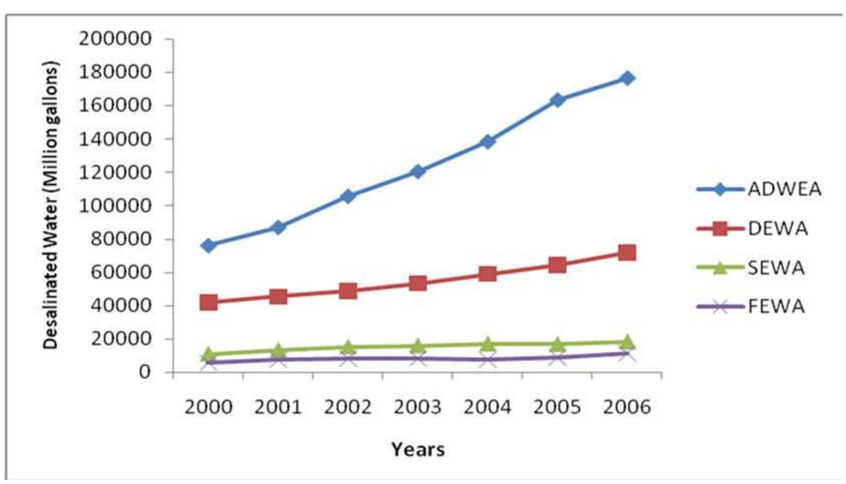


Figure 16 Production of desalinated water in UAE by different water authorities from 2000 to 2006.

Groundwater is one of the conventional water resources in UAE which occurs in many different aquifers. Groundwater is produced by major authorities in the country such as ADWEA, DEWA, SEWA and FEWA. In the UAE, Groundwater resources can be classified into renewable resources and non-renewable resources. The availability of water in shallow aquifers is relatively small because of over abstractions of groundwater. It mainly depends on the rainfall which is low and might differ from one year to another. Groundwater is produced from four main aquifers which are of limestone aquifer in the north and southeast, an ophiolite aquifer in the east, gravel aquifers adjacent to the eastern mountain ranges on the east and west of the ophiolite aquifer, and sand dune aquifers in the south and west. The total estimated groundwater productions are decreasing with time and it was 35557.25 and 20033.93 million gallons in 2000 and 2006 respectively. Figure 17 shows the groundwater production in UAE by different water authorities from 2000 to 2006.

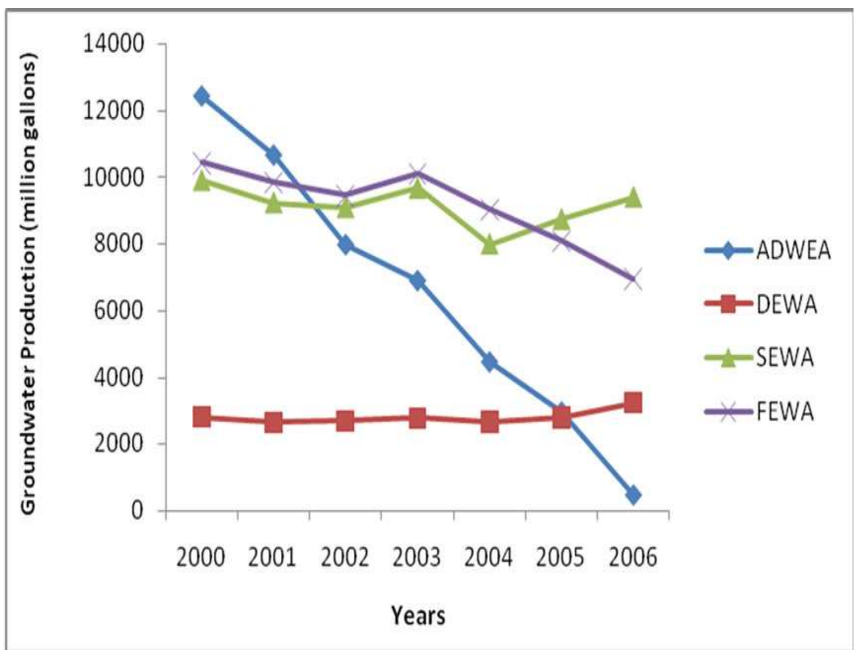


Figure 17 Groundwater production in UAE by different water authorities from 2000 to 2006. (Source: http://file.scirp.org/pdf/JWARP20100200010_12015024.pdf)

The dependency of desalinated water for all emirates is higher than groundwater and the percentages of dependence have increased significantly due to the shortages of groundwater. The eastern and northern emirates of the country depend on both groundwater and desalinated water, whereas both Abu Dhabi and Dubai Emirates mainly rely on desalinated water. The production of groundwater in eastern and northern emirates is relatively high due to the closeness from recharge area.

3.3.2 Desalinated Water Used in United Arab Emirates

The water desalination industry in the United Arab Emirates began in 1969 with total production of around 27,000 m3 /d (see figure 18); by 2000, however, overall output had reached about 2.5 MCM/d. This figure is expected to double by the year 2005, according to the IDA. Figure 18 shows the cumulative desalination capacity in the United Arab Emirates since 1970.

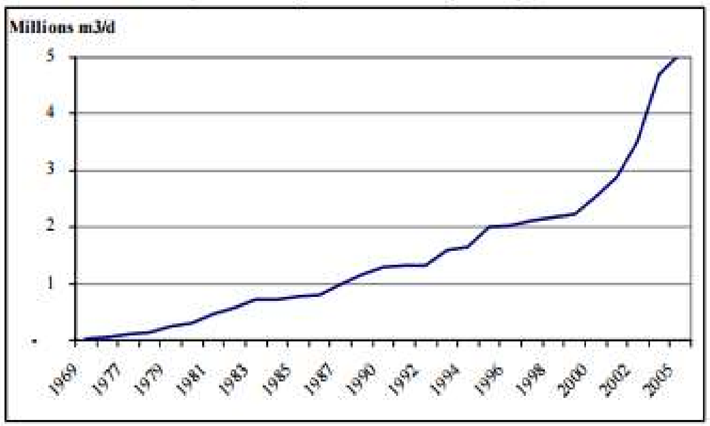


Figure 18 Cumulative desalination capacity in the United Arab Emirates since 1970 (Source:http:// www.escwa.un.org/ContentPages/17952025.pdf)

Water consumption is expected to grow by 8 per cent annually. This fact, coupled with the shrinking contribution of groundwater to the national supply, is behind the country's efforts to build more desalination plants.

1) *Distribution of desalination plants in the United Arab Emirates according to technology*

   MSF, VC and RO are the three desalination methods most commonly used in the United Arab Emirates. MSF is by far the most prevalent, accounting for 88 per cent of total capacity, while VC and RO are ranked a distant second, with 6 per cent each.

2) *Distribution of desalination plants in the United Arab Emirates according to area*

   Figure 18 represents the distribution of desalination capacity among the country's seven emirates in the year 2000 and as expected in 2003. Abu Dhabi occupies a leading position, with 55 per cent of total desalination capacity, followed by Dubai (32 per cent) and Sharjah (6 per cent).

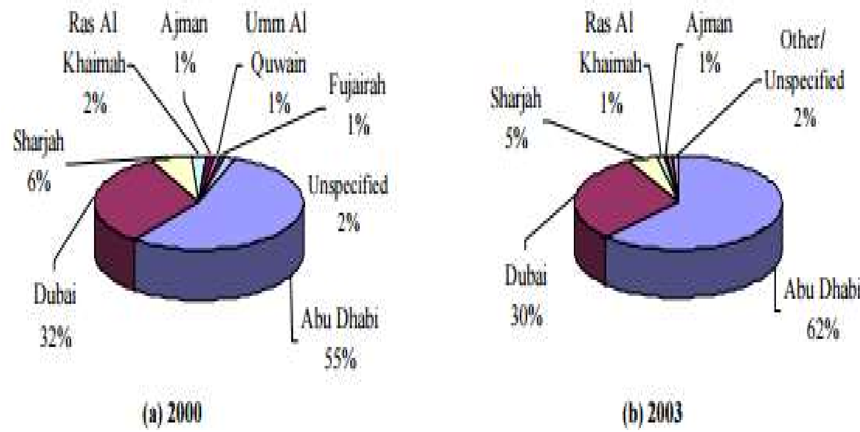


Figure 19 Distribution of desalination capacity in the United Arab Emirates, by emirate (Source:http://www.escwa.un.org/ContentPages/17952025.pdf)

With regard to capacity distribution by technology in the top three water-producing emirates, table 8 indicates that MSF technology accounts for almost all of the desalination capacity in Abu Dhabi and 88 per cent in Dubai. Sharjah has a more balanced mix of technologies, with MSF, VC and RO accounting for 52, 30 and 18 per cent of capacity, respectively. Figure 20 shows the distribution of desalination capacity in Abu Dhabi, Dubai and Sharjah according to technology.

Table 8 Distribution of desalination capacity in Abu Dhabi, Dubai and Sharjah according to technology (Source:http://www.escwa.un.org/ContentPages/17952025.pdf)

Emirate	Main process	Total capacity(m^3/d)	Share of total capacity
Abu Dhabi	MSF	2797654	88%
	VC	311822	10%
	RO,MED,Hybrid	52045	2%
Dubai	MSF	1514370	99.8%
	ED,RO	3045	0.2%
Sharjah	MSF	120620	52%
	VC	68248	30%
	RO	41700	18%

3.3.3 Wastewater Treatment and Water Re-use in UAE

The United Arab Emirates treated wastewater is one of the non-conventional water resources that is considered a supportive source for fresh water that is used for irrigation activities, which account for 70% of groundwater production in the country. The percentage of treated water accounted for 5.1% of the total water production in UAE in 1995. Due to the shortages in conventional resources, the production of treated water is increasing 10% annually in which this type of water can be utilized for domestic purposes after assurance of being suitable for use. Numbers of wastewater treatment plants were increased in the country. There are 19 plants in Abu Dhabi Emirate with a total capacity of 233502.98 million gallon/year. Dubai Municipality produced 19008 million gallons of treated water in 2000 and this production jumped to 37512.424 million gallons in 2006. The percentage of treated water production in Dubai has increased by 97.4% during the period of 2000 to 2006. Also, there are 7 wastewater treatment plants in Sharjah Emirate with a total capacity of 42.438 million gallon/day. However, the total production of treated water from all seven stations in Sharjah was 40.9741 million gallons in 2006. Increasing the production of treated wastewater is a result of shortages in water availability which could harm the agriculture activities. Most of the treated water in the country is used for landscaping and irrigation as the agriculture practices are one of the main land uses in the area.

4 GENERAL DESALINATION PROCESS TECHNOLOGIES

Desalination is a process that is used to recover pure water from saline water using different types of energy. It is also a process of removing salts from water. Saline water has been classified to be either seawater or brackish water depending on the salinity and water sources. There are two main streams of water that desalination produces, the freshwater and a more concentrated stream (brine). The two main commercial desalination technologies are those based on thermal and membrane processes. With the rapid improvement in technology, desalination processes are becoming cost-competitive with other methods that are used to produce usable water for human consumption and growth. Figure 21 shows worldwide installed capacity for different desalination processes.

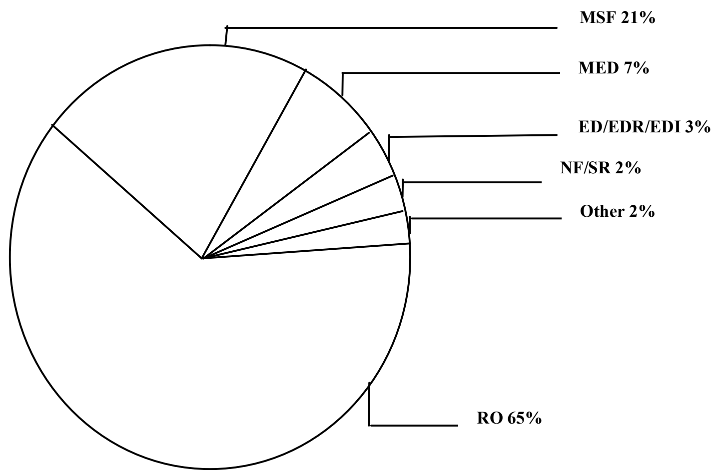


Figure 20 Worldwide installed capacity for different desalination processes, (IDA 2014).

4.1 Thermal Desalination Processes

Thermal desalination is a process whereby saline water is heated to produce water vapour and in turn collecting the condense vapour (distillate) to produce pure water. Thermal desalination is not often used for brackish water desalination. The reason being that it involves high costs.The thermal processes have, however, been used for sea-water desalination. Thermal desalination process includes, multi-stage flash desalination (MSF), multiple-effect distillation (MED), vapour compression (VC) and low temperature evaporation (LTE). In these processes condensed steam is used to supply latent heat that is required to vaporize the water. Due to their outstanding high energy demands, this process is basically used for seawater desalination process, and they are able to produce high purity water suitable for industrial process applications. Thermal process unit capacities are higher compared to membrane process and also account for 55% of the total production. Table 8 shows the thermal desalination technologies which can use energy from renewable sources. Figure 22 shows the breakdown of the cost in thermal desalination.

Table 9 Thermal desalination technologies which can use energy from renewable sources (Isaka, 2012)

Thermal Technologies	MSF	MED	VC	RO	ED
Renewable energy	✓	✓	✓	✓	✓
Solar thermal			✓	✓	✓
Solar PV			✓	✓	✓
Wind	✓	✓	✓	✓	✓
Geothermal	✓	✓	✓	✓	✓

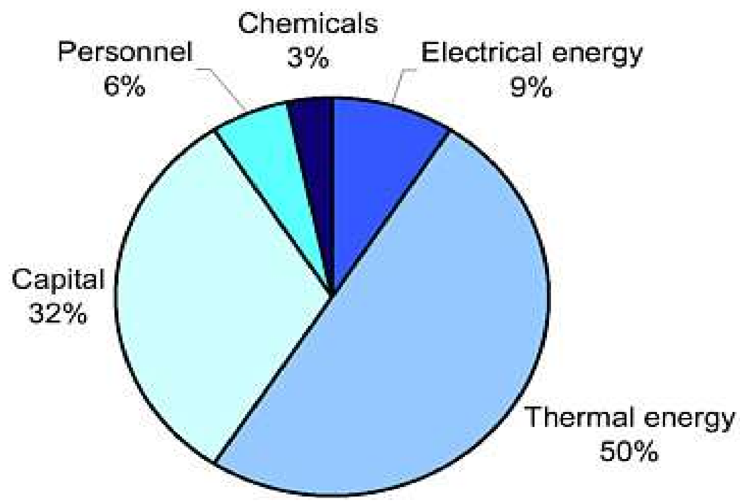


Figure 21 **Breakdown of the cost in thermal desalination (National Research Council, 2004).**

4.1.1 Multi Stage Flash Distillation(MSF)

In multi stage flash distillation process, the basic principle is to heat the saline (sea or brackish) water to a temperature of about 90–120°C using the heat of condensation of the vapour produced. Then the heated water is then evaporated. The pure water is then obtained by the condensed vapour produced. The water temperature and pressure increases when heated in a container, the heated water passes through to another chamber at a lower pressure which causes vapour to be formed, the vapour is led off and condensed to pure water using the cold sea water which feeds the first heating stage. The concentrated salt water is then passed to the second chamber at the same lower pressure as the first stage and more water evaporates and the vapour is condensed as before. The pro-cess is repeated through a series of chambers until atmospheric pressure is reached. Multi stage flash (MSF) accepts higher contaminant levels (heavy metals, oil, suspended solids, COD, BOD etc.) in feed sea water. It also has the capacity of producing distilled quality water product good for power plants, for industrial processes and many other high purity applications. Figure 23 shows the schematic diagram of multi-stage flash process.

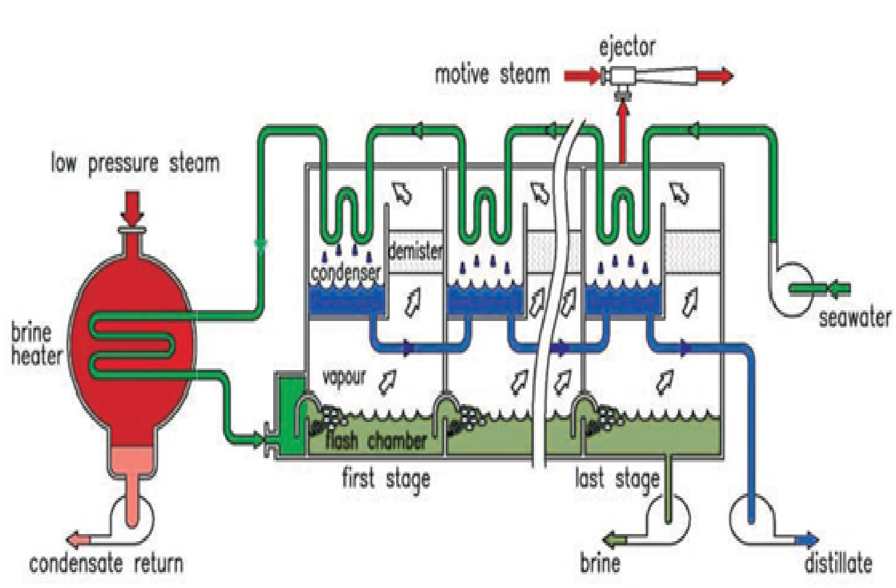


Figure 22 Schematic Diagram of Multi-Stage Flash (MSF) Process (Source: http://www.barc.gov.in/publications/tb/desalination.pdf)

The main advantages of MSF include the following:

- Simple to operate;
- Generates high quality water;
- Marginal costs drop significantly at larger capacities;
- Can be semi-operational during cleaning or replacement of equipment periods, thereby limiting down time;
- Few pretreatment requirements;
- Does not generate waste from backwash of pretreatment filters.

The main disadvantages of MSF include the following:

- High energy consumption compared to RO;
- Creates a large amount of air pollution (primarily from high-energy consumption);
- Slow response to water demand fluctuations;
- High rate of scaling in tubes.

4.1.2 Multi Effect Distillation (MED)

MED is an evaporation process going through a series of chambers (also known as "effects"), with each successive chamber operating at a progressively lower pressure. However MED differs from MSF in that the vapour formed in one chamber condenses in the next chamber with the heat released acting as a heating source. In addition, feed water is sprayed over the tube bundle on top of each chamber in a typical MED process. As shown in Figure 23, external steam is introduced in the first chamber and feed water evaporates as it absorbs heat from the steam. The resulting vapour enters through the tube to the second chamber at a reduced pressure.

The heat released by condensation causes the feed water in the second chamber to evaporate partly. The process repeats in the third chamber and so on. In each chamber, the vapour condensing into fresh water inside the tube is then pumped out.

The efficiency of MED can be raised with the addition of a vapour thermo-compressor. As indicated in Figure 23, the thermo-compressor extracts part of the steam generated in the final chamber for recycling use. The extracted steam will be mixed with the external steam for compression under a high pressure, which then acts as a heating source in the first chamber.

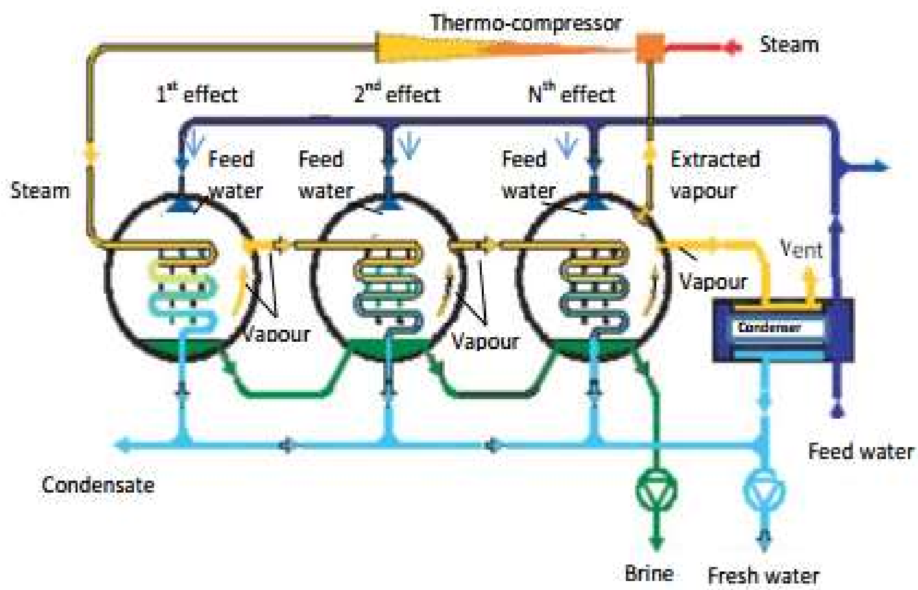


Figure 23 Schematic Diagram of Multi-Effect Distillation (Source: http://www.barc.gov.in/publications/tb/desalination.pdf)

The main advantages of MED include the following:

- Wide selection of feedwater;
- High quality of product water with high reliability;
- Less energy consumption than MSF;
- Requires lower temperature operation (reduces scaling and energy costs).

The main disadvantages of MED include the following:

- Higher energy requirements than RO;
- Slow response to water demand fluctuations;
- Lower capacity than MSF.

4.1.3 Vapour Compression Distillation(VCD)

In vapour compression distillation, the source of heat is used to generate the steam from seawater and the vapour is then compressed using a compressor. The temperature and pressure of the steam will increase as a result of the compression. The work done in the compressor is changed into heat. The incoming seawater is used to cool the compressed steam which then condenses to distilled fresh water and at the same time the seawater is heated further producing more steam. (VCD) can also be used in combination with (MED) or by itself. Vapour compression units are built in different variety of configurations. As a result the mechanical compressor is used to produce heat for evaporation. Vapour compressors are usually small in unit capacity, and are mainly used in hotels, resorts and in industrial applications. Figure 25 shows the vapour phase compression desalination.

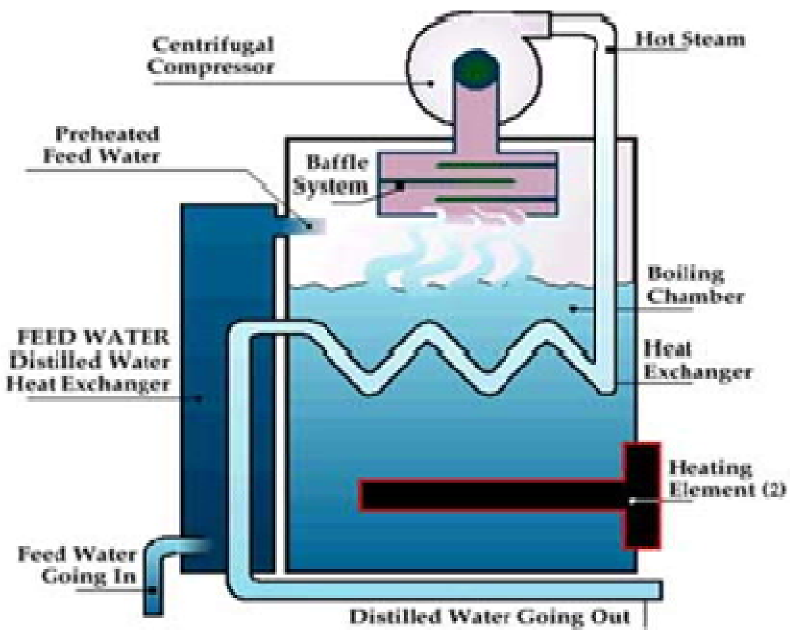


Figure 24 Vapour phase compression desalination, (source: http://efdcorp.com)

4.1.4 LTE Desalination using Waste Heat

Low temperature evaporation desalination unit basically consists of three parts i.e.a heater, separator and condenser. In the heater shell, vertical tubes are used. Feed seawater enters the unit at the bottom of the tubes and partly evaporates by the time it comes out from the top. When the water and vapour mixture comes out of the tubes, the vapour rises through the vertical shell, then enters the horizontal tube bundle kept at the top of the vertical shell and condenses around the tubes (which are cooled by seawater flowing inside) producing desalinated water. The product water is pumped out.

Due to high energy costs in components that is a major fraction of desalinated water cost, the use of waste heat as energy input for seawater desalination is then a good option. It is one of the environmentally friendly ways to produce desalinated water, because it does not require a chemical pre-treatment of feed seawater. Ocean thermal energy can also be utilized for seawater desalination. Figure 26 shows the LTE desalination using waste heat

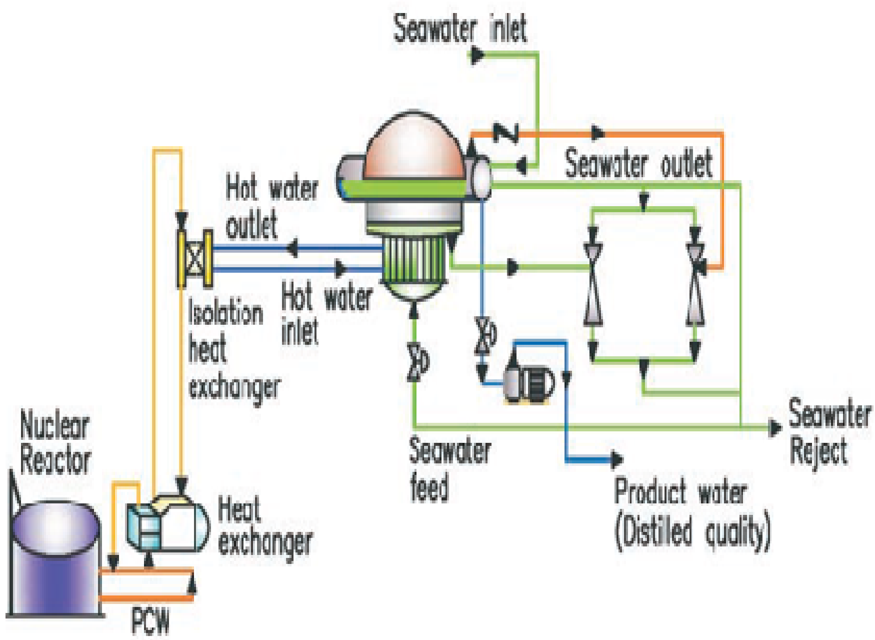


Figure 25 LTE Desalination using waste Heat (Source: http://www.barc.gov.in/publications/tb/desalination.pdf)

4.1.5 Solar Desalination

Solar desalination is a simple method of technology suitable for small community level plants considering the economic viability. The heat generated from the sun by the solar energy source warms up the seawater in a glass covered tank causing some to evaporate. The vapour is condensed on a glass cover and the resulting fresh water is collected. This system of technology is a good alternative for remote and rural areas where grid electricity supply is not available. The most widely used renewable energy source is the sun. This source of solar energy is unlimited and free. No harmful gases are emitted such as mercury, nitrogen ox-ide, carbon dioxide or sulphur dioxide. This method of seawater desalination is cheap, but is not suitable for large scale water production. The process requires proper maintenance due to the growth of algae on the underside of the glass cover and also good sealing to avoid vapour and heat from escaping to reduce the effectiveness of the system. Figure 27 shows the diagram of solar desalination system.

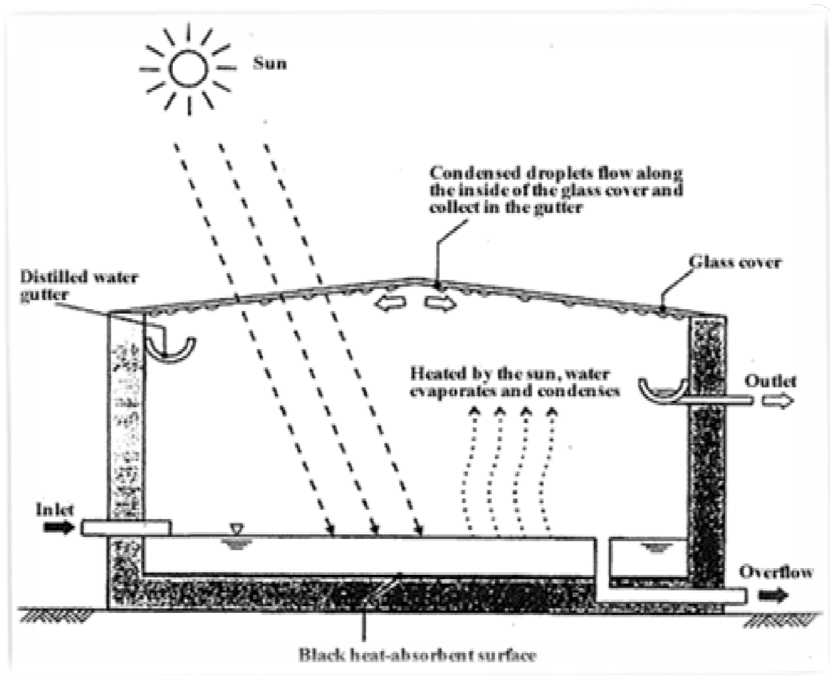


Figure 26 Diagram of solar distillation system, (source: http://www.unep.or.jp)

4.1.6 Vacuum Freeze Desalination(VFD)

A vacuum freeze desalination process can be carried out in different ways. This process involves three separate steps from obtaining fresh water from a saline source: ice separation from the brine, melting of ice and ice formation by the heat removal of saline water. Almost all the freezing process utilizes the same functional components, because they use the same mechanisms for forming ice and separate from salt water, and melting of ice. The vacuum freeze desalination process has four main components: freezer, washer, melter and heat removal system. The freezer consists of a vessel in which ice crystals and vapour are formed simultaneously. The different freezing processes usually vary in the apparatus that removes heat from the brine to enable the production of ice crystals that can easily be transferred, removed, separated, washed and then melted. The heat removed during the freezing process is usually transferred to the melter where it is utilized for melting the ice. The design and operating system of the vacuum freezer are the two main inputs to producing a high proportion of discrete ice crystals rather than clumps of ice, so that the amount of seawater trapped between the crystals formed is minimized. In this process the size of crystal formed is important because fine crystals are hard to wash. The ice crystal formed are pumped as slurry into the washer where it separates the ice crystal for the salt water. The washer which is usually the counter current wash column is utilized as the washer, in which a small portion of the product water, flowing in a direction counter to that of the ice motion is used to wash the ice to remove the brine adhering to the crystal surfaces. In the melter, ice from the washer is melted by transferring the heat crystallization removed from the brine in the freezer to the melter. This is basically done by discharging the refrigerant into the melter, where the ice picks up heat and melts. In theory, freeze desalination has a lower energy requirement than other thermal processes and little susceptibility to the scaling problems which can affect the desalination process. Figure 28 shows vacuum freeze desalination.

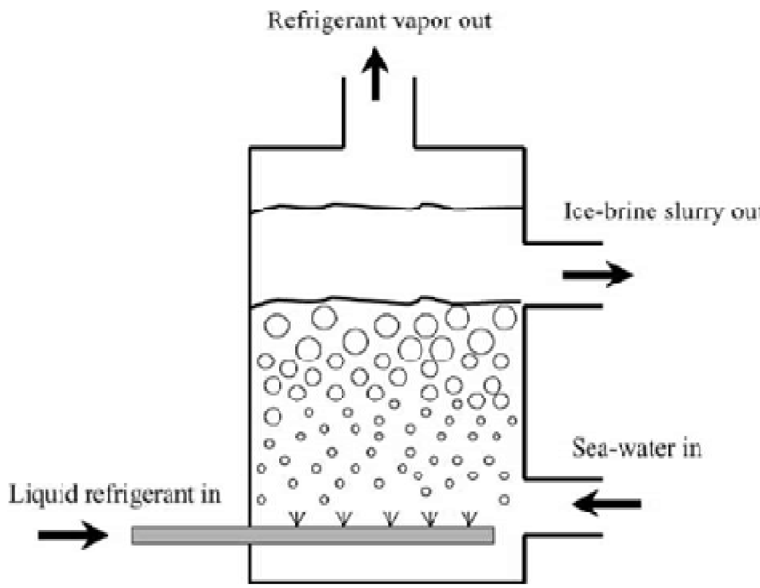


Figure 27 Vacuum freeze desalination, (source: https://www.researchgate.net)

4.2 Membrane Desalination Processes

Membrane desalination processes can be subdivided into two broad categories: Electrodialysis/Electrodialysis Reversal (ED/EDR), and Reverse Osmosis (RO). These will be discussed below:

4.2.1 Electrodialysis (ED/EDR)

Electrodialysis (ED) or electrodialysis reversal (EDR) is an electrochemical charge-driven separation process where dissolved ions are separated through ion permeable membranes under the influence of an electrical potential gradient. Ion exchange membranes, fabricated from ion exchanges polymers, have the ability to selectively transport ions with a positive or negative charge and reject ions of the opposite charge. An electrical potential is used to move salts through a membrane, leaving fresh water behind as product water. Electrodialysis (ED) desalination process has generally been used for brackish water desalination. In a saline solution, the dissolved ions such as sodium (+) and chloride (-) travel to the opposite electrodes passing through. Membranes are basically positioned in an alternate form, with the anion selective membrane followed by cation selective mem-brane. In this process, the content of salt water channelled is diluted, while the concentrated solutions are formed at the electrodes. Electrodialysis (ED) unit consist of several hundreds of cells bound together with electrodes, referred to as a stack. Feed water passes through all the cells simultaneously to provide a continuous flow of desalinated water and a steady stream of concentrate (brine) from the stack. An Electrodialysis

Reversal (EDR) unit operates in the same process as Electrodialysis (ED), except that both the product and concentrate channels are identical in construction. The reversal process is useful in breaking up and flushing out scales, slimes, and other deposits in the cells before they build up. Flushing helps in reducing the problem of membrane fouling.

ED depends on the following general principles:
- Most salts dissolved in water are ions, either positively charged (cations), or negatively charged (anions).
- Since like poles repel each other and unlike poles attract, the ions migrate toward the electrodes with an opposite electric charge
- Suitable membranes can be constructed to permit selective passage of either anions or cations. Figure 29 shows electrodialysis (ED/EDR).

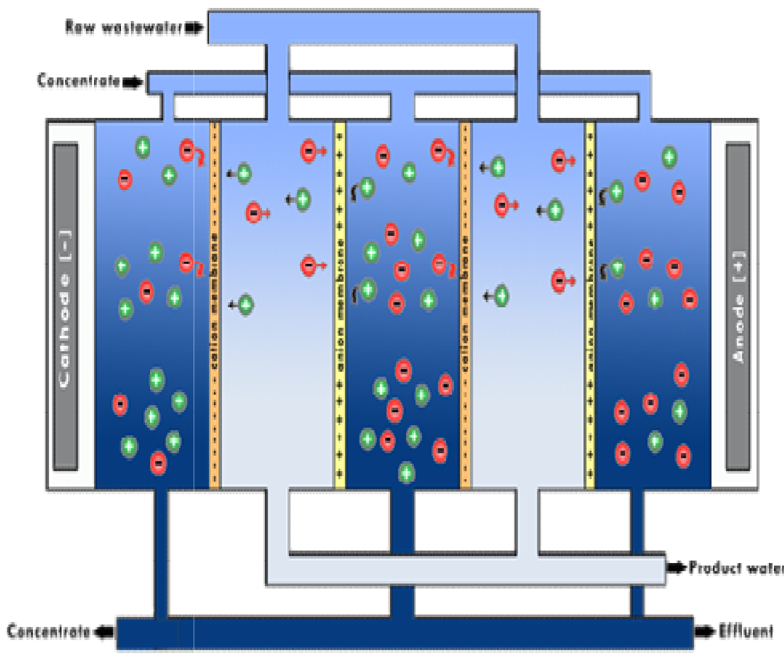


Figure 28 Electrodialysis (ED/EDR), (source: http://waterions.aceenvironment.com)

4.2.2 Reverse Osmosis(RO)

Reverse osmosis is a process in which water passes through a semi-permeable membrane from a lower-concentration solution to a higher-concentration solution. Reverse osmosis is used for both brackish water and seawater desalination as well as for waste treatment and water recovery/reuse. This process occurs in both plant animal tissue including the human body (e.g secretion and absorption the small intestine). When pressure is applied to the higher concentration part of the membrane the reverse process occurs, whereby water diffuses through the semi-permeable membrane from the high-concentration solution to the lower-concentration solution. Figure 30 shows the basic process of a reverse osmosis.

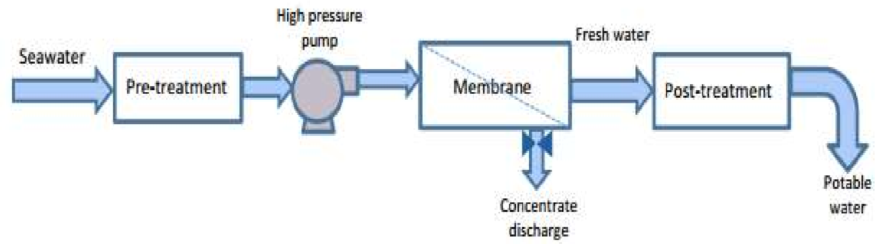


Figure 29 Basic process of a reverse osmosis (Source: http://www.barc.gov.in/publications/tb/desalination.pdf)

The seawater has been pumped under pressure across the surface of the membrane, water molecules diffuse through the membrane leaving a concentration brine solution on the feed-side of the membrane and fresh water on the low-pressure product side. Brine solution is rejected as wastewater and is usually between 10% and 50% of the feed water depending on the salinity and pressure of the feed water. A typical RO desalting plant consists of three sections, namely pre-treatment section, membrane section and post treatment section which is discussed below. Figure 31 shows the principle of osmosis and reverse osmosis. Figure 32 shows the breakdown cost for RO.

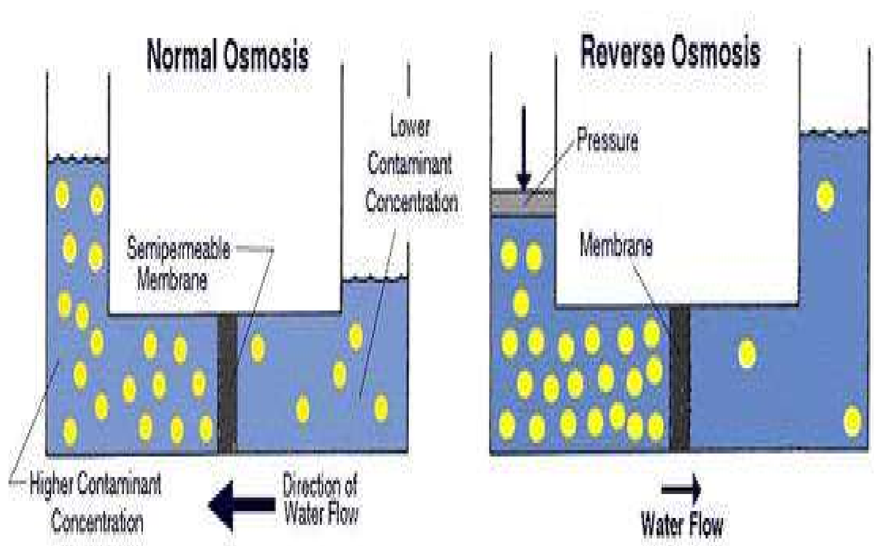


Figure 30 Diagram showing the principle of osmosis and reverse osmosis, (source: http://www.kineticonc.com)

The main advantages of RO plants include the following:

- Low energy consumption.
- Low thermal impact of discharges.
- Fewer problems with corrosion.
- Higher recovery rates (about 45 percent for seawater).

- Removal of contaminants (such as trihalomethane-precursors, pesticies and bacteria).
- Plant footprint is smaller than other desalination processes.
- Flexible to meet fluctuations in water demand.

The main disadvantages of RO plants include the following:

- Sensitivity to feedwater quality.
- Membrane fouling calls for frequent chemical cleaning of the membrane and loss of productivity.
- More complex to operate.
- Lower product water purity.

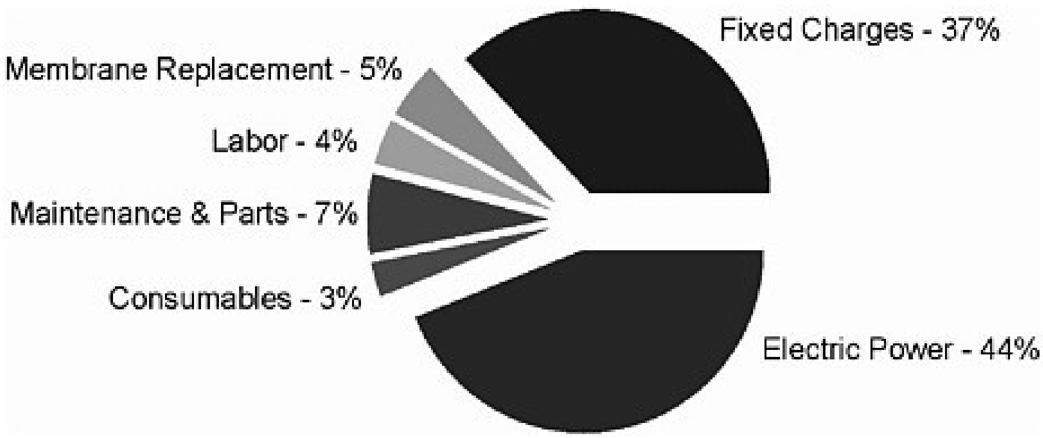


Figure 31 Breakdown cost for RO (Lenntech)

4.2.3 Forward Osmosis(FO)

Forward osmosis (FO) is a fast rising water desalination system that has been gaining huge ground in the desalination market. As in RO, it uses a membrane, but in the area of desalination with membrane, it uses what is called "draw solution" where water is drawn from brackish water or salty water. The solution drawn contains larger molecules, that is the (draw chemical) which inhibit the rate of flow of water molecules back into the salt solution so that there is a net flow of water from the salty water to the draw solution. The draw solution will then be passed through a recovery system which separates the draw chemical from the water. The water that is desalinated passes out of the recovery system for subsequent use, and the draw chemical recycled. As shown in figure 33 below. The draw chemical is ammonium carbonate which can be removed from the water by heating the solution which drives off the ammonium carbonate as ammonia gas and carbon dioxide gas leaving pure water behind. The gases are recovered and recycled.

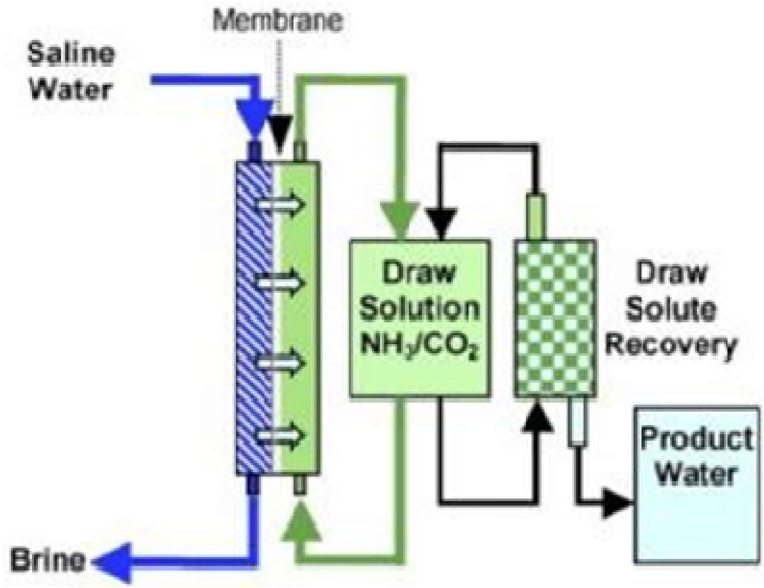


Figure 32 Diagram of forward osmosis process, (source: http://www.odec.ca)

4.2.4 Membrane Distillation

Membrane distillation is a thermal membrane based separation process which uses the vapour pressure difference across the membrane produced by a temperature difference. This method of water desalination was investigated in the late 1960s but was not commercialized at that time due to its relatively high cost and unavailability of suitable membrane. Membrane distillation have the same similarity with conventional distillation process and its membrane variant as both technologies are based on the vapour liquid equilibrium for separation and both of them requires latent heat of evaporation for the phase change from liquid to vapour which is achieved by heating the feed solution the driving force of the membrane distillation is given by the vapour pressure gradient which is generated by a temperature difference across the membrane. Membrane distillation can be held at a much lower temperature than conventional thermal distillation. The incapable nature of the membrane prevents the penetration of pores by aqueous solutions due to surface tensions, except a trans-membrane pressure that is higher than the membrane liquid entry pressure (LEP) is applied. At this point the liquid and vapour interfaces are then formed at the entrance of each pore.

The transportation of water through the membrane can be summarized in three phases:

I. The formation of a vapour gap at the hot feed solution membrane interface
II. The transportation of the vapour phase through the microporous system.
III. Condensation of the vapour at the cold side membrane-permeate solution interface.

4.2.5 Rapid Spray Evaporation

The rapid spray evaporation technique is a newly developed technology that makes effective use of waste heat generated from gas fired electrical generating plants, water treatment plants, landfills, marine engines and other sources for desalination. The rapid spray desalination is a process that involves spraying droplets of salty water into a container where they evaporate rapidly causing the dissolved salts to fall to the bottom of the container. The vapour leaves the container and then condenses to form pure water. This application of this water desalination process is used mostly in the coastal and inland locations for production of fresh drinking water. Other used process of this method is for recovering or disposing of the dissolved materials. Another used method also is for reducing the volume of waste water. The most obvious use of RSD is desalination in coastal and inland locations for the production of fresh drinking water. Other potential users are interested in recovering or disposing of the dissolved materials. Others are interested in using the process for reducing the volume of their wastewater.

4.2.6 Capacitive Deionisation

Capacitive deionisation is a variant of Electrodialysis that operates adsorbing the ions of the TDS in the solution double layer formed at the electrodes when an electrical current flows. The capacitive deionisation is used to treat brackish with TDS in the range of 800-10,000 mg/l. The CDI has a much more lower energy consumption than RO and ED, and can also be used in conjunction with ED to desalinate seawater. The benefits of the capacitive deionisation technique is that it uses no chemicals, no membranes and has a lower power consumption. But unfortunately, this process requires a discharge stage to remove the retained ions, and this has caused limitation to its application. However, some research was made in Korea which found out a brilliant and suitable way to overcome the limitation using a suspension of active carbon nano particles with membranes, which has also helped in opening a wider application on a larger scale. This new technique has achieved up to 95% reduction of TDS in a salt solution of about 32,100mg/l. But only a small unit is available commercially at this time. However, this may change over the next few years. Figure 34 shows the schematic diagram of capacitive deionization.

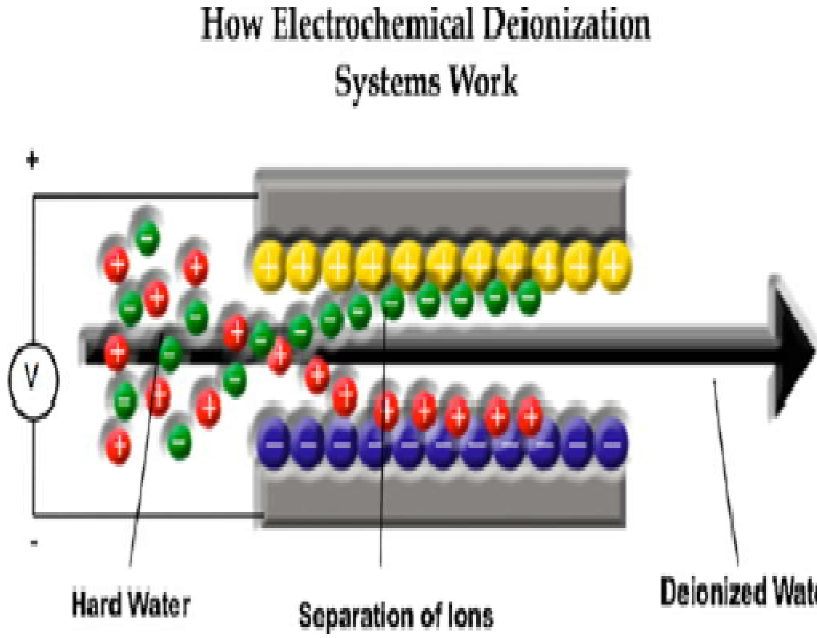


Figure 33 Schematic diagram of capacitive deionization showing the removal of charged ions or species by two charged electrodes., (source: https://www.researchgate.net)

4.3 Pre-treatment System

Pre-treatment is very important in reverse osmosis because the surface of the membrane must be kept in clean condition at all times. By doing this, feed water can then be treated to protect the membranes and to make easy membrane operation. This system ensures the removal of all suspended solids, and the water pre treated to also ensure that salt precipitation or microbial growth does not occur on the membranes. These impurities can cause a severe effect on desalination processes. These causes of bacteria effect mainly cause serious effect in the case of ro system, which builds up on the surfaces of membranes resulting in a decrease of flow rates. This can decrease the effectiveness of the membranes and cause an increase in operating costs. Pre-treatment may involve conventional methods such as a chemical feed followed by coagulation/flocculation/sedimentation, and sand filtration, or pre-treatment may involve membrane processes such as microfiltration (mf) and ultra-filtration (uf). The choice of a particular pre-treatment process is based on a number of factors such as feed water quality characteristics, space availability, ro membrane requirements, etc. Therefore, it is very important to include a pre treatment stage in desalination plants. Figure 35 shows simplified flow sheet of complete desalination process.

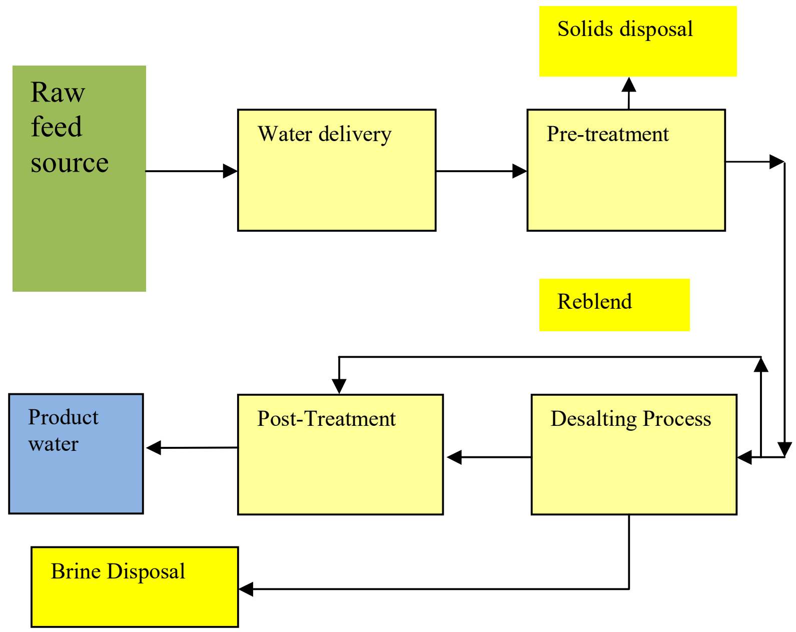


Figure 34 Simplified flow sheet of complete desalination process (Source: http://www.fwr.org/desal.pdf)

4.4 Post-treatment System

Post-treatment stabilizes the water and prepares it for distribution. In thermal desalination processes, water produce is very low in dissolved content, in effect, the water they produce is distilled water. If the water is to be used for drinking purposes, some dissolved solids and air must be added back to the desalinated water. As shown in figure 35 , this is actually done by combining a proportion of the feed water with the desalinated water, aerating the water and adding some chemicals to reduce its corrosivity. The post-treatment also consists of ph adjustment and disinfection to control microorganisms during distribution, as well as eliminating pathogens from the blending process. In some cases desalinated water maybe blended with other sources of water supply from other sources to improve its taste, to extend supplies of desalted water and to improve the quality of other water.

5 BEST SUITABLE DESALINATION TECHNOLOGY

Selecting the best suitable desalination technology is very important, depending on different site-specification, including the concentration of organic and inorganic material in the incoming feed water, the required quality of the treated water, the level of pre-treatment that maybe required prior to desalination, the availability of energy and chemicals to treat the water, and the ease with which waste concentrates can be disposed. Many other aspects that should be taken into consideration include. The availability of construction and operating personnel, waste concentrate disposal, environmental considerations, maintenance requirements and costs.

5.1 Reducing Financial Costs of Desalination

Reducing financial costs of desalination could greatly benefit the water stressed countries of the ESCWA region and low-income countries where desalination is also feasible. In addition, this would provide those countries that are already using desalination with significant savings. Cheap and abundant desalination has been a long standing goal of science and society, while this vision is yet to be achieved, the cost of desalination can be reduced in many ways. It is important to note that while these options are not intended as a silver bullet to solve completely the issue of cost, desalination has gone from being prohibitively expensive to merely costly.

Energy is a major cost incurred in the operation of desalination plants. There are two ways to reduce energy costs, namely: (a) by increasing the energy efficiency in the desalination process and (b) by using a cheaper energy source.

5.1.1 Increase in Energy Efficiency

One way of increasing energy efficiency is to combine a desalination plant with a power plant, thereby creating a cogeneration desalination-power unit. In such setup, hot exhaust gases from a power plant are used either to desalinate water in a distillation plant or to heat incoming feedwater. Cogeneration desalination plants can be more energy efficient than standalone plants. Higher temperature feedwater reduces the amount of energy needed to desalinate water. Cogeneration is usually used in combination with distillation desalination, RO plants can also operate more effectively with higher temperature feedwaters.

Another way of increasing energy efficiency is to combine a thermal desalination unit and a single pass RO unit into a hybrid plant. The single pass RO unit is used as opposed to the more common multi-pass RO plant given that a single pass unit uses less energy than a multi-pass. The single pass RO is made possible in this configuration by blending its output with the output from the thermal desalination unit. The blended water is then potable and allows for a less energy-intensive operation of the RO plant.

5.1.2 Cheap Energy Sources

In the Gulf subregion, desalination plants have been developed to take advantage of the variation in demand for electrical power. Energy demand spikes during the hot summer months give the need for additional power for air conditioning. Energy demand in winter is substantially lower, thereby leading to an excess of generating capacity during the winter. Various plants have been designed to take advantage of this cheap excess capacity to produce more water during the winter. This water can then be stored for later use.

In addition, alternative energy sources can be used for desalination and can reduce the cost of desalination. Specifically, renewable solar energy can be used as an alternative fuel for electric or thermal plants. Renewable wind energy and nuclear energy can be used to generate electricity for use in desalination plants. The alternative energy sources and their application are explored below.

5.1.3 Renewable Energy

Renewable energy can possibly provide less expensive energy in certain desalination applications. Renewable energy sources have been explored for desalination primarily in research settings. In the ESCWA region no large scale renewable desalination is presently taking place. This owes largely to the high, though declining, cost of renewable energy. The Red-Dead Sea project, which aims to channel water from the Red Sea to the lower altitude Dead Sea, represents arguably the first very large desalination scheme in the region that would be driven by a renewable energy source, hydropower. While still in the design phase in 2009, the project has the capacity to produce up to 850 million m^3 /year of potable water. Renewable desalination plants do not produce CO2, which is a main advantage of such plants that translates into cost savings.

5.1.4 Solar Energy

The ESCWA region, which is abundantly rich in solar energy, receives more than 4 kWh/m^2 /day (electric equivalent) of solar energy, with very few cloudy days. Combining the two characteristics of water poverty and abundant sun wealth could be a bonus to the region in saving energy cost. However, the development in solar desalination is still primarily limited to research prototypes and small-scale systems designed for remote and rural areas. Research and development in solar desalination is promising, and the solar energy available for harnessing is abundant.

Two types of solar power can be harnessed, namely, solar photovoltaic (PV) and solar thermal. Solar PV uses a silicon-based system to produce electricity from solar rays. As such, solar PV can be used primarily for RO plants or to provide some of the electrical power required by thermal plants. Solar PV is currently very expensive and does not compete with other forms of electricity generation. Solar PV can also be used in remote locations to satisfy small scale RO demands.

Solar thermal power is used to produce both thermal and electrical energy that is capable of powering a desalination plant. Thermal energy is created by collecting solar radiation and generating heat. In general, solar thermal takes the form of a collector that concentrates solar ray into a liquid medium, usually oil, water or molten salt, thereby creating a hot fluid. For desalination, this hot fluid can be used to provide direct thermal energy needed for thermal plants, namely, MED or MSF, or it can also be used to create steam to generate electricity. For direct thermal energy purposes, the liquid medium used is often oil or water, while for electricity generation molten salt is often used due to is higher temperature profile. Some of the thermal energy gained during the daylight can also be stored so that there will be a continuous provision of energy all through the night. Traditional energy sources can also be use to increase solar thermal power to enable continuous power output.

In addition, solar thermal energy can be used to desalinate water directly without going through a conventional desalination plant. The simplest format is a solar still, whereby water is evaporated by solar thermal energy and is condensed and collected separately from the brine. Multiple-effect dehumidification is a more sophisticated version of a solar still, and it uses multiple temperature evaporation and condensation cycles to reduce the overall amount of energy used. However, direct solar desalination often requires significant land areas and is less productive than solar thermal coupled with conventional desalination plants.

5.1.5 Nuclear Energy

Nuclear desalination is achieve through a cogeneration unit that couples a desalination plant with a nuclear reactor, which is used as the source of energy. Nuclear reactors can be coupled with thermal plants to provide steam for desalination processes, or with membrane plants to generate electricity to drive the desalination process. Generally, small- or medium-sized reactors are best suitable for desalination when the reactor is used solely for desalination purposes. While nuclear desalination does not produce greenhouse gases, which constitutes a main advantage, the disposal of nuclear waste and the threat of nuclear proliferation are unresolved issues that need to be considered.

In the ESCWA region, Egypt has explored several options for nuclear desalination and Jordan is exploring nuclear power options. The renewed interest in nuclear power comes along with new standardized plant designs that could theoretically reduce the cost of nuclear power. As practical construction experience increases, the cost of commissioning nuclear power plants and, by extension, of nuclear desalination facilities will decrease. While estimated costs vary, in general, nuclear power is considered to be cost competitive with fossil fuel sources when subsidies and opportunity cost are accounted for.

5.1.6 Wind Energy

Wind power can be used to provide electricity for a desalination plant. It cannot provide thermal energy directly. In this case the future of wind power for desalination is by providing electric energy for RO plants. As a result, the focus of wind power for desalination depends mainly on reducing the cost of wind per kWh of electricity, thereby competing with other electricity generation methods.

Wind power is becoming more competitive with conventional electric power sources, particularly in windy areas. Generally, wind power is competitive in areas where wind speeds are at least 6 m/s. More work needs to be done to identify locations in the ESCWA region that have high winds speeds that are capable of supporting large scale wind power. The most promising areas for wind power production in the ESCWA region are the east coast of Egypt; some sites in Jordan and some of the coastal regions in the Gulf sub-region.

5.2 Suitable Desalination Techniques used in the GCC Countries

The Gulf Cooperation Council (GCC) countries have been witnessing an accelerating development over the last three decades in terms of the social, construction, industrial and agriculture aspects, accompanied by remarkable increase in the demand for water. As a result, the GCC countries have made tremendous continues efforts to increase the utilization of their water resources and introducing new resources by building desalination stations, reusing the sewage water, building dams for reserving the surface water and increasing the utilization of underground water resources. Their Majesties and Highnesses, the GCC leaders, pay great attention to the water issue due to water rareness in the GCC countries and the resulting challenges facing the sustainable development. This interest resulted in the establishment of a ministerial committee consisting of the ministers concerned with water in the GCC counties. The committee is concerned with developing this vital sector as a part of the Gulf mutual work. The GCC countries have taken serious steps in the field of water cooperation, through adopting policies and programs, and relentless pursuit to strengthen the methods, ways and steps that ensure achieving water security, which is the essential foundation for achieving the comprehensive development of the GCC countries.

There are many water desalination processes used in GCC and they are divided into two categories, the first category is based on thermal processes while the second category is based on membranes processes. The following processes used by the GCC countries in water desalination has already been explained in the text above.

The Vapor compressor VC distillation process is used in small and medium capacity units to desalinate sea water. In general, the capacity of desalination units using compressed vapor process varies between 20-2000 m3/day (4400-440000 gallon/day). This process is often used in tourist resorts, industries and well excavation sites. The heat required for evaporation comes from compressing the vapor instead of direct heat transfer from steam produced in boilers. 3- Vapor compression (VC) In this process, a mechanical compressor driven by electric motor or a steam ejector is used to create vacuum inside evaporation chamber, which will cause the water to evaporate at the feed water temperature. The produced vapor is compressed till its temperature increase and subsequently becoming the source of heat required to evaporate another part of feed water. The pressurized vapor is pumped to the shell side of tubes containing salt water causing the vapor to condense on the outer surface of tubes and also heating the salt inside the tubes producing additional quantities of water vapor which will be compressed again so the cycle will continue to produce condensed water as product water. Figure 35 and 36 shows the mechanical VC process and reheating process.

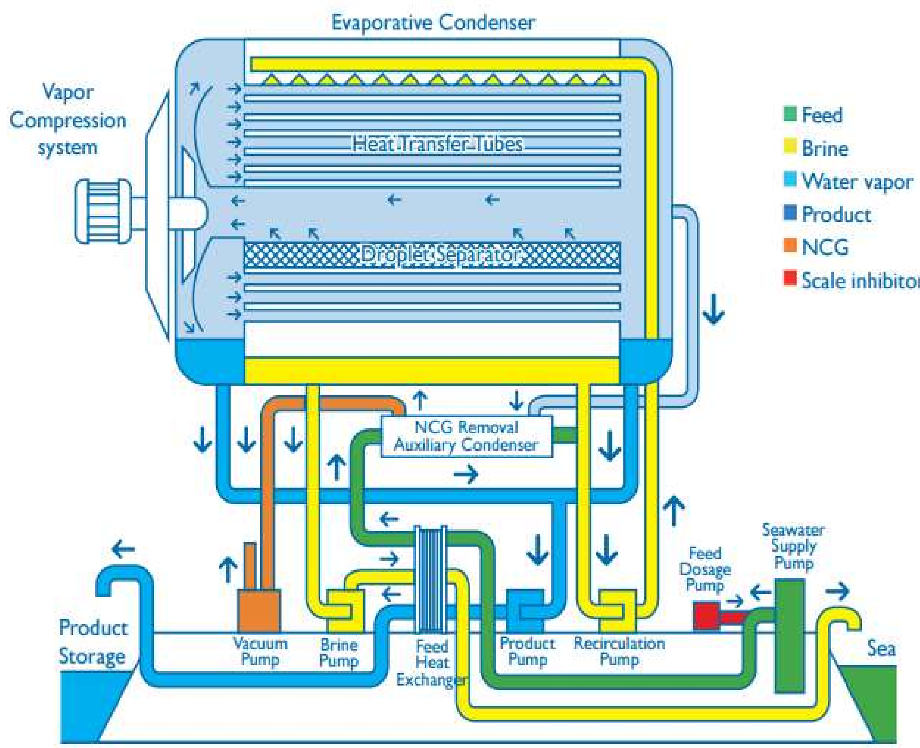


Figure 35 Mechanical VC process schematic, (Sources: http://www.gcc-sg.org/en-us/CognitiveSources/)

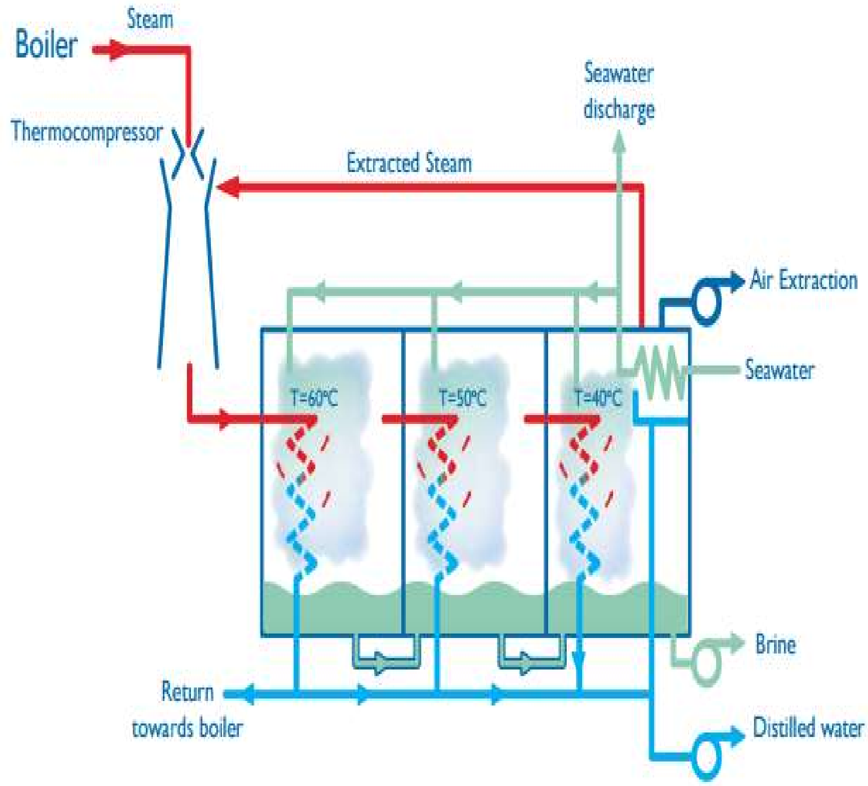


Figure 36 Reheating Process Schematic, (Sources: http://www.gcc-sg.org/en-us/CognitiveSources/)

6 ENVIRONMENTAL IMPACTS

The environmental impacts of desalination are generally associated with the disposal of waste concentrate produced during the process of desalination and the disposal of sludge from the pre-treatment of incoming feed water. One main importance to note is that the construction and operation of desalination facility can also create many other secondary or indirect impacts that may be associated with transporting raw water to the plant, generating electric power etc.

6.1 Waste Concentrates

Desalination processes produce high salinity waste concentrate that should be disposed of. The portion of feed water that becomes wastewater depends of the desalination process used, the feed water composition, the plant design and the type of concentration treatment required prior to disposal. The amount of waste concentrate can be reduced by further desalinating the waste concentrates produced during the first process or stage of desalination. The larger the percentage of feed water recovered, the smaller the amount of concentrates that must be disposed of, but the higher the concentration of salt and other dissolved chemicals in the concentrate. The temperature of the waste concentrate that is moderately elevated may also cause significant ecological changes in the immediate area of concentrate of discharges in marine environments. The composition of waste concentrates usually makes them unsuited for most subsequent industrial, municipal or agricultural uses.

Waste concentrate from brackish water reverse osmosis (RO) and electrodialysis (ED) plants have been disposed of in different number of ways including: pumping into lined evaporation ponds, injection into ground rock formations, spreading on unusable arid land or discharging through a pipeline into sewers, rivers, or ocean. The waste concentrate from RO and distillation plants would probably be discharged into adjacent marine environments. All the options related to disposal require site specific and evaluations of costs and significant environmental impacts. Till now, the problems associated with the disposal of waste concentrates have generally not been significant enough to override a decision to build a desalination plant. However, with the increasingly effect of environmental and regulatory programs, disposal of waste concentrates could become a primary consideration in setting future plants.

When evaluating several alternatives for increasing supplies of freshwater, it is important to evaluate the significant environmental problems associated with the development of conventional sources of freshwater. For example, diversions from lakes and rivers may reduce the flow and adversely impact the environment. Table 9 shows the amount of waste concentrate during disposal.

Table 10 Waste Concentrate Generation

Process	**Percentage recovery of feed water**	**Percentage disposal of waste concentrate**
Brackish water RO	50 to 80	20 to 50
Seawater RO	20 to 40	60 to 80
ED	80 to 90	10 to 20
Distillation	25 to 65	5 to 75

Determining the amount of waste concentrate during disposal, the percentage of salt rejected during desalination must also be considered.
SOURCES: Office of Technology Assessment, 1957.

6.2 Land Disposal

Waste concentrate disposal is a very significant problem in inland areas, where the options of disposal are limited to evaporation ponds (deep injection wells). Concentrate disposal costs may range from 5 to 33 percent of the total cost of desalination depending on the characteristics of the waste concentrate, the level to which it must be treated prior to disposal, means of disposal and the nature of the disposal environment. Land disposal is a risk to groundwater contamination.

6.3 Marine Disposal

Concentrate disposal has less significant effect in coastal and marine environments due to high level of concentrate dilution that usually occur. However, with seawater RO and distillation, some organisms might be adversely impacted by the increase salinity of the wastewater or by a higher concentration of pre treatment chemicals or natural contaminants in the effluent. Moderately increased temperatures of distillation effluents, which run about 10° to 15° F above feedwater temperatures may not be a potential concern depending on the organisms near the point of concentrate discharge.

6.4 Environmental Impact of Desalination Plants in the Arabian Gulf Countries

Desalination plants are being widely used in the Gulf countries as a main source of providing fresh water to overcome the water shortage. Some other Middle East countries have already started building desalination plants like Egypt which built a large plant on the Mediterranean coast. Most of the desalination plants are combined with power plants for power production. There are many desalination plants in the gulf region and there are plans to build more. Abu Dhabi Emirate, as an example, has 5 plants producing 550 MIGD water and 7,164 MW power. There is a plane to extend the capacity of the existing plants in parallel with building new ones to satisfy the rapid urban and industrial developments in the emirate. Figure 38 shows a general layout of the desalination plants in Abu Dhabi Emirate. The desalination plants in the Gulf region are built either on the coast of the Arabian Gulf or in the lagoons. They abstract the seawater through their intakes and discharge the effluents back to the sea through the outfalls. The effluent discharges have a high concentration of seawater temperature and salinity and other substances which may adversely affect the water quality in the plant vicinity species living in the area.

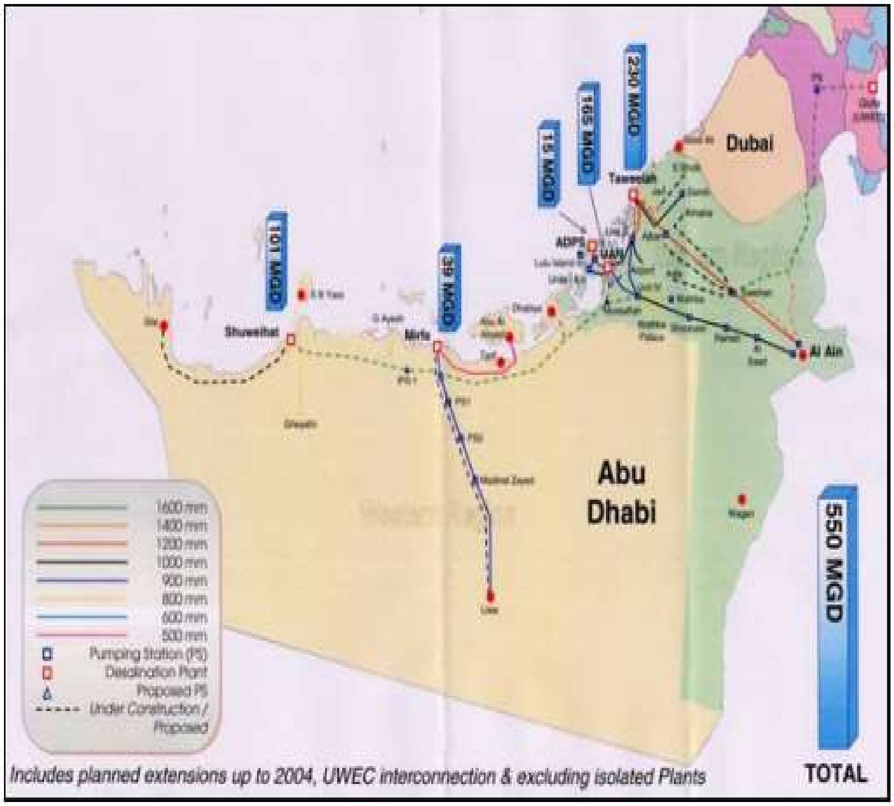


Figure 37 General layout of the desalination plants in Abu Dhabi Emirate. (Source: http://www.iwtc.info/2009_pdf/11-3.pdf)

6.4.1 Possible Effects of the Effluents of Power and Desalination Plants

The effects on the marine environment arising from the operation of the power and desalination plant from the routine discharge of effluents. Water effluents typically cause a localized increase in sea water temperatures, which can directly affect the organisms in the discharge area. Increased temperature can affect water quality processes and result in lower dissolved oxygen concentrations. Furthermore, chlorination of the cooling water can introduce toxic substances into the water. Additionally, desalination plants can increase the salinity in the receiving water. The substances of focus for water quality standards and of concern for the ecological assessment can be summarized as follows:

- **Salinity**: High concentration of salt is discharged to the sea through the outfall of desalination plants, which leads to the increased level of salinity of the ambient seawater. Generally, the ambient seawater salinity in the Gulf is about 45 ppt and the desalination plants increases this level in its vicinity by about 4 to 5 ppt on average above the ambient condition.

- **Temperature**: If the desalination plant is combined with a power plant as the case in most plants in the Gulf area, the water temperature of the effluents of the power plants will be high and will increase the seawater temperature of the ambient water in the plant vicinity. In summer the ambient seawater temperature is about 35 °C on average and the power and desalination plants cause an increase in the temperature level in its vicinity by about 7 to 8 °C above the ambient condition.

- **Oxygen**: Dissolved oxygen in water in the plant vicinity is affected by the effluent discharges from the plant. The concentration and saturation of oxygen will decrease due to the higher temperature and salinity of the effluents. The concentration of dissolved oxygen depends on the seawater temperature in the plant vicinity, concentration of oxygen in the discharge and the mixing of the discharge with the ambient water.

- **Chlorine Concentration**: Chlorine concentration in the effluents of the plants depends on the dosing rates used in chlorination of the seawater. Increasing the concentration of residual chlorine may affect the water quality of the ambient water and hence, the ecological system. The concentration of Chlorine in the discharge depends on the number of dosing per day concentration of the Chlorine used in each dosing.

- **Un-ionized ammonia**: Ammonia is one of the substances of concern as unionized ammonia (NH_3) is very toxic to aquatic species. In the environment, both ionized and unionized species occur. The ratio of the two species is a function of the pH. If pH is high then the concentration of the un-ionized ammonia is high and may affect the marine life.

The concentrations and levels of these substances in the plant vicinities depend on the size of the plant and the ambient seawater conditions. Generally the concentrations and levels of these substances should be within the water quality standards to avoid the negative impact on the environment.

6.4.2 Main Eco System in the Arabian Gulf

The main hydrodynamic forcing in the Arabian Gulf is the tide. Large areas of tidal flats are in the Arabian Gulf. These areas are flooded during high tide and dried during low tide. Tidal flats, subtidal areas and mudflats are good environment for many habitat and species. The following ecotopes are the main ecosystem in the Arabian Gulf region:

- **Mangrove swamps**: They are extensively grown in the tidal flats. The combinations of the mangrove swamp and the large neighboring mudflat is an important eco system for many birds.

- **Seagrass meadows**: Dense and spare seagrass were observed in large areas in the Arabian Gulf water. They differ in types and density from one location to another. Seagrass plays an important role in the Gulf marine environment. About 9 % of the Gulf's faunal texa are endemic to seagrass meadows (48 out of 530 recorded species). Of these, about half are molluses. Seagrass also play a major role as a sole food for endangered species such as dugong and the main food source for all marine turtle species, but in particular green turtle. Among the commercial species, the pearl oyster often settles in or near seagrass beds and of course many important fisheries species, such as shrimps. Seagrass helps in stabilization of mobile sands and therefore shorelines.

- **Corals**: Coral areas in the Arabian Gulf are primarily controlled by the availability of suitable substratum. They are extensively found in the Gulf region with marvelous colures. Coral reefs are the most diverse environment of the marine realm. They are not only important biodiversity batteries, but also important for fisheries. While the mortality of a part of the coral reef system may have somewhat decreased the number of fishes.

6.5 Techniques to Minimize the Negative Impact of Desalination Plants on the Environment

The role of the water and power research centers in the Arab countries; especially in the Gulf area is very important in minimizing the impact of the desalination plant on the environment. It is a big challenge to get use of the desalination techniques with a minimum adverse impact on the water quality and environment. A comprehensive environmental impact assessment study should be carried out before building a new desalination plant or extending the capacity of the existing one to limit the negative impact of the plant.

The Water and Power Research Center of Abu Dhabi Water and Electricity Authority has set up study procedures to be followed on the study of the environmental feasibility of building or extending the capacity of the desalination plants. These procedures are as follows:

6.5.1 Baseline Data Collection

Field measurements should consist of hydrodynamic, water quality and biological measurements as follows:

- **Hydrodynamic field measurements**: Measurements should be carried out in the plant vicinity and should include water levels, current flow velocities and directions and flow discharges. The hydrodynamic measurements will be used in understanding the flow pattern in the plant vicinity and in the calibration of the hydrodynamic model of the area.

- **Water quality measurements**: water quality measurements should be carried out to evaluate the concentrations of the substances of importance to the water quality and aquatic species. The substances include residual chlorine, dissolved oxygen, ambient seawater temperature and salinity, pH and ammonia. The measurements will be used to evaluate the water quality with regard to the water quality standards and used for the water quality model calibration.

- **Biological survey**: A biological survey should be carried out in the plant vicinity to evaluate the ecosystem in the area. A detailed sampling grid should be constructed in the plant vicinity and surveyed by the ecologist. Data should provide a detailed description of local habitats and species. Photos on the ecosystem should be taken on the grid by divers with underwater camera. The value of the ecosystem in the study area can be evaluated by the ecologist based on the finding of the survey.

6.5.2 Developing the Numerical Hydrodynamic Flow Model

The flow velocities and flow pattern is the main transport and dispersion mechanism of the effluents from the outfall. A numerical flow model simulates the flow pattern in the plant vicinity and the configuration of the intake and outfall of the plant should be developed and calibrated with the field measurements. In the Arabian Gulf the main driving hydrodynamic force is the tide. The model will reproduce the flow pattern which will be used as an input for the water quality model. The flow pattern from the hydrodynamic model can be used to predict the morphological changes of the shoreline due to the construction of the intakes and outfall of the plant.

6.5.3 Developing the Numerical Water Quality Model

A numerical water quality model should be developed. The goal of water quality modeling is to simulate the water quality of the waters around the plant, as influenced by the discharges from the power and desalination plant. The diffusion and dispersion of the modeled substances discharged from the outfall to the sweater will be simulated. The flow pattern from the hydrodynamic model will be used as an input for the water quality model as it is the main transport mechanism of the substances. The model calibration will be carried out by with the water quality measurements.

6.5.4 Evaluation of the Water Quality Results

Water quality model results should be evaluated against the water quality standards. If the modeled substances violates the water quality standards and may affect the marine life, the configuration of the intake and outfall of the plant should be modified (I.e. using pipeline instead of open channel) in the hydrodynamic model and repeat the water quality model computations until the modeled substances meet the requirements.

6.5.5 Habitat Evaluation Procedures

The Effect of the water quality change due to the outfall discharge should be evaluated against the nature of the habitat in the plant vicinity. The output concentrations of the modeled substances obtained from the water quality modeling should be compared with the species thresholds. If the study shows that the plant discharge will adversely affect the environment, measures should be taken to minimize this effect like changing the proposed configurations of the intake and outfall structures to redistribute the substances in the effluent discharge in a way to reduce their concentrations. Hydraulic structures can be designed and used to guide the flow pattern and flow velocity to control the diffusion and dispersion of effluents. This can be a solution to minimize the negative impact of the effluents on the environment.

7 ARABIAN GULF CASE STUDY OF SEAWATER DESALINATION

Desalination is widely used in Gulf Cooperation Council (GCC) countries as a main source for fresh water supply for domestic sector due to the scarcity of renewable natural fresh water resources. Some other Middle East countries have already started building desalination plants such as Egypt. The largest number of desalination plants can be found in the Arabian Gulf as shown in Figure (38). Most of the desalination plants are combined with power plants for power production. At present there are more than 199 plants and there are a plan to add 38 in the future as shown in table (11) and table (12). The total seawater desalination capacity is about 5000 million m3 /year, which means a little less than half (45%) of the worldwide production as shown in Table (13). The main producers in the Gulf region are the United Arab Emirates (35% of the worldwide seawater desalination capacity), Saudi Arabia (34%, of which 14% can be attributed to the Gulf region and 20% to the Red Sea), Kuwait (14%), Qatar (8%), Bahrain (5%) and Oman (4%) (Lattemann and Höpner, 2008). The expected increase in the total capacity is about 1800 million m3 /year by 2013. The total capacity of desalination in GCC countries increased from 3000 million m3 /year in 2000 to about 5000 million m3 /year by 2012. It is expected that the capacity will increase to be about 9000 m3 /year in 2030 as shown in Figure (39).

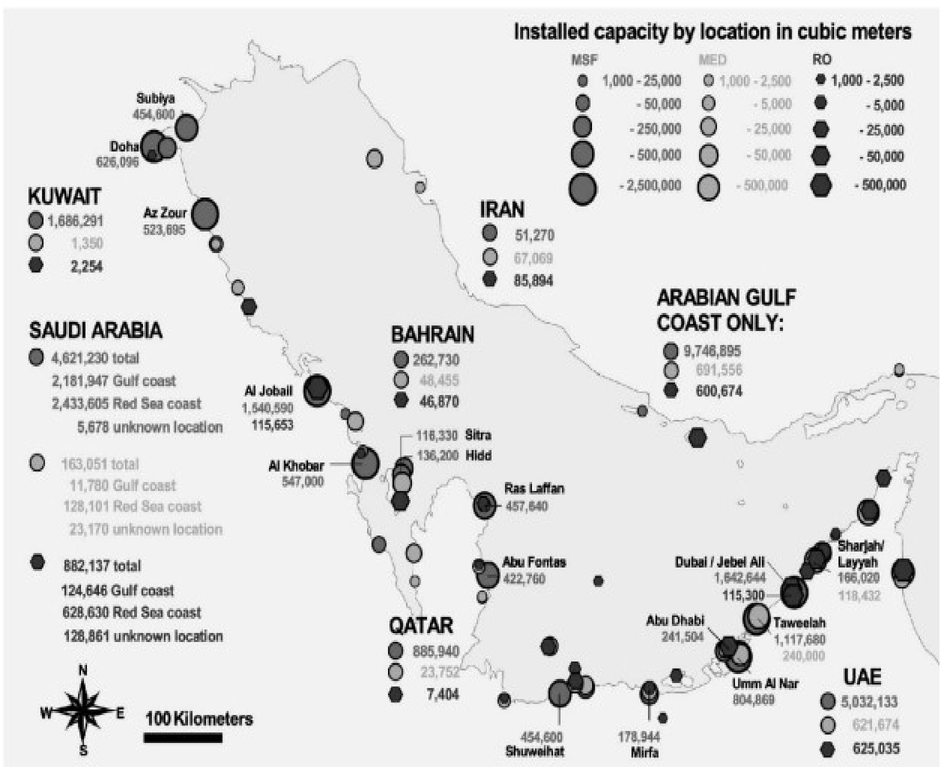


Figure 38 Seawater desalination capacity in the Arabian Gulf (Lattemann and Höpner, 2008)

Table 11 Existing desalination plants in GCC countries in 2010 (Source: https://www.sciencetarget.com)

Technology	Country Capacity (Million m^3/year)						
	UAE	**Bahrain**	**KSA**	**Oman**	**Qatar**	**Kuwait**	**Total**
MSF	20	1	18	3	5	6	53
RO	18	2	76	31	2	0	129
MED	8	1	3	0	1	0	13
VC	0	1	0	0	0	0	1
ED	0	0	0	0	0	0	0
Combined (MSF+RO)	1	1	0	1	0	0	3
Total	**47**	**6**	**97**	**35**	**8**	**6**	**199**

Table 12 Future Planed Desalination Plants in GCC countries (Source: https://www.sciencetarget.com)

Technology	Country Capacity (Million m^3/year)						
	UAE	**Bahrain**	**KSA**	**Oman**	**Qatar**	**Kuwait**	**Total**
MSF	0	0	2	0	1	1	4
RO	7	1	3	14	0	1	26
MED	1	0	6	0	1	0	8
VC	0	0	0	0	0	0	0
ED	0	0	0	0	0	0	0
Combined (MSF+RO)	1	0	0	0	0	0	1
Total	**8**	**1**	**11**	**14**	**2**	**2**	**38**

Table 13 Desalination Capacity in GCC countries (2010) (Source: https://www.sciencetarget.com)

Technology	Country Capacity (Million m^3/year)						
	UAE	**Bahrain**	**KSA**	**Oman**	**Qatar**	**Kuwait**	**Total**
MSF	1307	91.25	1078	157.61	386.57	701.96	3722.67
RO	152.9	43.96	640.9	10.12	0.66	0	848.56
MED	315.3	111.16	2.671	0	3.32	0	432.41
ED	0	0	0	0.0332	0	0	0.0332
Total	**1776**	**1776**	**1721**	**167.77**	**390.55**	**701.96**	**5003.67**

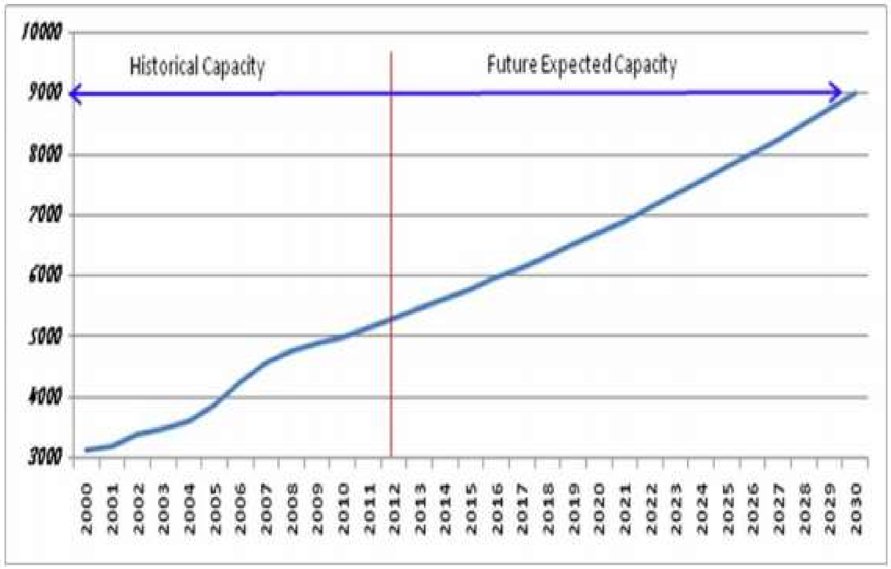


Figure 39 Historical and future increase in the desalination capacity in GCC (2000-2030)

Although desalination of seawater offers a range of human health, socio-economic, and environmental benefits by providing a seemingly unlimited, constant supply of high quality drinking water without impairing natural freshwater ecosystems, concerns are raised due to potential negative impacts (Dawoud, 2006). These are mainly attributed to the concentrate and chemical discharges, which may impair coastal water quality and affect marine life, and air pollutant emissions attributed to the energy demand of the processes as shown in Figure (41)

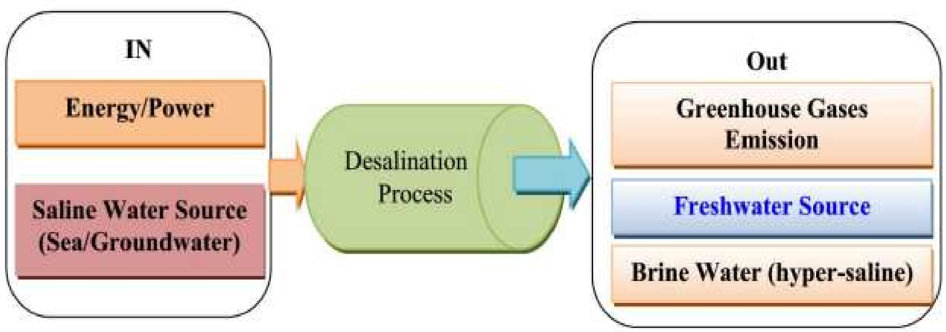


Figure 40 Schematic diagram for the desalination process (Source: https://www.sciencetarget.com)

The effects on the marine environment arising from the operation of the power and desalination plant from the routine discharge of effluents. Water effluents typically cause a localized increase in sea water temperatures, which can directly affect the organisms in the discharge area. Increased temperature can affect water quality processes and result in lower dissolved oxygen concentrations. Furthermore, chlorination of the cooling water can introduce toxic substances into the water. Additionally, desalination plants can increase the salinity in the receiving water.

7.1 Environmental Impacts Assessment

There are many potential environmental impacts of desalination process in GCC countries similar to any other industry. However there are effects more specific to desalination plants such as impingement and entrainment of marine organisms due to the intake of seawater, the Green House Gases GHG) emission due to a considerable energy demand of fossil fuel, and brine water discharge to the marine environment. A list of the potential environmental impacts of desalination on the environment can be given as follows:

7.1.1 Seawater Intake

Seawater desalination plants can receive feed water from different sources, but open seawater intakes are the most common option. The use of open intakes may result in losses of aquatic organisms when these collide with intake screens (impingement) or are drawn into the plant with the source water (entrainment). The construction of the intake structure and piping causes an initial disturbance of the seabed, which results in the resuspension of sediments, nutrients or pollutants into the water column. After installation, the structures can affect water exchange and sediment transport, act as artificial reefs for organisms, or may interfere with shipping routes or other maritime uses

7.1.2 Marine Water Salinity

All desalination processes produce large quantities of brine water, which may be increased in temperature, contain residues of pretreatment and cleaning chemicals, their reaction (by-) products, and heavy metals due to corrosion. High concentration of salt is discharged to the sea through the outfall of desalination plants, which leads to the increased level of salinity of the ambient seawater. Generally, the ambient seawater salinity in the Gulf is about 45 ppm and the desalination plants increases this level in its vicinity by about 5 to 10 ppm on average above the ambient condition. Also, chemical pretreatment and cleaning is a necessity in most desalination plants, which typically includes the treatment against biofouling, scaling, foaming and corrosion in thermal plants, and against biofouling, suspended solids and scale deposits in membrane plants. The chemical residues and by-products are typically washed into the sea.

Negative effects on the marine environment can occur especially when high waste water discharges coincide with sensitive ecosystems. The impacts of a desalination plant on the marine environment depend on both, the physico-chemical properties of the reject streams and the hydrographical and biological features of the receiving environment. Enclosed and shallow sites with abundant marine life can generally be assumed to be more sensitive to desalination plant discharges than exposed, high energy, open-sea locations (Hoepner and Windelberg, 1996), which are more capable to dilute and disperse the discharges. The desalination process and the pretreatment applied have a significant influence on the physico-chemical properties of the discharges, as shown in Table (14) below.

7.1.3 Marine Water Temperature

In all GCC countries most of the desalination plant is combined with a power plant in which the water temperature of the effluents of the power plants will be high and will increase the seawater temperature of the ambient water in the plant vicinity. In summer the ambient seawater temperature is about 35 °C on average and the power and desalination plants cause an increase in the temperature level in its vicinity by about 7 to 8 °C above the ambient condition.

Most organisms can adapt to minor deviations from optimal salinity and temperature conditions, and might even tolerate extreme situations temporarily, but not a continuous exposure to unfavorable conditions. The constant discharge of reject streams with high salinity and temperature levels can thus be fatal for marine life, and can cause a lasting change in species composition and abundance in the discharge site. Marine organisms can be attracted or repelled by the new environmental conditions, and those more adapted to the new situation will eventually prevail in the discharge site. Due to their density, the reject streams of RO and thermal plants affect different realms of the sea. The concentrate of RO plants, which has a higher density than seawater, will spread over the sea floor in shallow coastal waters unless it is dissipated by a diffuser system. Benthic communities, such as seagrass beds, may thus be affected as a consequence of high salinity and chemical residues. In contrast, reject streams of distillation plants, especially when combined with power plant cooling waters, are typically positively or neutrally buoyant and will affect open water organisms.

7.1.4 Green House Gas Emission (GHG)

Water desalination in GCC countries is an energyintensive activity with non-renewable fossil fuel. One of the key concerns with the proposed desalination project is its potential effects on climate change. Much effort has gone into reducing these impacts. However, it is important to distinguish between reducing GHG emissions and reducing fossil fuel energy use. Only with renewable energy projects can both GHG emissions and fossil fuel energy use potentially be reduced. The present and future expected increase in CO2 GHG emissions in GCC countries are summarized in Table (15) below (Meed, 2008).

Due to high energy consumption, the desalination industry is exacerbating air pollution through NOx and SO2 emissions. However, NOx emissions are decreasing due to technological upgrades and SO2 emissions fluctuate depending if oil is used instead of natural gas. In addition, the water production sector is the second largest emitter of CO2 and contributor to climate change after the oil sector in GCC countries. Fossil fuel consumption in desalination plants is expected to continue to increase as new desalination capacity becomes operational with the increasing water demand. Figure (41) below shows the calculated carbon dioxide emission from power plants in Abu Dhabi emirate as an example. However, in Abu Dhabi recently and due to technological upgrades and use of natural gas, NOx and SO2 emission reduced as shown in Figure (42 and 43) below.

7.1.5 Dissolved Oxygen

Dissolved oxygen in water in the plant vicinity is affected by the brine discharges. The concentration and saturation of oxygen will decrease due to the higher temperature and salinity of the effluents. The concentration of dissolved oxygen depends on the seawater temperature in the plant vicinity, concentration of oxygen in the discharge and the mixing of the discharge with the ambient water.

7.1.6 Chlorine Concentration

In most desalination plants, chlorine is added to the intake water to reduce biofouling, which leads to the formation of hypochlorite and mainly hypobromite in seawater. In RO plants, the intake water is also chlorinated but dechlorinated again with sodium bisulfite before the water enters the RO units to prevent membrane damage. Chlorine concentration in the effluents of the plants depends on the dosing rates used in chlorination of the seawater. Increasing the concentration of residual chlorine may affect the water quality of the ambient water and hence, the ecological system.

Due to environmental and health issues raised by residual chlorine and disinfection by-products, several alternative pretreatment methods have been considered. These include e.g. sodium bisulfate (Redondo and Lomax, 1997), monochloramine (DuPont, PERMASEP, 1994), copper sulfate (FilmTec, 2000), and ozone (Khordagui, 1992). None of these has gained acceptance over chlorine use, however, chlorine dioxide is presently evolving into an alternative to chlorine dosing in many areas of the Arabian Gulf.

7.1.7 Heavy Metals

Copper-nickel alloys are commonly used as heat exchanger materials in distillation plants, so that brine contamination with copper due to corrosion can be a concern of thermal plant reject streams. The RO brine may contain traces of iron, nickel, chromium and molybdenum, but contamination with metals is generally below a critical level, as non-metal equipment and stainless steels predominate in RO desalination plants. Copper concentrations in reject stream are expected to be in the range of 15–100 μg/L. The presence of copper does not necessarily mean that it will adversely affect the environment. Natural concentrations range from an oceanic background of 0.1 μg/L to 100 μg/L in estuaries.

Table 14 Typical effluent properties of (RO) and thermal MSF seawater desalination plants

	RO Plants	MSF Plants
Physical properties Salinity Temperature	Up to 65,000–85,000 mg/L Ambient seawater temperature.	About 50,000 mg/L +5 to 15°C above ambient.
Plume density	Nagatively buoyant	Positively, neutrally or negatively buoyant depending on the process, mixing with cooling water from co-located power plants and ambient density stratification.
Dissolved oxygen (DO)	If well intakes used: typically below ambient seawater DO because of the low DO content of the source water. If open intakes used: approximately the same as the ambient seawater DO concentration.	Could be below ambient seawater salinity because of physical deaeration and use of oxygen scavengers
Biofouling control additives and by-products Chlorine	If chlorine or other oxidants are used to control biofouling, these are typically neutralized before the water enters the membranes to prevent membrane damage.	Approx. 10–25% of source water feed dosage, if not neutralized
Halogenated organics	Typically low content below harmful levels.	Varying composition and concentrations, typically trihalomethanes
Removal of suspended solids Coagulants (e.g. iron-III-chloride)	May be present if source water is conditioned and the filter backwash water is not treated. May cause effluent coloration if not equalized prior to discharge.	Not present (treatment not required)
Coagulant aids (e.g. polyacrylamide)	May be present if source water is conditioned and the filter backwash water is not treated.	Not present (treatment not required)
Scale control additives Antiscalants Acid (H_2SO_4)	Not present (reacts with seawater to cause harmless compounds, i.e. water and sulfates; the acidity is consumed by the naturally alkaline seawater, so that the discharge pH is typically similar or slightly lower than that of ambient seawater). Typically low content below toxic levels	Typically low content below toxic levels. Not present (reacts with seawater to cause harmless compounds, i.e. water and sulfates; the acidity is consumed by the naturally alkaline seawater, so that the discharge pH is typically similar or slightly lower than that of ambient seawater)
Foam control additives Antifoaming agents (e.g. polyglycol) *Contaminants due to corrosion* Heavy metals Cleaning chemicals	Not present (treatment not required) May contain elevated levels of iron, chromium, nickel, molybdenum if low-quality stainless steel is used.	Typically low content below harmful levels May contain elevated copper and nickel concentrations if inappropriate materials are used for the heat exchangers
Cleaning chemicals Cleaning chemicals	Alkaline (pH 11–12) or acidic (pH 2–3) solutions with additives such as: detergents (e.g. dodecylsulfate), complexing agents (e.g. EDTA), oxidants (e.g. sodium perborate).	Acidic (pH 2) solution containing corrosion inhibitors such as benzotriazole derivates

Table 15 CO_2 GHG emissions for the GCC (million metric tons) (Source: https://www.sciencetarget.com)

Year	Bahrain	KSA	UAE	Kuwait	Qatar	Oman
1996	15.6	248.9	103.0	49.1	30.9	14.5
1997	18.3	254	111	52	32	17.8
1998	19.1	256.8	116	56	33.2	21.7
1999	20.2	262.7	117	60	31	20.4
2000	20.3	289.3	109	59	34.5	21.6
2001	20.7	299.9	118	60	27.4	22.1
2002	21.6	309.6	125	55	29.13	22.8
2003	22.3	344.7	126	63	32.35	22.5
2004	23.0	385.7	132	67	38.48	24.2
2005	25.2	415.4	137.8	76.7	53.5	29.7
2006	26	433	141	79	56	31
2007	27.1	452	145	82	58	33
2008	28.0	470	149	85	61	34
2009	29	489	153	88	63	36
2010	30	507	157	92	66	38

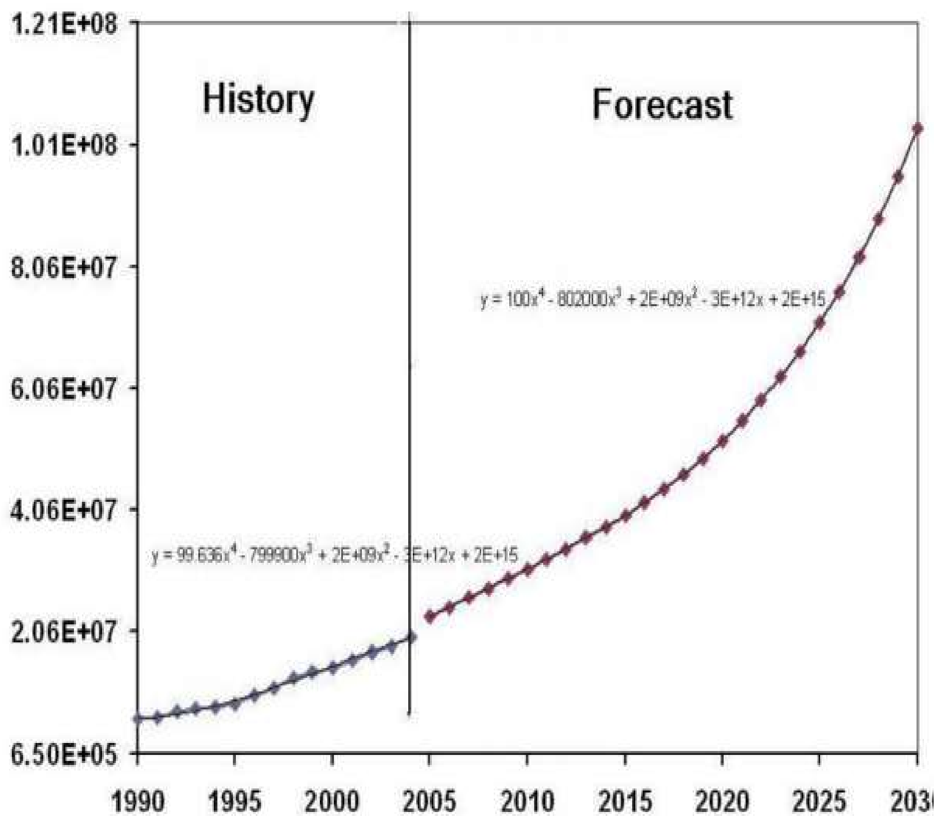


Figure 41 CO_2 Calculated emissions from desalination plants in Abu Dhabi (Source: https://www.sciencetarget.com)

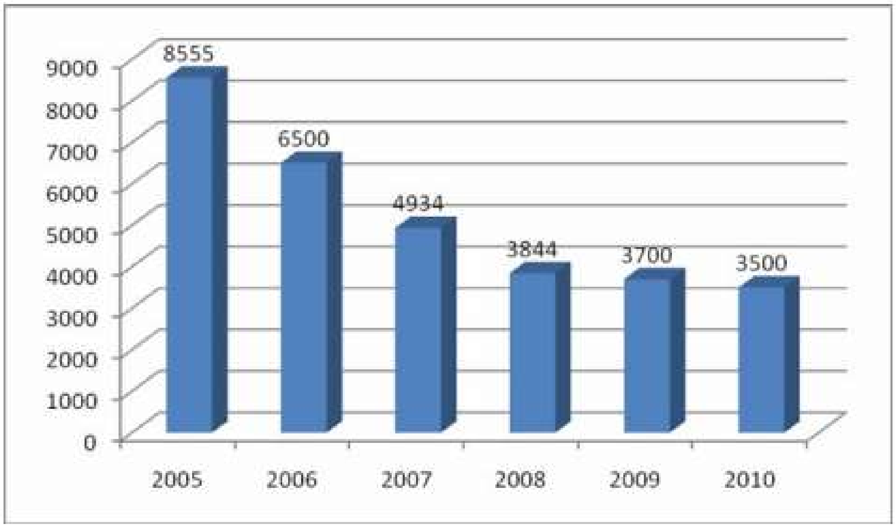


Figure 42 Reduction in NOx emissions from desalination plants in Abu Dhabi (Source: https://www.sciencetarget.com)

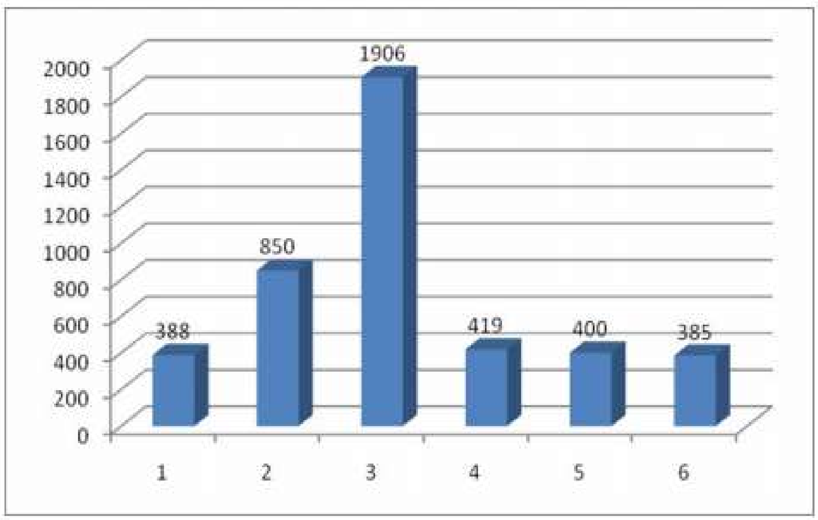


Figure 43 Reduction in SO2 emissions from desalination plants in Abu Dhabi (Source: https://www.sciencetarget.com)

7.1.8 Un-ionized ammonia

Ammonia is one of the substances of concern as unionized ammonia (NH3) is very toxic to aquatic species. In the environment, both ionized and unionized species occur. The ratio of the two species is a function of the pH. If pH is high then the concentration of the un-ionized ammonia is high and may affect the marine life. The concentrations and levels of these substances in the plant vicinities depend on the size of the plant and the ambient seawater conditions. Generally the concentrations and levels of these substances should be within the water quality standards to avoid the negative impact on the environment.

7.2 Mitigating Measures

To assess the any environmental impact a risk assessment matrix is used. The environmental risk matrix is the product of two factors, namely the probability of occurrence and severity of the effect. The environmental risk matrix used in assessing the environmental impacts of desalination is shown in Figure (41).

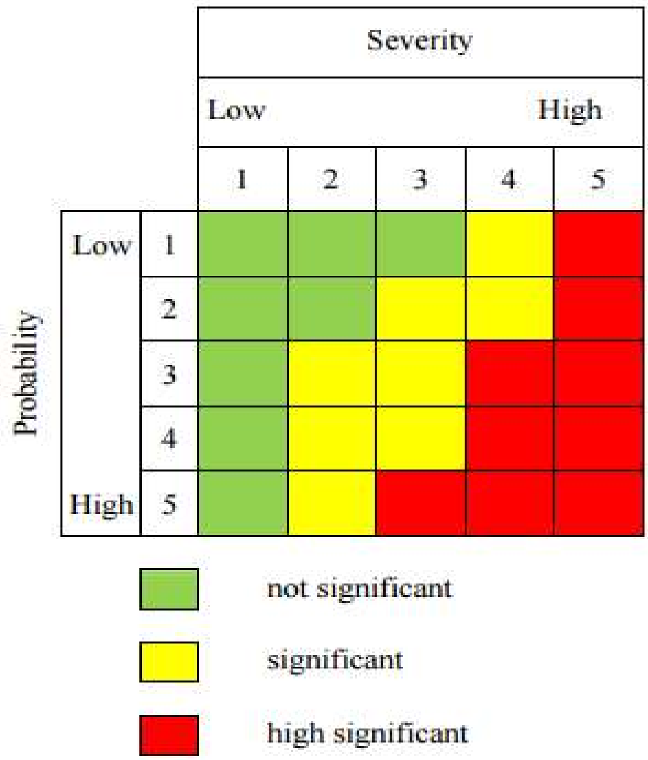


Figure 44 Environmental risk assessment matrix(Source: https://www.sciencetarget.com)

7.2.1 Brine water discharge

It is estimated that for every 1 m3 of desalinated water, 2 m3 is generated as reject brine. The common practice in dealing with these huge amounts of brine is to discharge it back into the sea, where it could result, in the long run, in detrimental effects on the aquatic life as well as the quality of the seawater available for desalination in the area. Although technological advances have resulted in the development of new and highly efficient desalination processes, little improvements have been reported in the management and handling of the major by-product waste of most desalination plants, namely reject brine. The disposal or management of desalination brine (concentrate) represents major environmental challenges to most plants, and it is becoming more costly. To avoid impacts from high salinity, the desalination plant brine can be pre-diluted with seawater or power plant cooling water. To avoid impacts from high temperature, the outfall should achieve maximum heat dissipation from the waste stream to the atmosphere before entering the water body (e.g. by using cooling towers) and maximum dilution following discharge. Negative impacts from chemicals can be minimized by treatment before discharge, by substitution of hazardous substances, and by implementing alternative treatment options. Especially biocides such as chlorine, which may acutely affect non-target organisms in the discharge site, should be replaced or treated prior to discharge. Chlorine can be effectively removed by different chemicals, such as sodium bisulfite as practiced in RO plants, while sulfur dioxide and hydrogen peroxide have been suggested to treat thermal plant reject streams (Khordagui, 1992). Filter backwash waters should be treated by sedimentation, dewatering and landdeposition, while cleaning solutions should be treated on-site in special treatment facilities or discharged to a sanitary sewer system.

The current options for reject brine management are rather limited and have not achieved a practical solution to this environmental challenge. There is an urgent need, therefore, for the development of a new process for the management of desalination reject brine that can be used by coastal as well as inland desalination plants. The chemical reaction of reject brine with carbon dioxide is a new approach that promises to be effective, economical and environmental friendly (El-Naas et al, 2010). The approach utilizes chemical reactions based on a modified Solvay process to convert the reject brine into useful and reusable solid product (sodium bicarbonate). At the same time, the treated brackish water can be used for irrigation.

7.2.2 Energy use

Energy use is a main cost factor in the desalination industry and has already been reduced by some technological innovations, such as the use of energy recovery equipment or variable frequency pumps in RO plants. A very low specific energy consumption of 2–2.3 kW h/m3 has been reported for a seawater desalination plant that uses an energy recovery system consisting of a piston type accumulator and a low pressure pump (Paulsen and Hensel, 2007). Furthermore, the potential for renewable energy use (solar, wind, geothermal, biomass) should be investigated to minimize impacts on air quality and climate. This may be in the form of renewable energy driven desalination technologies or as compensation measures such as the installation and use of renewable energy in other localities or for other activities. There many research investigating using different renewable energy sources in GCC countries (Dawoud et al., 2006;). Recently, Abu Dhabi Emirate 30 small scale solar powered desalination plants were constructed using photovoltaic solar energy for powering RO system for the desalination of brackish and saline groundwater abstracted from the shallow aquifer system, with salinity ranges between 5,000 to 20,000 ppm. The design capacity of each unit is 5 m3 /hr (Dawoud, 2012). Also, at present Saudi Arabia's national research agency, King Abdulaziz City for Science and Technology (KACST), is building what will be the world's largest solar-powered desalination plant in the city of Al-Khafji. The plant will use a concentrated solar photovoltaic (PV) technology and new waterfiltration technology, which KACST developed with IBM. When completed at the end of 2012, with a capacity of 30,000 m3 /day.

Although the level of technological development of PV–RO desalination plants has allowed their commercialization, market penetration has thus far been small, mainly due to the high investment costs for the PV modules. Research in the field of PV modules, however, is developing rapidly, which seems to offer hope that significant cost reductions can be expected in the short-medium term. Promising lines of research are the exploration of the properties of both crystalline and amorphous silicon and of other semi-conductors such as cadmium telluride and copper indium gallium diselenide for application in thin-film cells, and the development of concentrating PV systems (Kehal, 1991). Table 15 shows the main environmental impacts and mitigation measures of desalination process.

Table 16 Main environmental impacts and mitigation measures of desalination process. (Source: https://www.sciencetarget.com)

Risk	**Potential impacts**	**Mitigation measures**
Brine discharge	Salinity increase	Brine water dilution with seawater or cooling water. Brine water harvesting.
	Temperature increase	Brine water dilution with seawater or cooling water.
Air pollution	Emission of NOx, SO2, and CO2	Using natural gas. Using renewable energy sources.
Noise	Construction and operation of the desalination plants would result in an increase in noise levels surrounding the location.	Noise levels in most cases of desalination plants not exceed the 'normally acceptable' noise level limit of 65 dBA Ldn. So, no mitigation measures required.
Land Use and Planning	Most of desalination plants is on sea coast where the value of the land is very high.	Proper selection of sites to minimize to offset the loss of this open space land.

8 CASE STUDY OF TAWEELAH POWER AND DESALINATION PLANT

8.1 Plant Description

Taweelah Power and Desalination Plant is one of the main plants in Abu Dhabi Emirate. The Plant is located at the coast of the Arabian Gulf, as shown in figure 39 and 40 below.

Figure 45 General layout of Taweelah plant (Source: http://www.iwtc.info/2009_pdf/11-3.pdf)

Figure 46 Taweelah A1 Power Plant in Abu Dhabi (United Arab Emirates)

The plant produces 1000 MW and 100 MIGD of power and water, respectively. It is proposed to extend the plant capacity by 66.5 MIGD.

Water quality modeling and ecological study were carried out to evaluate the impact of the proposed capacity extension on the water quality and the marine life in the plant vicinity. An ecological reach and unique sea area with coral reefs, dense seagrass, mangroves and aquatic life is located at Ras Ghanada, which is about 1 km east of the plant intake. A biotopes survey was carried out in the vicinity of the plant to collect information on the species and habitat living in this area. Figure 31 shows the biotope map of the habitat in the vicinity of the plant.

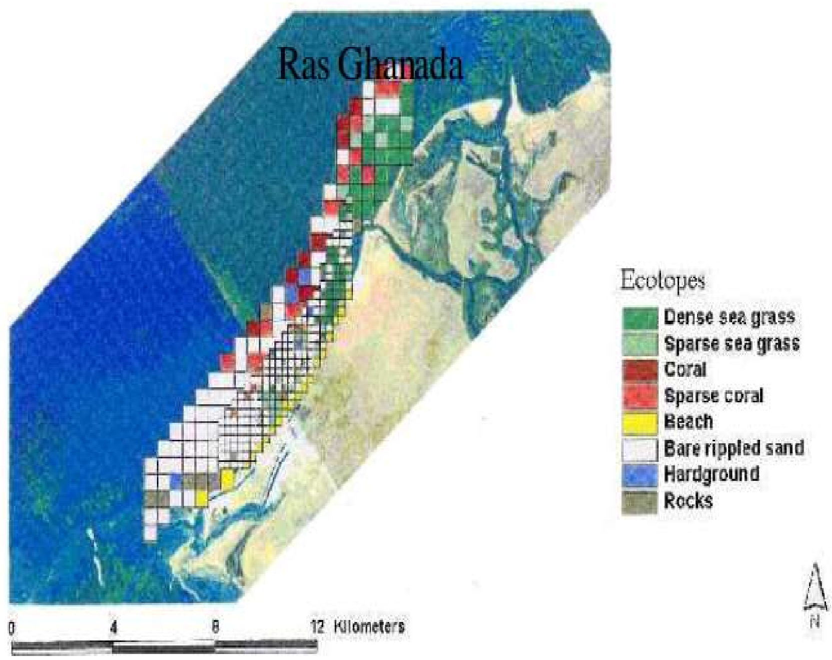


Figure 47 Ecotopes at the marine environment near Taweelah Plant (Source: http://www.iwtc.info/2009_pdf/11-3.pdf)

Ecological information was gathered on their specific sensitivities and threshold values for abiotic parameters, such as temperature, salinity and oxygen. A water quality model was developed, describing the transport, diffusion and dispersion of a number of typical pollutants associated with the power and desalination plant. The results from the water quality model serve as an input for the study to assess the impact on the environment and quality of local habitats.

8.2 Water Quality Model Set Up

The water quality model was set up after the feasibility of the hydraulic extension was confirmed. A number of the important substances for the marine life were modelled. These substances are the fraction of water from the discharge, age of water from the outlet, dissolved oxygen in water and chlorine concentration. Modeling considers the effects of the loads of the plant discharges as shown in table 12 below.

Table 17 Concentration of substances in the outfall discharge (Source: http://www.iwtc.info/2009_pdf/11-3.pdf)

	Discharge concentration	**Peak concentration**	**Remarks**
Oxygen	2.68 (mg/l)	-	67% saturation
Chlorine low decay	0.15 (mg/l)	-	
Chlorine high decay	0.15 (mg/l)	0.6 (mg/l)	Peak 1 hour at High tide
Acid wash	-	5.7x10 -4 (m 3 /m 3)	10 minutes at high tide
Fraction water	1.0 (m 3 /m 3)		

The basis for the water quality model is the hydrodynamic model. The water quality simulations use the computed water levels and velocities from the hydrodynamic computations as an input.

Three situations are modeled as follows:

1- The present situation (reference);

2- T03: proposed extension is a hybrid of RO + MSF plant. The intake of the RO is an offshore pipeline at about 3.8 km offshore and it uses the existing outfall. The intake of the MSF is onshore at about 1200m to north-east of the existing intake and the outfall of the plant is about 2 km from its intake.

3- T32: same as T03 but the intake of the RO is at 2000 m offshore and the outfall of the MSF is moved 2000 m further north east.

The spreading and the distribution of the main substances influencing the eco-system. The water quality results are presented as a contour plots comparing the extension scenario with the present design capacity for the two wind conditions. These substances are dissolved oxygen, residual chlorine, seawater temperature, and salinity, respectively. The residual chlorine and seawater salinity will not be affected by the proposed extension in the ecologically rich sea area of Ras Ghanada. The seawater temperature and dissolved oxygen in the sea area nearby Ras Ghanada will be affected by the proposed extension. No wind condition is worse than with a daily wind cycle because of the longer residence times of the water. See appendix below.

Table 18 presents the area violating the water quality standards as computed by the water quality model. In the table the notations a and b indicate the daily wind and no wind, respectively

Area violating WQ standard (ha)

Scenario	**Oxygen (<4mg/l)**	**Chlorine (>13ug/l)**	**Chlorine (>7.5ug/l)**	**Temp (>+2^{0}C)**	**Temp (>+3 ^{0}C)**	**Temp (>+5 ^{0}C)**
Reference-a	840	72	114	1871	1061	199
Reference-b	1313	74	119	2305	1396	280
T03-a	471	98	156	1944	726	90
T03-b	991	96	166	2456	1123	113
T32-a	452	110	169	1932	692	76
T32-b	1018	108	172	2560	1045	109

a) Daily wind cycle b) no wind

Summary of water quality results as compared to water quality standards. Worst case situations for each parameter is indicated as a shaded area

The effect of change in the water quality due to the proposed capacity on the marine life was obtained based on the knowledge on the species in the area. Based on the figures and tables it can be seen that the extension will have an effect on the water quality and marine life, but it is acceptable by the environmental authority. In some other plants the area violating the water quality is not acceptable by the client or the environmental authorities. In such cases a re-design of the intakes and outfall layout should be adjusted. The outfall can be an offshore pipeline instead of its location onshore.

9 CONCLUSION

According to the introduction of desalination technologies in different parts of the world, a clear trend of suitable and sustainable development is shown.

In the ESCWA member countries, water resources are in limited supply, while the demand for water continues to grow. Given this situation, the question of the optimal management of water resources is clearly of crucial importance, with implications not only for the future development of those countries, but also for the sustainability of their past economic and social achievements. The problem arises from the continuing growth in demand, which is as a result of population increase and other social factors, in conjunction with the fact that the region is already exploiting all its annual surface water resources, while its aquifers are becoming depleted.
In the ESCWA region where renewable freshwater source is extremely limited, desalination technology has been a potential source in dealing with water scarcity, there have been continuous improvements in desalination technology, and the most frequently used technologies are now, mature, efficient and reliable.

The state of Kuwait lies at the northeast edge of the Arabian Peninsula at the head of the Arabian Gulf and occupies a total area of 17,000km^2 of mostly desert land. The hot dry climate results in a very low rainfall with an annual average rainfall of around 110 mm, with a variation of 31mm to 242mm. Surface runoff and groundwater recharge from rainfall are rare, this is primarily due to factors such as the high potential evapotranspiration rate. Fresh water streams do not exist. The fresh water resources are limited to groundwater, desalinated seawater and brackish groundwater and treated wastewater effluents. The total of conventional fresh water resources available in Kuwait are 6 million m3/y while the total water demand has exceeded 350 million m3/y in the year 2000. With the continued deterioration of existing groundwater resources, almost 90% of the water demand is currently satisfied through seawater desalination plants. Currently the desalination capacity in Kuwait is 1.65 million m3/d of which 1.47 million m3/d is provided by multi-stage flash desalination (MSF) and 0.17 million m3/d is supplied by reverse osmosis (RO). The tertiary treated wastewater effluents of about 0.4 million m3/d are produced by three major municipal wastewater treatment plants, which is currently utilized in irrigation.

Reuse of wastewater for irrigation purposes has proved to be one of the best ways to recycle nutrients and water and thus protect the environment and the public health. It contributes directly to the environmental sustainability by increasing crop production and decreasing amounts of pollutants discharged into the environment. The prime goal of these plans is to utilize 100% of the reclaimed municipal wastewater mainly in restricted agricultural irrigation (e.g. fodder crops irrigation), greenery landscaping (grass, plants, trees and bushes) and in the development of a forestation areas.

To achieve sustainable water management and development in this region, suitable desalination technologies were introduced in this thesis. In this region for example, limited scale RO of brackish groundwater units could be used for remote areas for drinking water and agriculture, large scale desalination plants for major coastal cities could be used for drinking water to free the natural water for use in ag and privatization of the desalination industry.

In the Taweelah case, effect of change in the water quality due to the proposed capacity on the marine life was obtained based on the knowledge on the species in the area. It can be seen that the extension will have an effect on the water quality and marine life. To prevent this effect on the marine lifes a suitable re-design of the intakes and outfall layout should be adjusted. The outfall can be an offshore pipeline instead of its location onshore.

This thesis provide the public and policy makers information on desalination technologies in water management and sustainability. However due to limited time and resources, more study is needed for a deeper and more comprehensive introduction of desalination technologies.

SOURCES

Arabian Gulf countries. Almost all conventional. water resources have already been exploited in. Kuwait, Saudi Arabia, Bahrain, Qatar, United. Arab Emirates. Accessed on 18.01.2017. https://www.researchgate.net/.../228365403_Desalination_and_water_resource_mana

An Overview of Conventional and Non-Conventional Water Resources in Arid Region: Assessment and Constrains of the United Arab Emirates (UAE). Accessed on 20.01.2017. http://file.scirp.org/pdf/JWARP20100200010_12015024.pdf

Biomimetic Membranes: Taking on Energy Usage in WaterWorld. Accessed on 1.07.2016 www.waterworld.com/articles/wwi/print/volume-27/issue-3/editorial-focus/desalinatio.

Chaturvedi, M. 2000. Water for food and rural development: developing countries. Water International. 25: 40-53.

Cosgrove, J. and Rijsberman, F. (2000). World Water Vision: Making Water Everybody's Business. Earthscan, UK. Acessed on 13.02.2017 http://www.watervision.org.

Conner, S. and Freeman, L. 1998. Drinking Water Quality. Waterworks Publishing, Florida, USA. P. 31.

Dossier Water, Planet Water. 1997. Accessed on 28.06.2016 http://med.unex.es/medmund/mmeng/mmenrepo/ water_en.html.

Desalination Guidelines Development for Drinking Water: Background. Accessed on 13.02.2017 http://www.who.int/water_sanitation_health/dwq/nutdesalination.pdf

Desalination for Water Supply FR/R0013 - Foundation for Water. Accessed on 28.06.2016 www.fwr.org/desal.pdf

Desalination & Water Purification Technologies - BARC. Appreciation for desalination and water purification technologies, among the entrepreneurs, Several water technologies developed by Desalination Accessed on 5.08.2016 www.barc.gov.in/publications/tb/desalination.pdf

Dawoud, M. 2006, "The Role of desalination in the augmentation of water supply in GCC countries", Desalination, Vol. 186, pp. 187- 198

DuPont, PERMASEP, 1994, Products Engineering Manual, Bulletin 1020, 2010 and 4010, DuPont Company, Wilmington, DE

El-Naas, M. Al-Marzouqi A. Chaalal O. 2010, “A combined approach for the management of desalination reject brine and capture of CO2”, Desalination, Vol. 251, pp. 70–74

Energy Efficient Reverse Osmosis Desalination Process - Journal of. Accessed on 2.07.2016
www.ijesd.org/papers/243-B20001.pdf

ESCWA Water Development Report 3 Role Of ...Desalination In AddresingWater Scarcity. Accessed on 27.06.2016
large.stanford.edu/courses/2013/ph240/rajavi2/docs/sdpd-09-4.pdf

FilmTec, 2000, “FILMTEC Membranes Tech Manual Excerpts, FilmTec Corporation, The Dow Chemical Company, Liquid Separations, Customer Information Center, Midland, MI

Freezing Desalination Process Encyclopedia of Desalination. Accessed on 30.06.2016
www.desware.net/Sample-Chapters/D04/D08-063.pdf

Gardner-Outlaw, T. and Engleman, R.1997. Sustaining water, easing scarcity: A second update. Washington, D.C., Population Action International.

Gleick, P. 2000. The changing water paradigm: A look at 21st century water resources development. Water International 25: 127-138.

Gleick, P. 1999. The human right to water. Water Policy, 1, No. 5: 487-503.

Gleick, P.1998. The world’s water: the biennial report on freshwater resources. Island Press, Washington D.C

Gleick, P. 2004. The World’s Water 2004 – 2005. The biennial report of freshwater resources. Island Press, pp.7-41.

Hinrichsen, D., Robey, B. and Upadhyay, U. 1999. Solutions for a water-short world. Accessed on 27.06.2016
www. jhuccp.org/pr/m14edsum.stm.

Hoepner T. and Windelberg J., 1996, “Elements of environmental impact studies on coastal desalination plants”, Desalination, Vol. 108, pp. 11–18

Kehal S.,1991, “Reverse osmosis unit of 0.85 m3/h capacity driven by photovoltaic generator in South Algeria”, Proc. Conference on New Technologies for the Use of Renewable Energy Sources in Water Desalination, Athens

Khordagui H.1992, “Conceptual approach to selection of a control measure for residual chlorine discharge in Kuwait Bay”, Environmental Management, Vol. 16 No. 3, pp. 309–316

Lalzad : An Overview of the Global Water Problems and Solutions. Accessed on 27.06.2016
www.ariaye.com/english/images/lalzad.pdf

Lattemann S. and Hoepner T. 2008, "Environmental impact and impact assessment of seawater desalination", Desalination, Vol. 220, pp. 1–15

Meed, 2008, Power and Water in the GCC: the Struggle to Keep Supplies Ahead of Demand Report; Research and Markets: Taylors Lane, Dublin, Ireland, pp. 1-79

Membrane Desalination Power Usage Put in Perspective – American, input to produce fresh water from brackish and seawater sources. Although there are many different types of desalination techniques. Accessed on 2.07.2016

Non-conventional resources are the desalinated water and treated-sewage. Improvement of water- resource management in the United Arab. Accesed on 2.01.2017.
https://www.researchgate.net/.../222412013_Water_resources_in_the_United_Arab_Emi

PAI, 1997. Sustaining Water, Easing Scarcity: A Second Update. Revised data for the population action international report, sustaining water: Population and the future of renewable water supplies. Accessed on 2.01.2017
http://www.populationaction.org/resources/publications/water/ water97.pdf

PAI, 1999. Sustaining Water: Population and the Future of Renewable Water Supplies. Accessed on 2.01.2017
http://www.cnie.org/pop/pai/h2o-toc.html.

Paulsen K. and Hensel F., 2007, "Design of an autarkic water and energy supply driven by renewable energy using commercially available components", Desalination, Vol. 203, pp.455–462

Rapid Spray Desalination Wastewater….WaterBank. Accessed on 30.06.2016
www.waterbank.com/Newsletters/nws43.html

Redondo J. and Lomax I., 1997, "Experiences with the pretreatment of raw water with high fouling potential for reverse osmosis plant using FILMTEC membranes", Desalination, Vol. 110, pp.167–182

Seawater Desalination - National Water Research Institute. Accessed on 23.10.2016
www.nwri-usa.org/documents/Elimelech_000.pdf

Serageldin, I. 1999. World's Rivers in Crisis, some are dying; others could die. 23.10.2016
http://watervision.cdinet.com/riversrelease.html.

Simonovic, S. 2000. Tools for water management: one view of the future. Water International. 25: 76-88.

The United Nations world water development ... - unesdoc - Unesco. Accessed on 27.06.2016
unesdoc.unesco.org/images/0023/002318/231823E.pdf

UNDP, 1994. Population and water resources. Accesses on 23.06.2016
www.undp.org/popin/fao/water.html.

Using Desalination Technologies for Water. Princeton University. Accessed on 23.06.2016
https://www.princeton.edu/~ota/disk2/1988/8842/8842.PDF

Water in 2050 - Growing Blue. The Future of Water Requires a Sustainable, Blue Path. ... Water is critical to future growth. The IFPRI study also found that 45% of total GDP ($63 trillion) will be at risk due to water stress by 2050. Accessed on 1.07.2016
growingblue.com/water-in-2050/

Water Desalination Processes - American Membrane Technology. Accessed on 17.08.2016
www.amtaorg.com/wp-

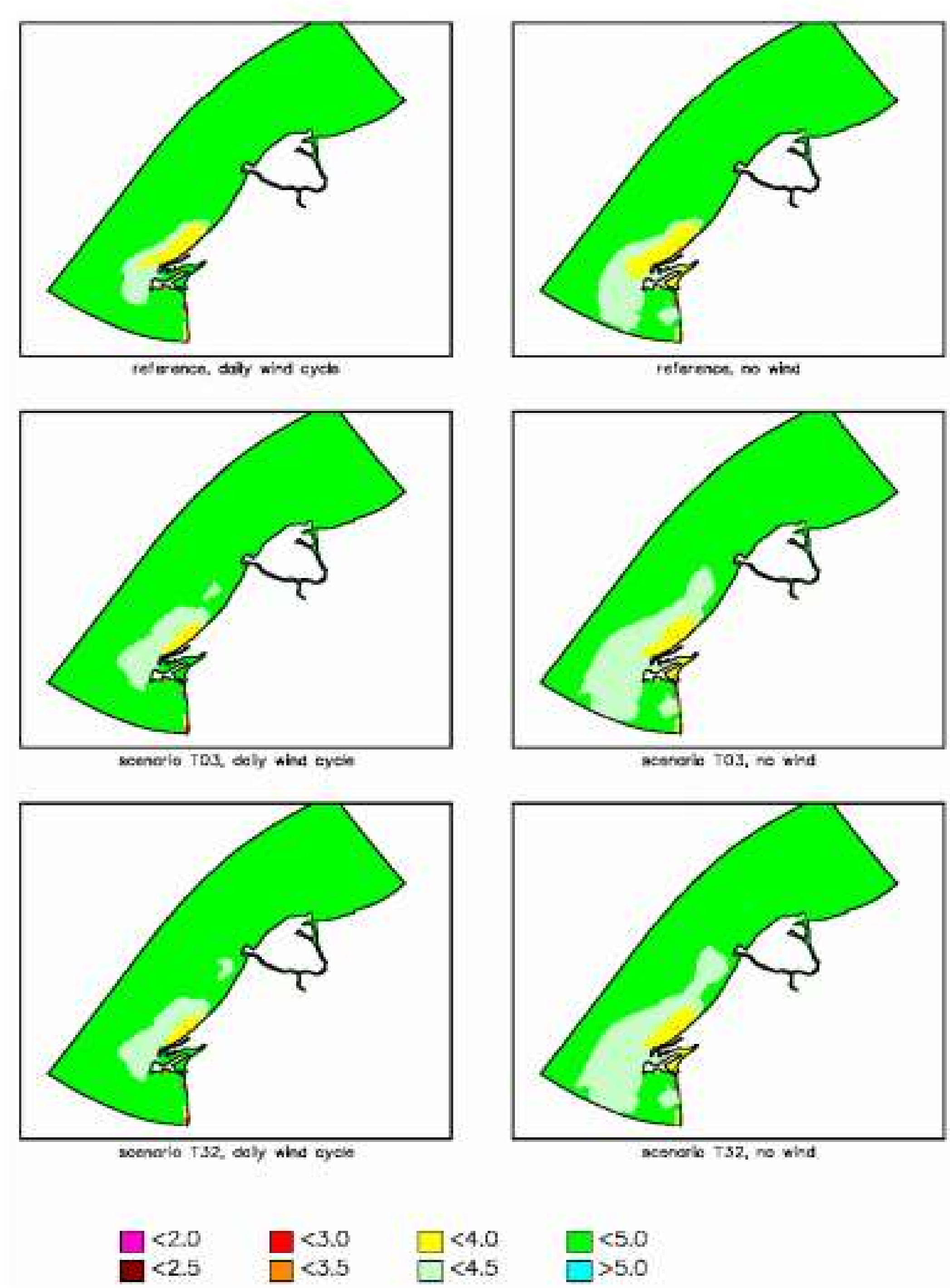
Water Treatment And Desalination Plants. Accesed on 11.12.2016
www.moa.gov.cy/moa/wdd/wdd.nsf/booklets.../pages%201-23%20(2.41MB).pdf

Water desalination technologies in the escwa member countries. Accessed on 5.02.2017
http://s3.amazonaws.com/zanran_storage/www.escwa.un.org/ContentPages/17952025.pdf

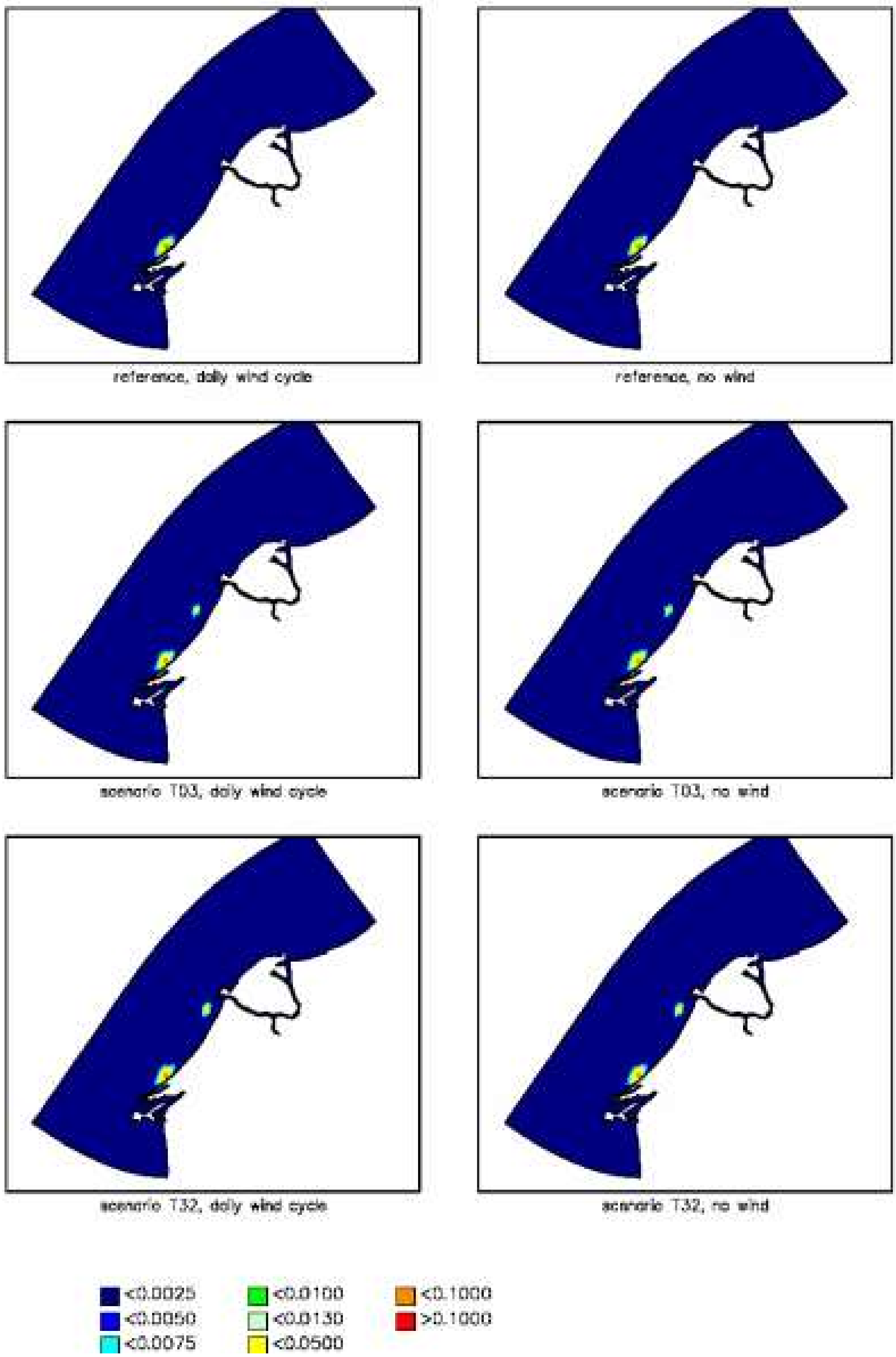
World Water Resources and Regional Vulnerability - Impact of …- IRC. Accessed on 2.07.2016
www.ircwash.org/sites/default/files/Kulshreshtha-1993-World.pdf

Appendix 1

Dissolved oxygen distribution (mg/l)

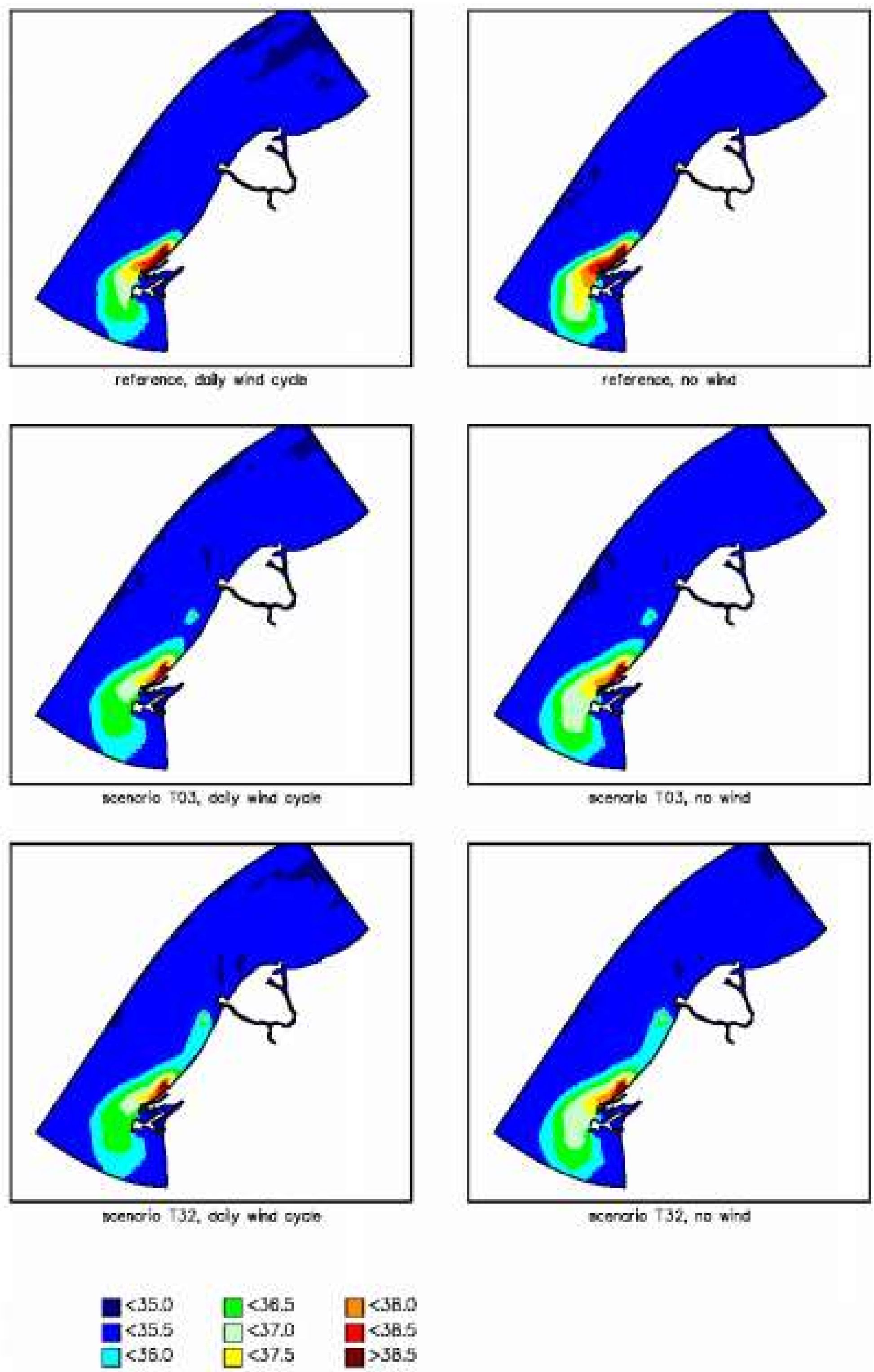


Residual chlorine distribution (ug/l)



Appendix 3

Temperature distribution (c)



Salinity distribution (ppt)