

Environmental Impacts of Seawater Desalination: Arabian Gulf Case Study

Mohamed A. Dawoud^{1*} and Mohamed M. Al Mulla²

¹Water Resources Department, Environment Agency, Abu Dhabi, United Arab Emirates

²Ministry of Environment and Water, Dubai, United Arab Emirates

Abstract

Desalination of seawater accounts for a worldwide water production of 5000 million m³/year. A “hot spot” of intense desalination activity has always been the Arabian Gulf, but other regional centers of activity emerge and become more prominent, such as the Mediterranean Sea and the Red Sea, or the coastal waters of California, China and Australia. The growth gap between supply and demand for water in the GCC countries can be attributed to limited available surface water, high population growth and urbanization development, deficient institutional arrangements, poor management practices, water depletion and deterioration of quality, especially in shallow groundwater aquifers. Increasing demand for water in the domestic sector has shifted attention to the role of desalination in alleviating water shortages. Experience in the Gulf States demonstrates that desalination technology has developed to a level where it can serve as a reliable source of water at a price comparable to water from conventional sources. Desalination remains in GCC countries the most feasible alternative to augment or meet future water supply requirements. It is considered a strategic option for satisfying current and future domestic water supply requirements, in comparison to the development of other water resources. Despite the many benefits the technology has to offer, concerns rise over potential negative impacts on the environment. Key issues are the concentrate and chemical discharges to the marine environment, the emissions of air pollutants and the energy demand of the processes. To safeguard a sustainable use of desalination technology, the impacts of each major desalination project should be investigated and mitigated by means of a project- and location-specific environmental impact assessment (EIA) study, while the benefits and impacts of different water supply options should be balanced on the scale of regional management plans. In this context, our paper intends to present an overview on present seawater desalination capacities by region, a synopsis of the key environmental concerns of desalination, including ways of mitigating the impacts of desalination on the environment, and of avoiding some of the dangers of the environment to desalination.

Keywords: *Seawater desalination; Environmental impact; Impact assessment; EIA; Marine environment; Brine discharge; Energy; Chemicals; Chlorine.*

1. Background

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

* Corresponding author: mdawoud@ead.ae

largest number of desalination plants can be found in the Arabian Gulf as shown in Figure (1). Most of the desalination plants are combined with power plants for power production. At present there more than 199 plants and there are a plan to add 38 in the future as shown in table (1) and table (2). The total seawater desalination capacity is about 5000 million m^3/year , which means a little less than half (45%) of the worldwide production as shown in Table (3). 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 m^3/year by 2013. The total capacity of desalination in GCC countries increased from 3000 million m^3/year in 2000 to about 5000 million m^3/year by 2012. It is expected that the capacity will increase to be about 9000 m^3/year in 2030 as shown in Figure (2).

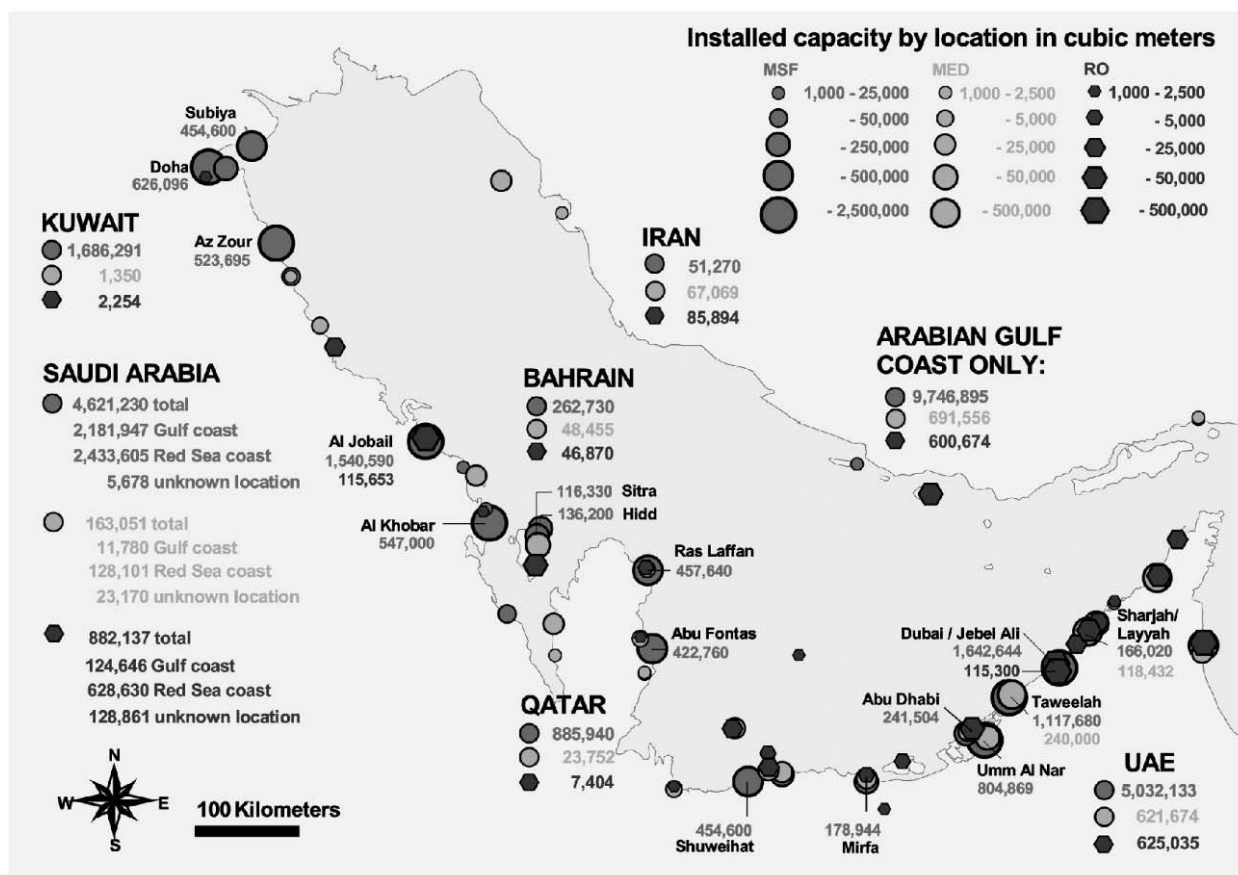


Figure 1: Seawater desalination capacity in the Arabian Gulf

Table 1

Existing desalination plants in GCC countries in 2010

Technology	Country Capacity (Million m3/year)						Total
	UAE	Bahrain	KSA	Oman	Qatar	Kuwait	
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

Note: The table is not including very small scale desalination plants in some countries.

Table 2

Future Planted Desalination Plants in GCC countries

Technology	Country Capacity (Million m3/year)						Total
	UAE	Bahrain	KSA	Oman	Qatar	Kuwait	
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 3

Desalination Capacity in GCC countries (2010)

Technology	Country Capacity (Million m3/year)						Total
	UAE	Bahrain	KSA	Oman	Qatar	Kuwait	
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	246.37	1721	167.77	390.55	701.96	5003.67

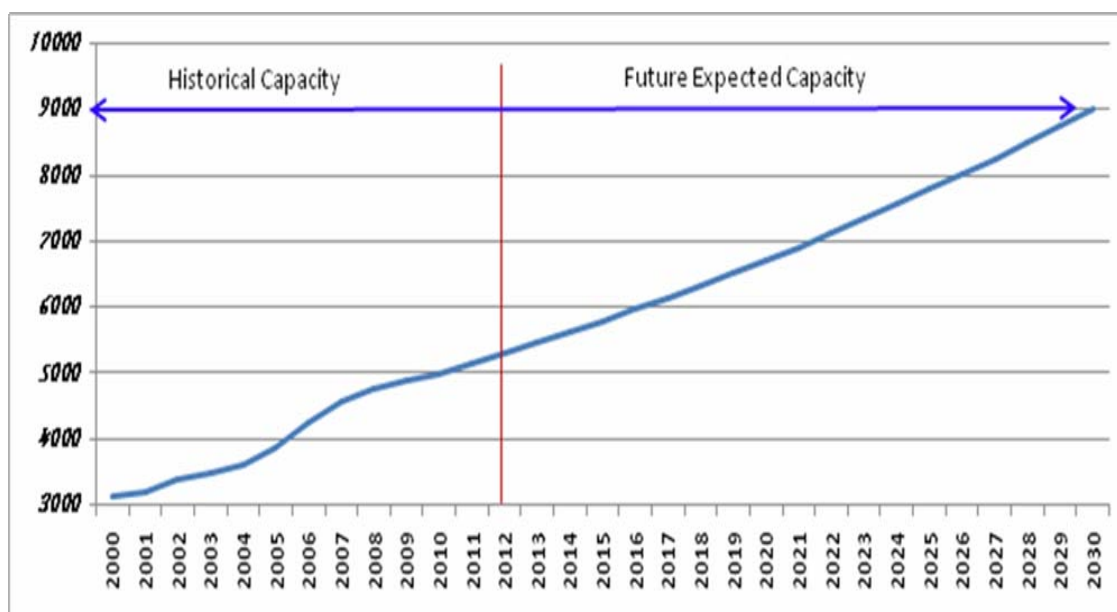


Figure 2 Historical and future increase in the desalination capacity in GCC (2000-2030)

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 (3). The list of potential impacts can be extended; however, the information available on the marine discharges alone indicates the need for a comprehensive environmental

evaluation of all major projects (Lattemann and Hoepner, 2003). In order to avoid an unruly and unsustainable development of coastal areas, desalination activity furthermore should be integrated into management plans that regulate the use of water resources and desalination technology on a regional scale (UNEP/MAP/MEDPOL, 2003). In summary, the potential environmental impacts of desalination projects need to be evaluated, adverse effects mitigated as far as possible, and the remaining concerns balanced against the impacts of alternative water supply and water management options, in order to safeguard a sustainable use of the technology.

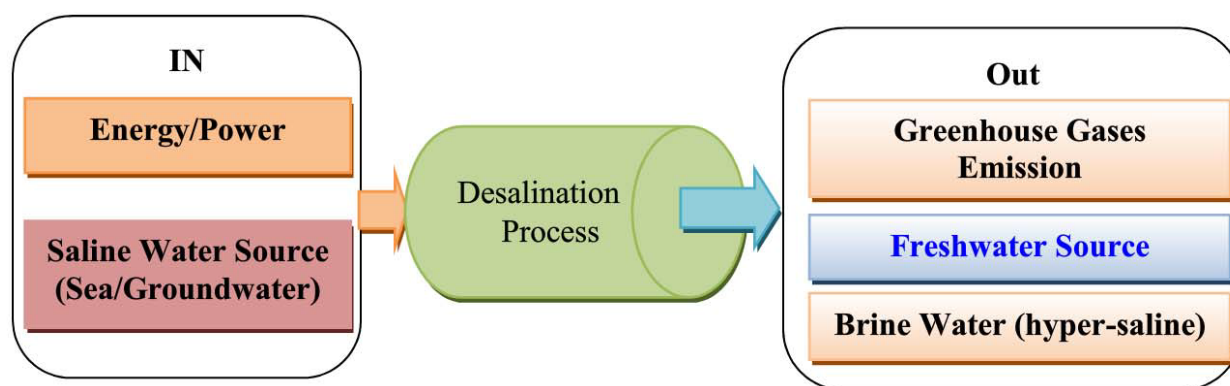


Figure 3: Schematic diagram for the desalination process

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:

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. In spite of the scale of this economical and environmental problem, the options for brine management for inland plants have been rather limited (Ahmed *et al.*, 2001). These options include: discharge to surface water or wastewater treatment plants; deep well injection; land disposal; evaporation ponds; and mechanical/thermal evaporation. Reject brine contains variable concentrations of different chemicals such as anti-scale additives and

inorganic salts that could have negative impacts on soil and groundwater.

By definition, brine is any water stream in a desalination process that has higher salinity than the feed. Reject brine is the highly concentrated water in the last stage of the desalination process that is usually discharged as wastewater. Several types of chemicals are used in the desalination process for pre- and post-treatment operations. These include: Sodium hypochlorite (NaOCl) which is used for chlorination to prevent bacterial growth in the desalination facility; Ferric chloride (FeCl_3) or aluminum chloride (AlCl_3), which are used as flocculants for the removal of suspended matter from the water; anti-scale additives such as Sodium hexametaphosphate (NaPO_3)₆ are used to prevent scale formation on the pipes and on the membranes; and acids such as sulfuric acid (H_2SO_4) or hydrochloric acid (HCl) are also used to adjust the pH of the seawater. Due to the presence of these different chemicals at variable concentrations, reject brine discharged to the sea has the ability to change the salinity, alkalinity and the temperature averages of the seawater and can cause change to marine environment. The characteristics of reject brine depend on the type of feed water and type of desalination process. They also depend on the percent recovery as well as the chemical additives used (Ahmed *et al.*, 2000). Typical analyses of reject brine for different desalination plants with different types of feed water are presented in Table (4).

Table 4

Characteristics of brine water from different desalination plants at GCC

Parameters	Abu-fintas-Qatar (Seawater)	Ajman (BWRO*)	Um Quwain (BWRO)	Qidfa I Fujairah (BWRO)	Qidfa II- Fujairah (Seawater)
Temperature, °C	40.0	30.6	32.5	32.2	29.10
pH	8.2	7.5	6.7	6.97	7.99
EC	NR**	16.5	11.3	77.0	79.6
Ca, ppm	1350	312	173	631	631
Mg, ppm	7600	413	282	2025	2096
Na, ppm	NR	2759	2315	17295	18293
HCO ₃ , ppm	3900	561	570	159	149.5
SO ₄ , ppm	3900	1500	2175	4200	4800
Cl, ppm	29000	4572	2762	30487	31905
TDS, ppm	52000	10114	8275	54795	57935
Total hardness, ppm	NR	NR	32	198	207
Free Cl ₂ , ppm	Trace	NR	0.01	NR	NR
SiO ₂ , ppm	NR	23.7	145	1.02	17.6
Langlier SI	NR	0.61	0.33	NR	NR

* BWRO : brackish water reverse osmosis

** NR : Not reported

2. Environmental Impacts Assessment

There 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 general overview on the composition and effects of the waste discharges is given in a recent WHO guidance document (WHO, 2007), and discussed in detail in Lattemann and Höpner (2003) and MEDRC (2002). In recent publications, special attention is furthermore given to some regional seas with high or increasing desalination activity, such as the Arabian Gulf (Lattemann and Hoepner, 2008; Khordagui, 2002), the Red Sea (Hoepner and Lattemann S., 2002), the Mediterranean or the coastal waters off California (AMBAG, 2006). Based on these and other sources, a list of the potential environmental impacts of desalination on the environment can be given as follows:

2.1 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 re-suspension 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.

2.2 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 increase 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 (5).

2.3 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.

2.4 GHG Emission

Water desalination in GCC countries is an energy-intensive 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. Because of the great public and regulatory concern with the potential climate change and energy impacts of the proposed desalination project, an Energy Technical Working Group, composed of recognized experts, was established to assist in evaluating and reducing the project's potential GHG impacts. This effort eventually resulted in an initial recommendation of 16 projects/programs which, after additional analysis, was reduced to 11. Each project/program has the potential to reduce energy usage and GHG emissions with feasible capital and annual costs. A number of individual projects and combined portfolios could reduce the indirect GHG emissions to a net-carbon-neutral status. The present and future expected increase in CO₂ GHG emissions in GCC countries are summarized in Table (6) (Meed, 2008).

Due to high energy consumption, the desalination industry is exacerbating air pollution through NO_x and SO₂ emissions. However, NO_x 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 (4) 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, NO_x and SO_2 emission reduced as shown in Figure (5 and 6).

2.5 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.

2.6 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. FRC levels (the sum of free and combined available chlorine residuals) of 200–500 $\mu\text{g/L}$ have been reported for distillation plant reject streams, which is approximately 10–25% of the dosing concentration. 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. The concentration of Chlorine in the discharge depends on the number of dosing per day concentration of the Chlorine used in each dosing. Following discharge, a further decline in FRC levels by up to 90% is expected (Shams El Din *et al.*, 2000), which yields estimated concentrations of 20–50 $\mu\text{g/L}$ in the discharge site. This is consistent with observed levels of 30–100 $\mu\text{g/L}$ in the mixing zones of large distillation plants (Ali and Riley, 1986; Abdel-Jawad and Al-Tabtabaei, 1999).

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.

2.7 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 $\mu\text{g/L}$. 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 $\mu\text{g/L}$ to 100 $\mu\text{g/L}$ in estuaries.

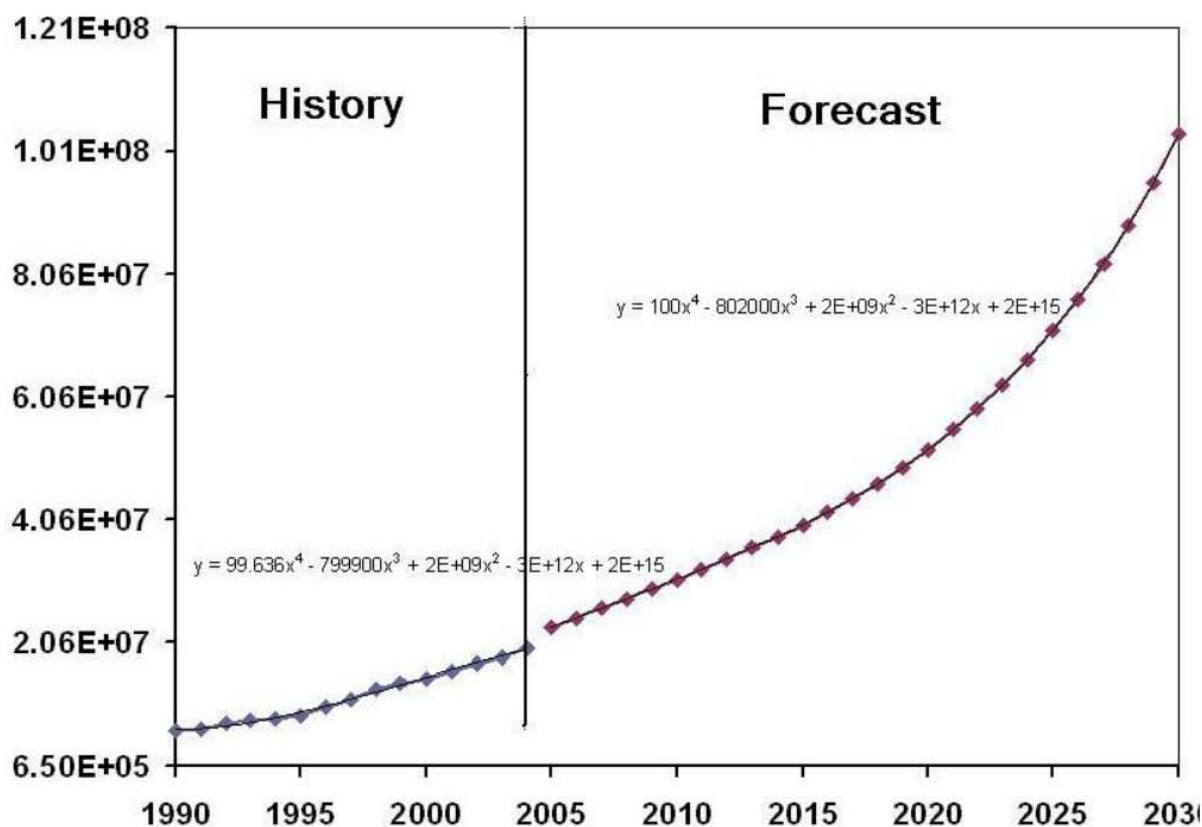
Table 5

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

	RO Plants	MSF Plants
<u><i>Physical properties</i></u>		
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	Negatively 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
<u><i>Biofouling control additives and by-products</i></u>		
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
<u><i>Removal of suspended solids</i></u>		
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)
<u><i>Scale control additives</i></u>		
Antiscalants Acid (H ₂ SO 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)
<u><i>Foam control additives</i></u>		
Antifoaming agents (e.g. polyglycol)	Not present (treatment not required)	Typically low content below harmful levels
<u><i>Contaminants due to corrosion</i></u>		
Heavy metals Cleaning chemicals	May contain elevated levels of iron, chromium, nickel, molybdenum if low-quality stainless steel is used.	May contain elevated copper and nickel concentrations if inappropriate materials are used for the heat exchangers
<u><i>Cleaning chemicals</i></u>		
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), biocides (e.g. formaldehyde)	Acidic (pH 2) solution containing corrosion inhibitors such as benzotriazole derivatives

Table 6CO₂ GHG emissions for the GCC (million metric tons)

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 4:** CO₂ Calculated emissions from desalination plants in Abu Dhabi

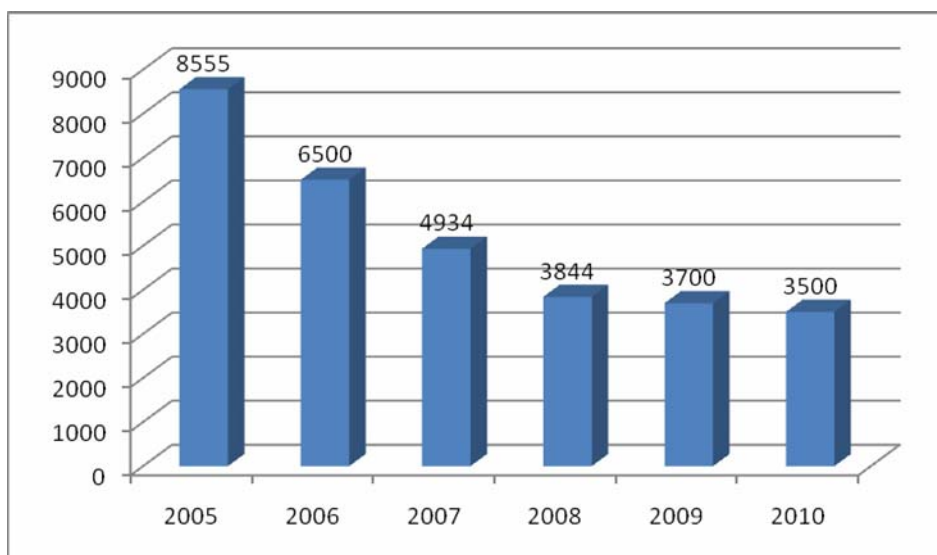


Figure 5: Reduction in NO_x emissions from desalination plants in Abu Dhabi

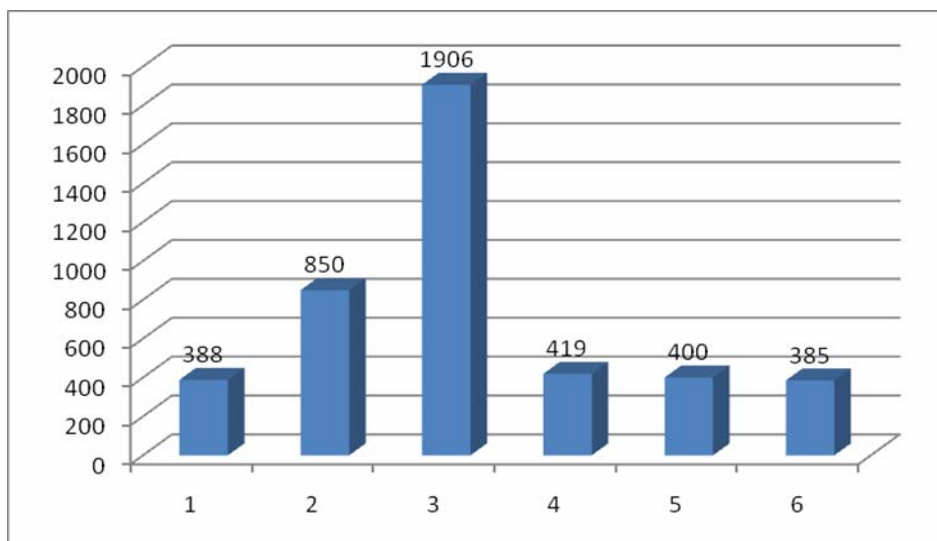


Figure 6: Reduction in SO₂ emissions from desalination plants in Abu Dhabi

In the Arabian Gulf, for example, copper levels were reported in the range of <1 µg/L Qatar to 25 µg/L Kuwait. It is generally difficult to distinguish between natural copper levels and anthropogenic effects, e.g. caused by industrial outfalls or oil pollution (Elshorbagy and Elhakeem, 2008). The discharge levels of thermal plants, however, are well within the range that could affect natural copper concentrations.

2.8 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.

3. Arabian Gulf Ecosystem

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:

3.1 Mangrove swamps

They are extensively grown in the tidal flats. The combinations of the mangrove swamp and the large neighboring mudflat is an important ecosystem for many birds.

3.2 Seagrass meadows

Dense and sparse 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 taxa are endemic to seagrass meadows (48 out of 530 recorded species). Of these, about half are molluscs. 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.

3.3 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.

4. 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 (7).

		Severity				
		Low		High		
		1	2	3	4	5
Probability	Low	1	2	3	4	5
		2	3	4	5	6
		3	4	5	6	7
		4	5	6	7	8
	High	5	6	7	8	9

not significant

significant

high significant

Figure 7: Environmental risk assessment matrix

4.1 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 land-deposition, 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. Another advantage is that the main gaseous reactant, carbon dioxide, can be pure or in the form of a mixture of exhaust or flue gases, which indicates that this approach can be utilized for the capture of CO₂ from flue gases or sweetening of natural gas. El-Naas *et al.* (2010) reported that the reactions of CO₂ with ammoniated brine can be optimized at 20 °C and can achieve good conversion using different

forms of carbon dioxide. Details of this promising approach are presented in the next sections.

4.2 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, 200). 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 water-filtration 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).

provides a summary of each impact, its significance by alternative, mitigation measures, and the impact's significance after mitigation has been applied.

Table (7) lists all environmental impacts and mitigation measures of desalination. The table

Table 7

Main environmental impacts and mitigation measures of desalination process

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 NO _x , SO ₂ , and CO ₂	• 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

5. Conclusions and Recommendations

Environmental impact assessment (EAI) of desalination process is very important. At present, a standard EIA procedure for evaluating and minimizing the effects of desalination projects is not available. The existing general concept of EIAs (which can be applied to all development projects) should thus be underpinned by reference material and a methodological approach that is specific to desalination projects, in order to facilitate the implementation of EIAs for desalination projects on a broader scale. This should include basic information on all relevant impacts of desalination activity, a modular framework for conducting monitoring activities in order to investigate the environmental impacts of each project, the establishment of criteria for evaluating and assessing the monitoring data, and a decision-

making tool for balancing the benefits and impacts of desalination and of other water supply options against each other.

Reject brine management represents a major environmental and economical challenge for most desalination plants. The current options for brine management are rather limited and have not achieved a practical solution to this environmental challenge. A new approach that involves reactions with CO₂ in the presence of ammonia has proven to be effective in reject brine management and capture of CO₂.

Research and development must examine energy issues for desalination that can reduce cost, environmental friendly, improve energy utilization, efficiency and develop new technologies. The following must be considered:

- Hybrid solar and solar/conventional fuel desalination plants;
- Development of energy efficient small desalination systems;
- Assessment of the impact of fuel cell integrated recovery systems and technology on desalination;
- Innovative alternate energy desalination plants.

The relevant power and water authorities in arid region in general and specially GCC countries must direct efforts towards more accurate

evaluation of the possible cost reductions of energy consumed for existing desalination processes by upgrading system efficiency and adopting the off peak desalination concept.

Cooperation and experiences exchange between the water research centers in this field will definitely lead to the optimum use of desalination plants with a minimum impact on the environment. Exchange experience and information on different desalination techniques used in the Arab countries are very essential.

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