

Environmental Assessment of Brine Discharge Including Wastewater Collection in the Arabian Gulf

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Abstract

The environmental effects of brine discharge in the Arabian/Persian Gulf have been assessed. The Arabic Gulf is a wide and shallow system having a horizontal shear dominance. The management choice of mixing brine with wastewater to reduce the salt content in the discharge has also been considered. Approximately 90% of the area around the Arabian Gulf has been compared with the world data for desalination and population growth rate. The Arabian Gulf region is occupying about 3.3% of the world area and 1.0, 2.0 and 2.2% of the total world population in the years 1950, 2008 and 2050 respectively. The annual population growth rate during the whole period is approximately 1.30 in the world and 2.07 in the area studied. The results for the study area were obtained from desalination capacities that are about 50, 40 and 45% of total world capacity for the end of 1996, 2008 and 2050 respectively.

The increased recovery ratio in desalination plants over the years was considered as one important environmental factor. At the end of 1996 it was about 30 to 35% and 2008 about 40 to 45%. In some countries it can reach 50%. This development will significantly increase the brine salt concentration from 1.5 to more than 2 times seawater and negatively affect the receiving water. Water and salt mass balance were used to calculate residual flow, exchange flow and exchange time of the Arabian Gulf. For example at zero wastewater discharge and from 1996 to 2008, the net volume has decreased by the amount of 7.4 millions m³/day, exchange volume increased by 69 millions m³/day and the mixing time decreased with 22.5 days. For the next 42 years from 2008 until the year 2050 the calculation shows a decrease in the net volume by 48.7 millions m³/day, an exchange volume increase by 424 millions m³/day and a mixing time decrease of about 126 days. The more desalted water that is collected from the Gulf, the higher remaining salinity is found in the Gulf.

With higher salinity in the Gulf, the exchange between the Gulf and the Indian Ocean will increase. Mixing brine with wastewater dampens the water and salt exchange between the Gulf and the Indian Ocean. This method will however also minimize the water that is coming from ocean to the Gulf. The content of nutrients in wastewater is positive for irrigation but with only secondary treatment problems like eutrophication in the Gulf may be increased if the exchange of water is low.

I. INTRODUCTION

1.1 General

The effect of desalination plant brine and wastewater discharge to the Arabian Gulf is calculated and used in this study from present, 12 years back and until 2050. Water and salt mass balances are used to find residual flow, exchange flow, and exchange time for the Gulf in three different years 1996, 2008 and the predicted values of year 2050. With an increase in population follows an increase of wastewater that is generated and that has to be treated. Mixing brine with wastewater has been calculated on a recycling percentage from 0, 25, 50, 75 and 100%. Many countries around the Arabian Gulf do already reuse the wastewater or have future plans, for example Kuwait and the United Arab Emirates. The amount of treated wastewater that will be reused can be assumed to be high in the future.

Usually a country is considered to face water shortage if renewable fresh water resources are much below 1000 m³/capita/yr [1]. To solve this, more desalination plants are built all over the world. Yet, an increasing amount of desalination plants around the coast lines and higher capacities recovery ratio, from 30 up to 50 percent in some countries, increase the brine discharge concentration from 1.5 to 2 times of the intake concentration. A higher brine concentration results in a weaker mixing, stronger stratification and longer traveling time that affect and may harm the coastal area. A comparison between the world as a total and the Arabian Gulf region was made for: 1) Average annual population growth rate (PGR) in three periods of time (1950, 2008 and 2050), 2) Average annual desalination growth ratio (DGR) during two periods (at the end of year 1996 to years 2007-08), 3) Coverage area ratio and, 4) Desalination recovery ratio related to: Freshwater production (Q_F) Brine discharge (Q_{Brine}) and, Seawater intake (Q_{Intake}).

The Arabian Gulf (AG) area has a very high evaporation rate, between 1200-2000 mm annually, and a very low annual precipitation, between 90-150 mm. The AG is a semi-enclosed nature and the arid climate is characterized by a higher salt content due to the high rate of evaporation [2]. The existing amount of water resources in our planet is substantial, but generally saline [3] and unevenly distributed. For instance, only five great rivers capture about 27% of the global renewable fresh water resources (Amazon, Ganges-Brahmaputra, Congo, Yellow and Orinoco) [4,5].

Desalination is an important source of potable water in arid areas. The consumption of desalinated water in the Arabian Gulf accounts for over 60% of the world's total production [6]. The installation capacity at the end of 1999 was 60% in the Middle East, 16% in the United State, 10% in Europe, 6% in the Arabian Mediterranean countries and 8% in the rest of the world [4]. In desalination capacity Saudi Arabia ranks first of about 24%, and United States is the second of about 16% of world capacity [7,8]. The installation capacities at 1998 were distributed as 60% in the West Asia and Middle East, 11% in the United State, 7% in the European Union, 7% in North Africa and 15% in the rest of the world [9]. The water sources are 58% seawater desalination, 22% brackish water treatment and 5% wastewater reuse. Six percent of all desalination plants are located in the Asia-Pacific region, 7% in the Americas, 10% in Europe and 77% in the Middle East and North Africa [10,11].

1.2 Environmental Impact and Brine Discharge Composition

In general, when water is extracted from a source supply on a small or large scale, considerable amounts of energy is used for desalination plants by forcing the water through filters and membranes system such

as RO. A large volume of liquid, having a higher concentration of dry matter than the water source, is normally returned back to the same source. Thus, it is a challenge for the researchers to minimize the direct and indirect environmental impacts to save the water sources. In all processes of sea water desalination, the discharged brine, with a concentration higher than that of the natural seawater of the three aimed regions, is returned to the sea. The concentrations of the brines are usually found to be double or close to double that of natural seawater [12]. (Table 1) present the major ion compositions of three different regions Mediterranean, Arabic Gulf and Red Sea compared to typical seawater [9].

Elements name	Typical Seawater	Eastern Mediterranean	Arabian Gulf at Kuwait	Red Sea at Jeddah
Chloride (Cl ⁻)	18,980	21,200	23,000	22,219
Sodium (Na ⁺)	10,556	11,800	15,850	14,255
Sulfate (SO ₄ ²⁻)	2,649	2,950	3,200	3,078
Magnesium (Mg ²⁺)	1,262	1,403	1,765	742
Calcium (Ca ²⁺)	400	423	500	225
Potassium (K ⁺)	380	463	460	210
Bicarbonate(HCO ₃ ⁻)	140	-	142	146
Strontium (Sr ²⁺)	13	-	-	-
Bromide (Br ⁻)	65	155	80	72
Borate (BO ₃ ³⁻)	26	72	-	-
Fluoride (F ⁻)	1	-	-	-
Silicate (SiO ₃ ²⁻)	1	-	1.5	-
Iodide (I ⁻)	<1	2	-	-
Others	-	-	-	-
Total dissolved solids, TDS	34,483	38,600	45,000	41,000

Table 1: Major ion composition of three different regions compare to typical seawater (mg/L) [9]

1.3 Dispersion of the Concentrated Salts

The major environmental problem associated with a desalination plant is to dispose or/and minimize the brine concentration. A natural and easy way is to discharge the brine to the sea, but an appropriate design is required in order to insure the proper dispersion of the brine. There are different alternatives which have been advised in previous studies as, discharge by a long pipe, direct discharge of the brines at the coastline, mixing of the brine via the outlet of the power stations cooling water or wastewater, using the brines to a salt production evaporation pond and, to have more than one outlet to the sea.

The forces of buoyancy in wastewater discharge are important in the dilution process of water jets [13] but do not exist in the case of brine discharge. The process of brine dilution is a combination of two physical processes: 1) the primary (jet) dilution and 2) the natural dilution process. The combination of a power station and a desalination plant holds many advantages, though most of these are relevant to plants that are based on the various evaporation systems and not to reverse osmosis plants [14,15,16,17,18].

The results from Ashkelon and Hadera indicate that the total salinity of the water at the vicinity of the outlet of the discharge pipe would increase by 1 to 5% (in the near filed). This results was shown according to the available models for dispersion [19,20] and the effect of the concentrated brine will disappear at a distance of a few meters from the outlet.

II. STUDY AREA: BACKGROUND & CHARACTERISTICS

2.1 General

Arabian Gulf bordering countries are: Iran, Iraq, Kuwait, Saudi Arabia, Qatar, Bahrain and United Arab Emirates (as shown in Figure 1). The Arabian Gulf is a shallow semi-enclosed marginal sea, with less than 100 m in depth over its entire extent and its mean depth only 35 m [21]. It covers an area of about 240,000 km², with 1000 km in length and widths ranging from 185 km to 370 km, with a mean of 240 km in which the volume is approximately 8,400 km³. There are freshwater inflows from the Tigris, the Euphrates and the Karun at the delta of the Shatt al Arab, estimated at 0.2 m/yr, in which fresh water and river inflow equals to 48 km³/yr (131.5 10⁶m³/day) [21,22]. The mean annual evaporation rate is estimated at approximately 1.5 m/yr [23]. For Iraq desalination plant, the brine percentage discharged to the Arabian Gulf is not clear to me but my guess is about 5%. The total discharge Q_T is equal to the summation of brine discharge Q_B and wastewater discharge Q_W . These values presented for Q_T is the total discharge at 100 percent wastewater will be mixed with brine water as seen in Figure 1.

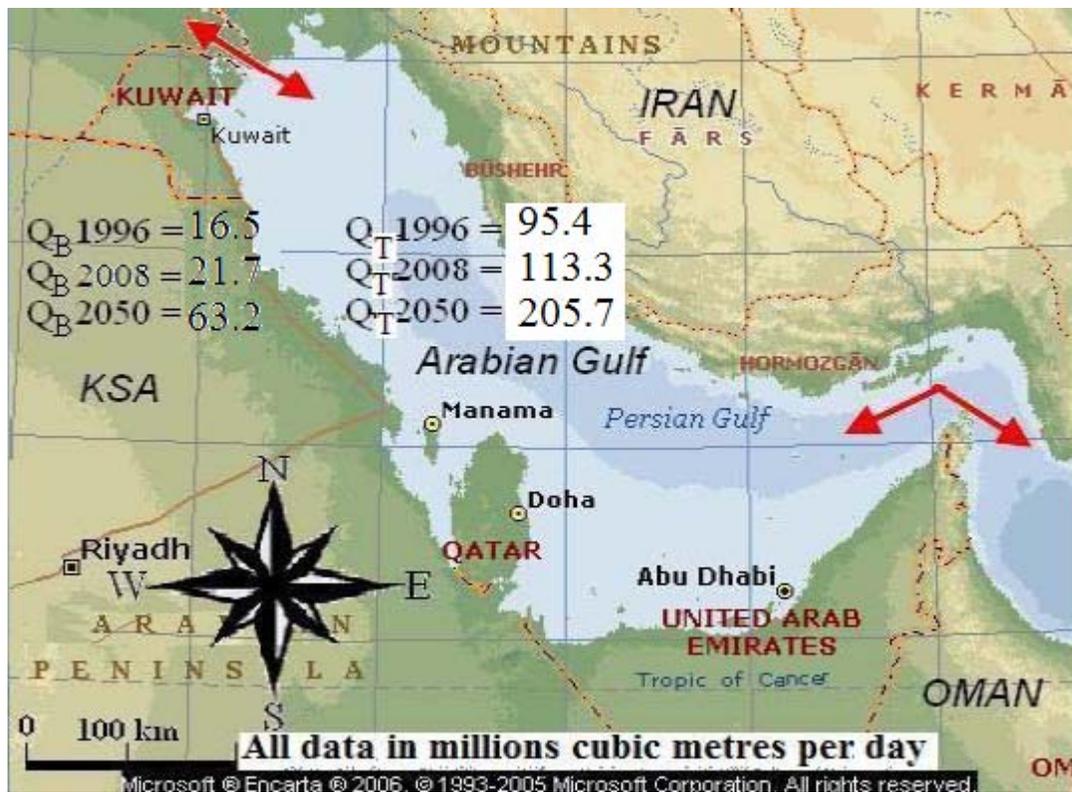


Fig. 1: Results of discharged water to Arabian Gulf in (10⁶ m³/d) at 1996, 2008 and 2050 (after: Google Earth)

The shallowness and humidity leads to the formation of very high saline, dense water, having maximum salinities as high as 57 g/l [24]. Ahmad and Sultan (1991) employing the Knudsen relations to estimate the annual mean Gulf water outflow transport at 14.7×10^9 m³/day [25] compared to the observation from an Acoustic Doppler Current Profiler (ADCP) moored in the Strait of Hormuz indicate no strong seasonal variation outflow transport and the annual mean of $(17.3-21.6) \times 10^9$ m³/day [26]. Typical mass transport estimate by the outflow from Arabian Gulf is about 34.5×10^9 m³/day, which is larger than those reported by others [27].

The largest number of desalination plants can be found in the Arabian Gulf with a total seawater desalination capacity of approximately 11 million m³/day (Fig. 2) which means a little less than half (45%) of the worldwide daily production. The main producers in the Gulf region are the United Arab Emirates (26% of the worldwide seawater desalination capacity), Saudi Arabia (23%, of which 9% can be attributed to the Gulf region and 13% to the Red Sea) and Kuwait (<7%) [11,28].

2.2 Population and Area

A comparison of population, area and population growth rate for the world and the study area are presented (in Table 2) for a span of 100 years. The total population in the study area are approximately 1.0 and 2.0% of the worlds population in the years 1950 and 2008 and will increase to 2.2% by the year 2050. The area around the Arabian Gulf occupies approximately 3.3% of the world area. The annual population growth rate in the world and study area in the period 1950 to 2050 is found to be 1.30 and 2.07 respectively. The growth rate from midyear of the whole period is the most common way to express population growth as a rate, the growth rates were calculated using the formula: $R(t) = \ln [P_{t+1} / P_t]$, in which t = year; R(t) = growth rate from midyear t to midyear t+1; P(t) = population at midyear t and Ln = natural log [29].

Country or area	Population			Area Km ²	Population growth rate PGR
	1950	2008	2050		
WORLD	2,555,948,654	6,677,602,292	9,392,797,012	130,772,667	1.30
Bahrain	114,840	718,306	973,412	665	2.14
Iran	16,357,000	65,875,223	81,490,039	1,636,000	1.61
Iraq	5,163,443	28,221,181	56,360,779	432,162	2.39
Kuwait	144,774	2,596,799	6,374,800	17,820	3.78
Qatar	25,101	928,635	1,239,216	11,437	3.90
KSA	3,859,801	28,161,417	49,706,851	2,149,690	2.56
UAE	71,520	4,621,399	8,018,904	83,600	4.72
Total	25,736,479	131,122,960	204,164,001	4,331,374	2.07
Percentage	1.0	2.0	2.2	3.3	0.77

Table 2: Comparisons for area and population growth rate in the worldwide and study area in 1996, 2008 and 2050 [29]

III. LONG TERM DATA COLLECTION AND CALCULATION

3.1 Desalination Capacities Distributions

With the available and calculated data an estimate of desalination capacity and capacity per capita up to year 2050 was made. (Figure 2) is the general typical diagram for seawater desalination plant and details for pre and post treatment, where S_{Intake} and Q_{Intake} are salinity and volume of seawater intake, S_{Brine} and Q_{Brine} are salinity and volume of brine discharge and S_F and Q_F are salinity and volume of fresh water produced by desalination plant. $S_{Brine} = S_{Intake}/(1-r)$ and $Q_{Brine} = (1-r)Q_{Intake}$, where, r is the recovery ratio between 35 to 45% of the intake and $S_F \approx 0$ and $Q_F = rQ_{Intake}$. The high concentration brine is discharged back to the open sea through pipes and open channel in the some cases. The cooling water flows in MSF and MED are omitted since these do not affect the salinity.

The last ten years of desalination development, the recovery ratio r has been increased in reverse osmosis plants significantly. For example from Al Shaaer et al., 2007 seawater intake salinity, S_{Intake} is equal to 41.7 ppt, and the brine directly front of output pipeline is equal to 74 ppt. The recovery ratio will be $S_{\text{Brine}} = S_{\text{Intake}}/(1-r)$, or $r = 44\%$ recovery ratio [30]. Desalination capacities in (1,000 m³/day), globally and studied area at the end of 1996, 2008 and the estimated values for year 2050 (see Table 3).

There are three types of water in the typical desalination plant (freshwater production Q_F , brine discharge Q_{Brine} , and seawater intake Q_{Intake}) were defined and compared in the last twelve years between the beginning of 1996 to 2008 and the year 2050 for the total desalination capacity in the world and study area. It has been calculated after S. Lattemann and T. Höpner (2008) and the IDA year books (2006-07; 2007-08 and 2008-09) that Saudi Arabia (KSA) has approximately 41.3% of its desalination capacity along the shores of the Arabian Gulf and 58.7% along the Red Sea [11,17,8,31].

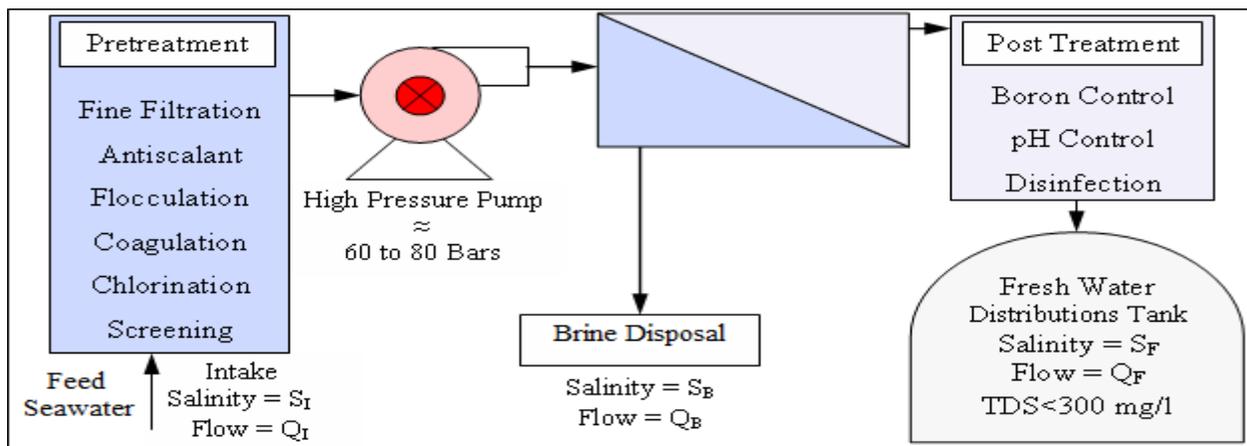


Fig. 2: Revers osmosis seawater desalination plant typical scheme showing input/output and different stages of treatment

In this study, just 41.3% will be considered from the total daily brine discharge of Saudi Arabia and the same will be followed in the wastewater calculations. The results describe the relation between three water types at three different time periods.

Country	Desalination capacity in 1,000 m ³ /day								
	1996			2008			2050		
	Q _F	Q _B	Q _I	Q _F	Q _B	Q _I	Q _F	Q _B	Q _I
WORLD	20000	46667	66667	47709	71564	119273	192211	192211	384422
Bahrain	283.0	660	943	825.2	1238	2063	3022	3022	6044
Iran	423.4	988	1411	547.8	822	1370	3138	3138	6276
Iraq	324.5	757	1082	476.6	715	1192	2519.3	2519	5039
Kuwait	1284.3	2997	4281	2308.7	3463	5772	10822	10822	21644
Qatar	560.8	1308	1869	1026.3	1539	2566	4762	4762	9524
KSA	5006.2	11681	16687	7750.8	11626	19377	39669	39669	79339
UAE	2134.2	4980	7114	6094.7	9142	15237	22533	22533	45065
Total	10016	23372	33388	19030	28545	47575	86465	86465	172931
Percentage	50.1	50.1	50.1	39.9	39.9	39.9	45.0	45.0	45.0
Total*	7078	16515	23592	14480	21720	36201	63179	63179	126359

Table 3: Comparisons between world and study area for desalination capacity at the end of 1996, 2008 and prediction of year 2050 [after: 9,10,11,28,16,17,18] where, Q_F=Freshwater Production; Q_{Brine}=Brine Discharge; Q_{Intake}=Seawater Intake and

*total with KSA of 41.3% flows to AG.

3.2 Wastewater Collections

During the last decades the water demand in the Gulf Cooperation Council (GCC) countries has more than doubled compared to the increase in population, due to more water supply, higher living standard, expansion of agriculture and green land irrigation [32]. The water consumption around the millennium was in UAE over 700 l/person/day (255 m³/capita/yr) and Kuwait and Qatar over 400 l/person/day (145 m³/capita/yr) [32]. In 2005 it was 920 m³/c/y [33]. USA has the largest consumption of 1720 m³/capita/yr and the lowest consumption is in Denmark with 130 m³/capita/yr [33]. These figures include notably water demand for agriculture. A possible increase in water consumption caused by expansion of agriculture has not been considered in this study because it uses groundwater as main source [32].

With the increase of population as well as specific water consumption, the amount of wastewater that has to be treated increases as well. More wastewater treatment plants must be built for protecting the environment. The amount of wastewater that will be recycled to agriculture, green land irrigation and augmentation of aquifers will most probably increase due to the water shortage [32]. Many countries around the Arabic Gulf do already reuse the wastewater or have future plans, for example Kuwait, where treated wastewater is used for irrigation and landscaping [34], and UAE, that has initiated a nation-wide program for reuse of treated wastewater in landscaping [35].

IV. METHODOLOGY AND MODELING

4.1 Wastewater Calculation

In order to estimate the amount of wastewater generated in year 2050 following assumptions have been made:

- Population increase calculated on the increase from 1996 to 2050.
- Water produced by desalination is only been distributed for domestic and industrial use. Therefore all the produced freshwater will end as potential wastewater.
- Leaks in pipes transporting potable water and wastewater are assumed to be equal to other potable water sources.

The amount of treated wastewater that will be reused will probably be high; an analysis of mixing brine with wastewater has also been done assuming:

- All wastewater is reused; 0% of produced desalinated water discharged with brine
- 25% of produced desalinated water is discharged with brine
- 75% of produced desalinated water is discharged with brine, or
- 100% of produced desalinated water is discharged with brine

4.2 Water and Salt Mass Balances

Generalized diagram summarizing water and salt budgets for coastal ecosystems is described (in Figure 3). The Arabian Gulf is considered to be a one-layer system (non-stratified) to easily modify and describe such budget in terms of a simple mass balance equation. Following the LOICZ biogeochemical modeling, it is important to estimate the mixing volume Q_{EX} (Exchange volume between system body and ocean) across the open boundary of the system. Q_{EX} is estimated from water and salt budgets [36].

In (Figure 3), the total water received from rivers and springs are denoted by (Q_{RI}) , average rainfall (Q_P) , average annual evaporation (Q_E) , (Q_W) is the amount of wastewater that will be added to the system and can be mixed with brine water and (Q_N) is the residual volume (net volume) transport associated with freshwater discharge. (Q_{Brine}) is brine discharge to sea surface from desalination plant with high concentration and (Q_{Intake}) is the amount of water intake to the desalination plant from open sea or from wells located about 20 to 30 meters away from the coastline. (S_{sys}) is the system salinity, (S_{ocn}) is the adjacent ocean salinity and all other terms have salinity values except precipitation and evaporation approximated to zero. The units for all output and input are common in (m^3/s) and all concentration will be taken as (g/l) .

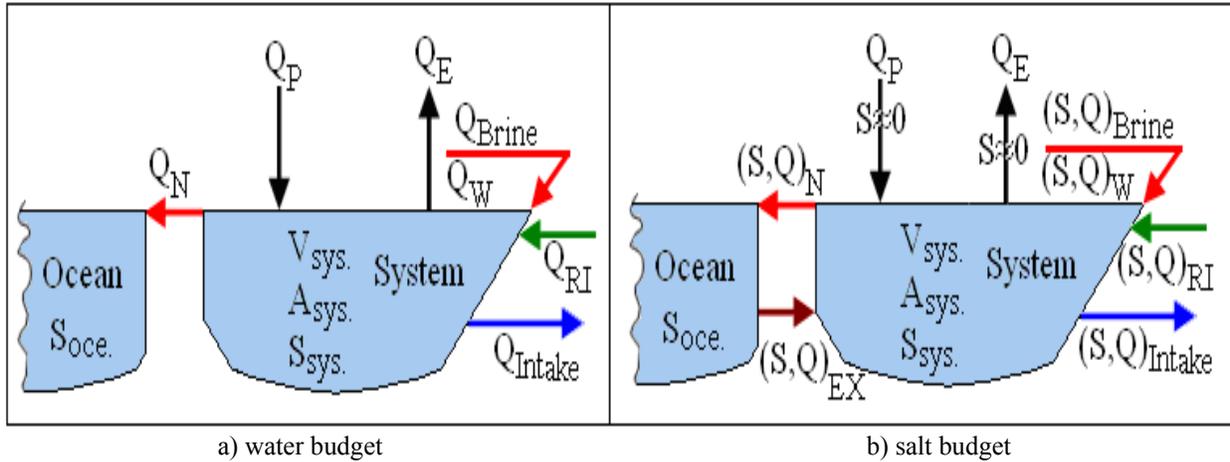


Figure 3: Generalized diagram summarizing water and salt budgets for coastal ecosystems

A. Water mass balance

The amount of waters flows into the system, the same amount of waters must flow out in order to keep the volume constant. In principle, this flow, called the "residual flow, Q_N " or the net residual volume can be written as:

$$Q_N = \sum Q_{in} - \sum Q_{out} = (Q_P + Q_{RI} + Q_W + Q_{Brine}) - (Q_E + Q_{Intake}) \quad (1)$$

B. Salt mass balance

For the salt budget, we assign related salinity to each one of the water inputs and outputs. The inputs and outputs then become each flow multiplied by the appropriate salinities (designated as S 's) for most of the terms if they are important. For the terms with small salinity (has no effect to the system) like evaporation and precipitation it is sufficiently accurate to assume their salinity to be 0 and excluding it from calculations.

$$Q_{EX} = [(Q.S)_N + (Q.S)_{RI} + (Q.S)_{Brine} + (Q.S)_W - (Q.S)_{Intake}] / (S_{ocn} - S_{sys}) \quad (2)$$

where, salinity of the exchange volume is the difference between ocean salinity S_{ocn} and system salinity S_{sys} , and the net volume Q_N salinity is equal to the average of ocean and system salinities.

$$\tau = V_{sys} / (Q_{EX} + |Q_N|) \quad (3)$$

where, τ is exchange time, system volume divided by the sum of Q_{EX} plus the absolute value of Q_N as stated in a single layer, single box system [36].

V. RESULTS AND RECOMMENDATIONS

5.1 Study Area Characteristics

The water mixing across the open boundary of the water system is governed by the dispersion process [37]. The following criteria are used to decide how the system will be treated in shape, shear and mixing. A system is considered to be "narrow and deep" if $L_C/B > 2$ and $B/H < 500$ (vertical shear dominant). A system is considered "wide and shallow" if $L_C/B < 2$ and $B/H > 500$ (horizontal shear dominant) as defined in Taylor, 1953 [38]. L_C (m) is the distance from the center of the system to its mouth; H (m) is the system average depth and B (m) is the width of the system.

The typical and calculated parameters related to the Arabian Gulf are presented (in Table 4). From Table 4, it can be concluded that the Arabian Gulf system should be considered "wide and shallow" dominated by horizontal shear. This result will help us to understand the circulation and mixing in the system.

Categories	Arabian Gulf
Parameters:	
L_{ave} ($\times 10^3$ m)	1,000
L_C ($\times 10^3$ m)	450
B ($\times 10^3$ m)	240
H (m)	35
A ($\times 10^6$ m ²)	240,000
V ($\times 10^9$ m ³)	8,400
Input/Output (10^6m³/day):	
Average Ppt., P_{ave}	65.8 ^a
Evaporation Rate, E	986.3
River Discharge, Q_{RI}	131.5
Average Outflow, Q_O	25,918
Classifications:	
(L_C/B) ratio	$1.9 < 2$
(B/H) ratio	$6857 > 500$
Shape	Wide and Shallow
Shear	Horizontal shear dominant

Table 4: The typical and calculated parameters for the Arabian Gulf [36,37,38,^a39]

5.2 Desalination and Wastewater Results

The result of net volume, exchange volume and exchange time and calculation of brine and wastewater discharge for the Arabian Gulf at the end of 1996 and 2008 and prediction of year 2050 are presented (in Table 5). The amount of wastewater is added gradually to the brine discharge from 0 to 100 percent in order to find the differences in exchange time and the behavior of mixing in the whole system. These percentages are also described as the result of wastewater used per capita per year in the countries in the study area in which zero percent in the table means that all wastewater are to be treated and used for different purposes on land, while 100 percent means that all wastewater will be mixed with the brine and discharged together in the Arabian Gulf.

The differences in result from zero to 100 percent were calculated for the three terms net volume, exchange volume and exchange time to evaluate and understand the changes in each period separately and between three periods. The net volume increased 79 million m³/day in 1996 when changing the wastewater discharge to the Gulf from zero to 100%, decreasing the exchange volume of about 524 million m³/day and increasing the mixing time with about 203 days.

Parameters	Brine and wastewater discharges in 10 ⁶ m ³ /day					Difference (0 compared with 100 % wastewater)
	0	25	50	75	100	
Wastewater Discharge in %						
Total Discharge in 1996:						
Q _N (10 ⁶ m ³ /day)	16.5	36.2	55.9	75.7	95.4	
Q _{EX} (10 ⁶ m ³ /day)	-796	-776.4	-756.7	-737.0	-717.3	79
τ (Time in years)	4507	4376	4245	4114	3983	-524
τ (Time in days)	4.34	4.46	4.60	4.74	4.89	0.56
	1584	1630	1679	1732	1787	203
Total Discharge in 2008:						
Q _N (10 ⁶ m ³ /day)	21.7	44.6	67.5	90.4	113.3	
Q _{EX} (10 ⁶ m ³ /day)	-804	-780.6	-758	-734.9	-712	92
τ (Time in years)	4576	4424	4272	4120	3968	-608
τ (Time in days)	4.28	4.42	4.57	4.74	4.91	0.64
	1561	1614	1670	1730	1795	233
Total Discharge in 2050:						
Q _N (10 ⁶ m ³ /day)	63.2	98.8	134.4	170.1	205.7	
Q _{EX} (10 ⁶ m ³ /day)	-852	-816.6	-781.0	-745.3	-709.7	143
τ (Time in years)	5000	4763	4527	4290	4053	-947
τ (Time in days)	3.93	4.12	4.33	4.57	4.83	0.90
	1435	1505	1583	1668	1764	328

Table 5: Results of brine and wastewater discharge for the Arabian Gulf in 1996 and 2008 and the prediction of year 2050

Correspondingly, the net volume increased with 92 millions m³/day in 2008, decreasing the exchange volume by 608 millions m³/day and increasing the mixing time in the system with about 233 days. In the result from the forecast for year 2050 after desalination and wastewater capacity calculations, the difference of net volume have increased to 143 millions m³/day, the exchange volume decreases 947 millions m³/day and this results in an increase of the mixing time with about 328 days.

The different years can be compared first without wastewater discharge. From 1996 to 2008, the net volume has decreased by the amount of 7.4 millions m³/day, exchange volume increased by 69 millions m³/day and the mixing time decreased with 22.5 days. For the next 42 years from 2008 until the year 2050 the calculation shows a decrease in the net volume by 48.7 millions m³/day, an exchange volume increase by 424 millions m³/day and a mixing time decrease of about 126 days. And within 54 years from 1996 to 2050, the net volume has decreased by the amount of 56 millions m³/day, exchange volume increased by 493 millions m³/day and the mixing time decreased 149 days. Obviously, the more desalted water that is collected from the Gulf, the higher remaining salinity is found in the Gulf. With higher salinity in the Gulf, the exchange between the Gulf and the Indian Ocean will increase (S_{EX} and Q_{EX} in Figure 3).

With 100% wastewater discharge together with brine, the different years can also be compared. From 1996 to 2008, the result of the net volume has increased by 5.3 millions m³/day, exchange volume decreased by amount of 15 millions m³/day and mixing time has increased by 7.8 days. For the next 42 years from 2008 until year 2050 the calculation shows an increase in the net volume by the amount of 2.3 millions m³/day, exchange volume increased by amount of 85 millions m³/day and mixing time has

decreased by 31 days. And within next 54 years from 1996 to 2050, the net volume has increased by the amount of 7.6 millions m³/day, exchange volume increased by 70 millions m³/day and the mixing time has decreased by 23.5 days. Mixing brine with wastewater dampens the water and salt exchange between the Gulf and the Indian Ocean.

In total the result from 1996 to 2008 showed that the net volume has amount of 13 millions m³/day, exchange volume decreased 84 millions m³/day and the mixing time has increased by 30 days. For the next 42 years from 2008 until year 2050 the calculation shows an increase in the net volume by the amount of 51 millions m³/day, exchange volume by amount of 339 millions m³/day and mixing time has increased by 95 days.

After these comparisons, the higher wastewater percentage added to the system, the more net volume flow and the less exchange volume due to mixing of high saline brine and less saline wastewater will take place. Thus, the exchange volume from ocean will be less and less due to a reduced water flow from less saline to higher saline concentration. On a local scale, the mixing of wastewater with brine will help to reduce the salinity gradients in the coastal areas. So is it better or worse to increase mixing of wastewater with brine? The decision here is hard to make. The environmental effects depend on all inputs and outputs as defined by water and salt mass balance, population growth and increasing in desalination. Mixing times are attributed to the net volume and exchange volume. When comparing 1996 with 2050, it is obvious that mixing times decreases with increasing desalination. Salinity will increase more if wastewater discharge goes down, reducing exchange volume.

Exchange time or mixing time calculations for these different water concentrations show that the higher amount of wastewater mixed with brine discharge, the longer is the mixing time. However, if untreated, the wastewater will contribute to an increased eutrophication in the Gulf. The proper management of the Arabian Gulf needs at least to be studied thoroughly. The amount of natural evaporation is huge when comparing to the total amount that extract from the Arabian Gulf and this is locally extracted but the evaporation is extracted from all over surface area of the Gulf which has very small effect compared to local problem.

VI. CONCLUSION

Desalination plants and wastewater treatment plants are needed for all countries due to scarcity of fresh water in the study area. Wastewater and brine discharge mixing together is an important methodology to minimize the salinity increase of the coastal waters in the Arabian Gulf. Therefore, it is possible to minimize the impact and reduces the salt concentration in the future when adding wastewater to the brine discharge. This method will however also minimize the water that is coming from ocean to the Gulf. The decision here will be very difficult to make whether to use the wastewater for mixing with brine or reuse after treatment process for other purposes.

There are some points have to be taken into account for the future such as:

- Wastewater treatment plants to be built to take care of increased wastewater production in the urban areas
- The extra cost for advanced treatment compared with the costs for extra production of desalinated water, damaged groundwater aquifers and possible environmental problems will probably stimulate water recycling

- In some cases there might not be land close enough to irrigate with treated wastewater and the treated wastewater may therefore be discharged with the brine
- The content of nutrients in wastewater is positive for irrigation but with only secondary treatment problems like eutrophication in the Gulf may be increased if the exchange of water is low
- Considering concentration of total dissolved solids in the Gulf water, simultaneous discharge of wastewater with brine conserves the salt. This may actually be one argument for not recycling the wastewater on land

The higher wastewater percentage added to the system, the more net volume flow and the less exchange volume due to mixing of high saline brine and less saline wastewater will take place. Thus, the exchange volume from ocean will be less and less due to a reduced water flow from less saline to higher saline concentration. On a local scale, the mixing of wastewater with brine will help to reduce the salinity gradients in the coastal areas. It is possible to minimize the impact and reduces the salt concentration in the future by adding wastewater to the brine discharge.

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