

# Risks and threats of desalination in the Arabian Gulf

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**Abstract.** Desalination constitutes the sole long-term reliable and sustainable source of fresh water for the desert Arabian Gulf Region. The region is facing unprecedented growth with continuous population increase and economies that diversify from oil production to manufacturing and industry, and real estate and tourism. The scarcity of water makes it in addition to its life-sustaining role a limiting economic resource for the region. The current article analyses the situation in terms of desalination production in the region, which for the majority of the Gulf countries has doubled during the last decade, but still does not keep up with the continuously increasing water demand. In addition, the paper presents the risks and threats from utilizing as a sole source of water that of a closed sea, the Arabian Gulf, which has a small opening to open ocean, a shallow depth, and a long residence time. The Arabian Gulf serves also as a major shipping route for oil exportation, navigation, wastewater effluent outlet, tourism, and entertainment making management of all its functions complicated. Parsimonious use of water in all facets of the economy is hence recommended.

## 1. Introduction

The Arabian Peninsula was created about 50 million years ago when it separated from Africa, opening up and filling with sea water the area known today as Red Sea. During the late Precambrian Period (ca. 542 Ma), the region appears to have been glaciated; during the middle Cambrian (ca. 542-488 Ma) it was covered by a shallow sea, and then moved close to the South Pole becoming possibly glaciated again during the Ordovician Period (488-444 Ma). Since the end of the Paleozoic (ca. 251 Ma) it has remained in tropical and subtropical latitudes resulting in a hyper-arid climate with very low precipitation and high evaporation rate.

The limitation in water resources has prompted the Gulf countries to rely on desalination technologies in order to provide fresh and uninterrupted water supplies. The current article presents the situation in the region in terms of desalination production and analyses the threats and risks to desalination from utilizing the water of a closed sea, such as the Arabian Gulf, which in addition serves as a major shipping route for oil exportation, navigation, wastewater effluent outlet, tourism, and entertainment.

## 2. Desalination production of the Arabian Gulf Countries

Production of desalinated water by an Arabian Gulf country cannot be viewed in isolation since the water of the Arabian Gulf is utilized by all other Gulf countries. In 2010 about 76% of the global seawater desalination capacity was concentrated in the Arabian Gulf with the United Arab Emirates



(UAE) leading desalinated water production with 35%, followed by Saudi Arabia with 14% (and another 20% in the Red Sea), Kuwait with 14%, Qatar with 8%, and Bahrain with 5%. That year total desalination capacity of the Gulf countries was assessed to be 5,000 Mm<sup>3</sup>/yr and was expected to rise to 9,000 Mm<sup>3</sup>/yr by 2030 [1]. Saudi Arabia, USA, and UAE top the list of the countries where major investments in desalination technology were planned by the end of 2020, with Kuwait and Qatar also included in the top fifteen [2].

The UAE has an average annual precipitation of about 100 mm, which varies significantly between desert and mountains regions and an evaporation rate that exceeds 2.5 m/yr. There exist about 33 major desalination plants in the UAE with a total estimated 2013 desalinated water production of 1,750 Mm<sup>3</sup> [3]. The increase in desalination between 2000 and 2010 in this country was over three-fold. In 2013, about 75% of the desalinated water was provided through MSF (Multi-Stage Flash Desalination) technology, 17% through MED (Multi-Effect Desalination), and the remaining through RO (Reverse Osmosis). In Abu Dhabi the sole buyer and seller of water and electricity is ADWEC (Abu Dhabi Water & Electricity Company), whereas in Dubai it is the DEWA (Dubai Electricity & Water Authority). The total water production in 2015 by ADWEC was 1,040 Mm<sup>3</sup> a 25% increase from the 831 Mm<sup>3</sup> of desalinated water produced in 2009, the most recent year that water data were collected (subsequent data are estimates based on the 2009 data). The annual desalinated water supply increased by about 5.5% annually from 2005 to 2015 [4]. The increased energy needs for desalination will be partially met by four nuclear plants that will produce 1,400 MW each, providing 25% of the country's electricity. Recently, on April 10, 2018, it was officially announced that apart from full completion of the first unit in 2017, overall construction progress for all four units at Barakah stood at 87 percent [5].

The World Bank Organization lists Saudi Arabia with an average annual precipitation of about 74mm for the period of 1901-2015 [6], whereas the evaporation rate in the Red Sea area was found to be about 2.06±0.22 m/yr [7]. This country produced the largest quantity of desalinated water in the world in 2010 with a total production of about 1,066 Mm<sup>3</sup> according to GWI data, or 1,253 Mm<sup>3</sup> according to the country's National Water Company's figures. Of these 532 Mm<sup>3</sup> were produced by 112 desalination units located in the West Coast, and 534 Mm<sup>3</sup> from 193 units in the Arabian Gulf Coast [8]. Production estimates for this country fluctuate and different sources report varying production rates. Later figures put the production at 2,780 Mm<sup>3</sup>/yr [9], whereas others put it at 2,190 Mm<sup>3</sup>/yr [10]. Approximately half of this utilizes water from the Arabian Gulf at 3.722 Mm<sup>3</sup>/day and the other half comes from the Red Sea at 3.892 Mm<sup>3</sup>/day. The country relies 64% on MSF, 20% on RO, and 16% on MED, and is also proceeding with solar, nuclear, and floating desalination.

Kuwait has an average annual precipitation of 114 mm over the last century and an annual evaporation approaching 4 m [11]. The country operates seven MSF with power cogeneration desalination plants with total maximum annual capacity of about 890 Mm<sup>3</sup>/yr, which provide 92% of the domestic and industrial needs and 60% of the total water supply [12]. The emergency water reserves stored in groundwater reservoirs and the distribution network in all Gulf countries with the exception of the UAE do not exceed 3 to 5 days. The UAE has recently completed its aquifer storage and recovery program [13], which allowed for three-months of water reserves to be built in the country.

Qatar has no surface waters, an average precipitation of 76 mm/yr, and saltwater intrusion and significant groundwater drops have occurred as a result of groundwater abstraction that exceeds five times natural replenishment. Groundwater abstractions were 220 Mm<sup>3</sup>/yr versus 40 Mm<sup>3</sup>/yr natural recharge, according to the Qatar Environment & Energy Research Institute, or 250 Mm<sup>3</sup>/yr abstractions versus 48 Mm<sup>3</sup>/yr groundwater recharge in 2013, according to the Qatar Ministry of Development Planning and Statistics. It completely depends on desalination to meet its municipal water needs (99% of domestic water demand is met by desalination), which in 2013 reached 453 Mm<sup>3</sup>/yr from its three desalination plants. Qatar is proceeding with an aquifer recharge project for water security reasons as it currently has only two days of emergency water supplies [14,15].

For Bahrain, Fichtner [8] reported that the two main desalination plants, the Hidd Power and Water

Plant and the oldest in the country Sitra Plant produced in 2008 about 191 Mm<sup>3</sup>/yr. An additional 26 Mm<sup>3</sup>/yr was produced from saline groundwater, instead of seawater. For Iran the total reported for 2009 desalination contracted capacity stood at 115 Mm<sup>3</sup>/yr, used primarily for industrial purposes [8].

Upon adding the 1,750 Mm<sup>3</sup> of desalinated water produced by the UAE [3]; half of the 2,780 Mm<sup>3</sup>/yr by Saudi Arabia [9]; 890 Mm<sup>3</sup>/yr by Kuwait [12]; 453 Mm<sup>3</sup>/yr by Qatar [15]; 191 Mm<sup>3</sup>/yr by Bahrain, and 115 Mm<sup>3</sup>/yr by Iran [8] the total desalinated water produced in the Arabian Gulf can be estimated in 2013 to be about 4,800 Mm<sup>3</sup>/yr. Using a ratio of 1:2 of desalinated water to brine discharge returns a volume of about 10,000 Mm<sup>3</sup> of brine discharged annually in the Arabian Gulf. Dilution of the brine is not assisted by the slow circulation in the Arabian Gulf, which has estimated residence times of between 2 to 5 years [16], and locally, in the vicinity of discharge areas and along the coast salinity spikes have been reported [1].

### 3. Threats and environmental concerns of desalination

A major threat to desalination operations in the Arabian Gulf consists of contamination of the sea water by hydrocarbon operations and heavy tanker traffic, which had reached 165,206 ship port calls and 50,700 ships passing the Strait of Hormuz in 2016 [17], leading to accidents during transport of oil (The National, April 3, 2017: Oil spill leaves UAE coastal waters and beach coated in crude, <https://www.thenational.ae/uae/environment/oil-spill-leaves-uae-coastal-waters-and-beach-coated-in-crude-1.71243>). Illegal tank washing [18] and spills during wars in the region [19] also endanger the quality of sea water. Major oil spills since 1980 in the world included the BP 2010 oil spill in the Gulf of Mexico with 205 mi gal of oil; the 1991 Kuwaiti Oil Field and the Kuwaiti Oil Lakes with 42,000 and 2,100 mi gal, respectively; the 1983 Nowruz Field Platform in the Arabian Gulf oil spill of 80 mi gal; the 1992 Fergana Valley in Uzbekistan oil spill of 88 mi gal, and the 1989 Exxon Valdez accident in Alaska with 11 mi gal, among others [20].

In addition, chemical pollutants enter sea waters in the Gulf through atmosphere-sea water interaction and air deposition from diverse pollution sources [21,22]. This includes multiple cement factories inside the cities while construction takes place (figure 1); raw sewage discharges, especially from the Iranian side, or from not-up-to standards sewage plants, pollution from the Shatt-al-Arab River at the northwest part of the Gulf [23], and red tides [24].



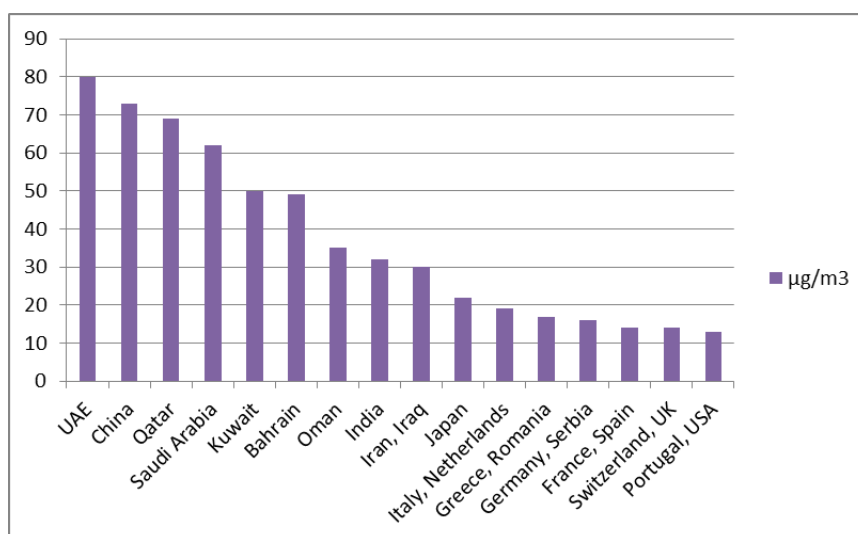
**Figure 1.** Cement factory inside a residential area of Abu Dhabi, UAE (photo by the authors).

Aerosols and desert dust (figure 2) are major contributors to the poor air quality in the region [19] and transport pollutants to the sea. The 2015 World Bank report on global environmental indicators placed the United Arab Emirates at the top of the list of countries in terms of PM<sub>2.5</sub> pollution with 80 µg/m<sup>3</sup> (micrograms of pollutants per cubic meter), followed by China with 73

$\mu\text{g}/\text{m}^3$ , and all Gulf countries, with the exception of Iran and Iraq, above India that had  $32 \mu\text{g}/\text{m}^3$  [25]. The chart in figure 3 shows the  $\text{PM}_{2.5}$  pollution of the eight countries along the Arabian Gulf compared to China, India, Japan, USA, and several European countries, the latter all falling within the range of 12 to  $19 \mu\text{g}/\text{m}^3$ .



**Figure 2.** Dust storm, April 2015, in Abu Dhabi, UAE (photos by the authors).



**Figure 3.**  $\text{PM}_{2.5}$  pollution in the eight nations along the Arabian Gulf, relative to China, India, Japan, USA and to several European countries.

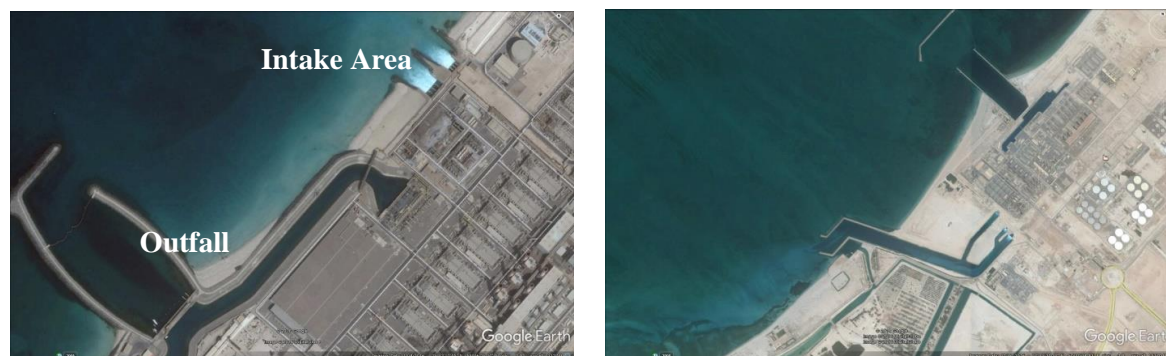
Anthropogenic  $\text{NO}_x$  emissions are also very high in the Gulf region. Iran with 1,291, UAE with 971, and Saudi Arabia with 955 Gg  $\text{NO}_2$ /year lead  $\text{NO}_x$  emissions in the area, which total 4003 Gg  $\text{NO}_2$ /year compared to California, which with the same population and area has 1,320 Gg  $\text{NO}_2$ /year [21]. Road traffic, shipping, and power generation (required for desalination operations, among others) are the leading sources of  $\text{NO}_x$  emissions in the region. In that respect the massive power and desalination plants located in the Gulf are partially responsible for this type of air pollution. Recent studies have also indicated that the European Union's limit of 40 ppbv for ozone pollution at which damage to crop and natural ecosystems takes place is exceeded throughout the year in the Gulf region, and the 1-hour health hazard limit of

80ppbv is exceeded most of the summer [21].

Lately, it has been observed that very small particles of plastic with diameter less than 5mm, microplastics, emanating from road traffic and other sources have been deposited into the sea transported by air currents, desert dust etc. Sources of microplastic include both primary sources from their use in aquaculture and fisheries, agriculture, construction, cosmetics, textiles, packaging, land transportation and shipping, and secondary sources due to weathering of larger plastic on land and beaches. Microplastics apart from floating onto the sea surface have been seen to be distributed along the water column and even to be embedded in sea sediments [26,27]. Wastewater treatment plants although removing most of the microfibers through sedimentation and biological filtration allow some quantities of microplastic in the effluent that is released in the water bodies [28].

Enclosed seas with stagnation points (Mediterranean Sea) and areas in oceans exhibiting gyre circulation (western North Atlantic and eastern North Pacific) are the dominant locations where microplastics and other contaminants have been reported to concentrate on surface and deep waters [29]. Given that the Arabian Gulf contains low energy areas, its long residence time, and the tidal vertical mixing taking place areas northeast of Qatar and southeast of Kuwait are prime locations for microplastic accumulation. In addition in the Gulf of Oman, where several UAE desalination plants are located, a double gyre circulation exists and hence the potential is high for the concentration of contaminants, nanomaterials, and microplastics. Other relevant to Gulf countries locations that have been seen in other parts of the world to have high concentrations of microplastics are ports and mangrove areas, the latter being dominant in the coast of Abu Dhabi, UAE.

Limits to desalination are imposed by the physicochemical, climatic, and hydraulic characteristics of the Arabian Gulf. The Arabian Gulf is a shallow sea with maximum depth less than 100 m, maximum width 338 km, and length to its northern coast of about 1000 km. It is replenished by ocean water through the narrow 56 km-wide Strait of Hormuz. Its salinity ranged from 39 ppt to 43 ppt westward of the coast of Abu Dhabi in the early 1990s [16], whereas recent measurements put its average TDS at 46 ppt [1,8].



**Figure 4.** (a) DEWA Jebel Ali power and desalination plant complex. (b): ADWEC Taweelah power and desalination plant complex (Google Earth).

Of particular concern to the marine environment is the brine discharge, which by 2050 is estimated to reach 2% of the volume of the nearshore waters [30]. Figure 4 illustrates the brine discharges from two major desalination plants in UAE, the first to the left in Dubai, and the second to the right in Abu Dhabi. The DEWA Jebel Ali power and desalination plant (figure 4(a)) is the largest in the UAE, inaugurated in 2013 with a capacity of 2,060 MW and 140 million gallons of water per day. A 237 million US Dollar contract awarded in March 2018 will augment it with a new reverse osmosis plant that would expand its production capacity to 305 million gallons of desalinated water per day [31]. The ADWEC Taweelah power and desalination plant complex (figure 4(b)) consists of three plants, the first one (named Taweelah A1) with net power generation capacity of 1,593MW and net water



production of 84MIGD (Million Imperial Gallons per Day), the second (Taweelah A2) with net power generation capacity of 710MW and net water production of 50MIGD, and the third (Taweelah B Plant) with net power generation capacity of 2,053MW and net water production of 160MIGD [32].

Recent UAE studies [1] have estimated that the combination of desalination and energy production, which is the case for most Gulf facilities, has increased sea water temperature by 7-8°C affecting dissolved oxygen content. Environmental impacts of desalination are extensively summarized by Bleninger and Jirka [33] and include chlorine by-products [34], antiscalants and copper in reject streams [35].

#### 4. Summary and conclusions

The Arabian Gulf countries depend very strongly on desalination to meet their water needs for sustenance of the population and growth of their economies. In order to meet increasing water demands most of them have more than doubled their production capacity in the last ten years, and currently four of them are in the top fifteen list of construction orders for desalination plants in the near future.

Limits to the expansion of desalination are placed by the physicochemical characteristics of the shallow, high-saline, low-circulating Arabian Gulf and the combined actions of all Gulf countries that depend on their fresh water from the same source. The effect of desalination on the Arabian Gulf, especially on the coastal areas, has already been noticeable in TDS measurements.

Less attention to the direct sea water pollution, caused by brine and chemicals and metals in the reject streams, has been paid to the indirect effects of desalination. Large power and desalination plant complexes are contributors to the poor air quality of the region and with the release of nitrogen oxides, among others, they may be assisting in the creation of photochemical smog over some of the larger cities in the Gulf area.

Threats to desalination operations in the Arabian Gulf include contamination from hydrocarbon operations, heavy tanker traffic, illegal tank washing, raw sewage discharge, pollution from the Shatt-al-Arab River at the northwest part of the Gulf, red tides, and the transfer of pollutants from land.

Low energy areas in the Arabian Gulf and the Gulf of Oman constitute areas where emerging pollutants, especially microplastics, may be accumulating. The existence of microplastics in the marine environment of Qatar that was recently reported necessitates that UAE monitors the situation in the Gulf of Oman, where several UAE desalination plants are found. In addition, the effluent released by wastewater treatment plants, needs to be assessed in terms of its microplastic content.

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