# Global Water Desalination: A Comparison Between Saudi Arabia and The United States of America

by

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# Global Water Desalination: A Comparison Between Saudi Arabia and The United States of America

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## Abstract

According to the United Nations (UN) report in 2018, there are more than 2 billion people who live in areas of high water stress and this number is expected to increase significantly by 2025. Saudi Arabia (SA) experiences particularly acute water stress because of its limited access to freshwater. On average, the United States of America (US) experiences less water stress compared to SA. The US southwest, Midwest, parts of California and Florid bear a bigger burden of the water shortage in the country. Nevertheless, both countries called for alternative sources of freshwater. Desalinated water represents the most efficient freshwater resource, particularly for countries that undergo water shortage. As of 2018, about 17,000 desalination plants were producing virtually 35.8 billion m3/ year (95.4 million m3/ day) to more than 300 million persons in 177 countries, of which, SA is the lead producer at approximately 12 million m3/ day of desalinated water, accounting for 22% of total global desalinated water demand. SA is followed by the US, which is leading the high-income western countries, with a production of 10.6 million m3/ day from desalinated water. Currently, both countries are exercising unprecedented growth in the production of desalinated water.

Although freshwater security stemming from desalination has a wide range of public health benefits, it remains controversial because of its potential economic and environmental impacts.

Mostly the desalination concerns are centered around cost efficiency, intake water, and the hypersaline concentrate (brine) production. With increasing water demand and water scarcity, it is projected that the desalination market will grow rapidly in the future. The decision regarding whether or not to adopt desalination is complicated. Freshwater availability, type of technology used, feedwater salinity, and plant size are the main determinants. Implementing strategies to manage brine discharge coupled with continuous improvement to the technology used is crucial to prevent the negative impacts on the environment while having cost-effective water desalination.

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# 1.0 Introduction

People who live in areas that rely on “conventional” sources of water (e.g. rain, river water or aquifers) as a major water resource are in danger of water scarcity, either through shortage or lack of access to clean water [8]. According to a Food and Agriculture Organization (FAO) of The United Nations (UN) report in 2018, there are more than 2 billion people who live in such areas that undergo high water stress [1]. The report has defined water stress as the proportion of all freshwater withdrawal (including surface freshwater, renewable groundwater, fossil groundwater) to the total available renewable freshwater resources. To measure this indicator, FAO has to determine the level of water stress by calculating how much freshwater has been withdrawn in relation to the whole freshwater resources that are available.

As the world population grows, water demand increases and exacerbates water scarcity. It has been suggested that 40% of the world population experiences extreme water scarcity, and this is estimated to rise to 60% by 2025 due to climate change [2]. The world map below shows the distribution of the physical water scarcity in several regions [Figure 1]. It is clear from the map that the Middle East and North Africa (MENA), Iran, part of India and the west coast of the US are suffering from high water scarcity.

Only 2.5 % of the earth’s water is fresh, most of which is located in the ice caps and the glaciers [3]. The remaining percentage of the freshwater that is available for human consumption is between 0.5 and 1.0 %, or 0.02 to 0.025 % of the total water resources that are available on the earth. Unconventional water-resource techniques (e.g. imported water from drains, wastewater recycled, or desalinated water) have been implemented to close the gap created because of growing freshwater demand [4]. The desalination of seawater represents the most efficient alternative water resource. This essay suggests that each planned desalination facility includes rigorous evaluation of the local demand, energy requirement, feedwater type, technology available, brine treatment methods, and location to limit the economic and environmental burden of desalination; ultimately, to obtain the optimum cost-effective process.

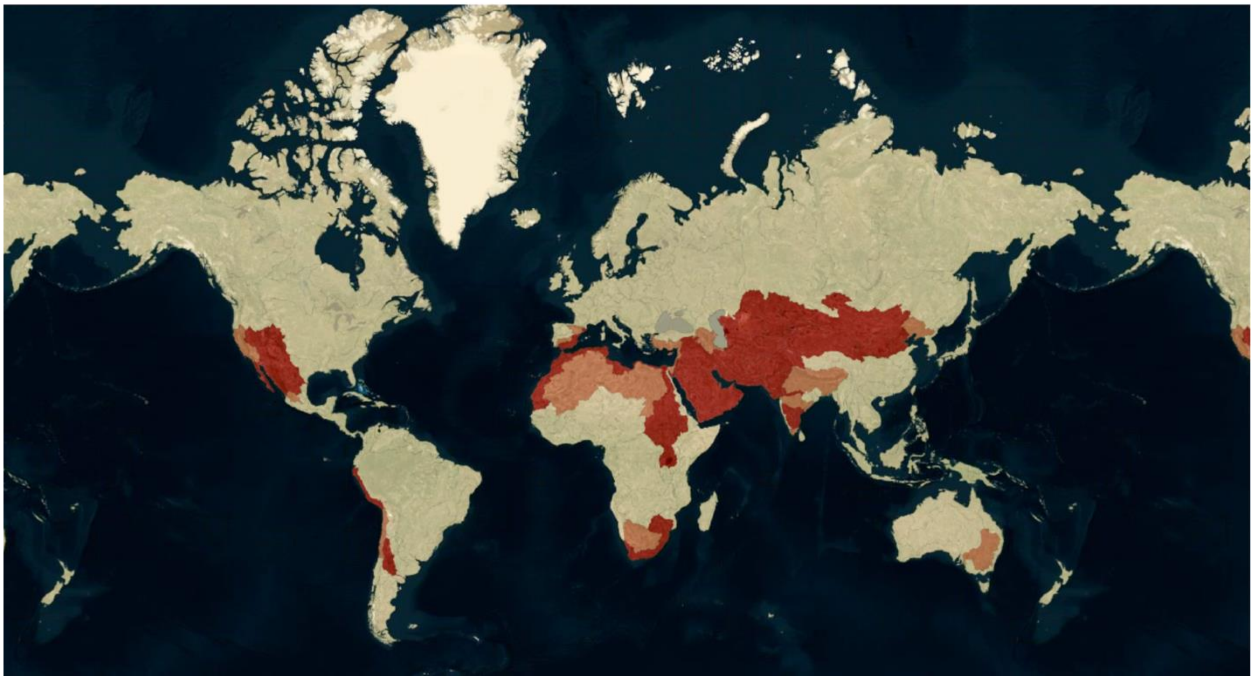

**Figure 1 Global Distribution of physical water scarcity in 2020. Generated from AQUASTAT - FAO's Global Information System on Water and Agriculture. https://data.apps.fao.org/aquamaps/ Data accessed [10/29/2020]**

Desalination is the process of removing the excessive amount of salts and other chemicals from seawater to become suitable for human consumption and other uses [5]. This process is aimed to comply with the Guidelines for Drinking-Water Quality (GDWQ) written by the World Health Organization (WHO) to reduce salt concentration below 500 ppm [6]. Desalination of both brackish water (1,000 – 10,000 mg/l of salt) and seawater (has a range of salinity between 30,000 and 44,000 mg/l) gained attention for several decades [7]. As of 2018, about 17,000 desalination plants were producing virtually 35.8 billion m3/ year (95.4 million m3/ day) to more than 300 million persons in 177 countries [7][8]. It is expected that the production capacity will reach 70.1 billion m3/ year by 2050 [9]. Most of the countries that are predominantly using desalinated water are high-income countries with limited conventional water resources. The Middle East and North Africa (MENA) countries represent approximately half of the global share of desalination capacity (48%) [8]. Saudi Arabia remains the largest producer of desalinated water that accounts for 22% of total desalinated water demand [8]. The USA production comes second with 14% of the global water desalination. Countries like Qatar and Kuwait rely exclusively on desalinated water for almost 100% of their water sources. Table 1 below shows the top 10 producers of desalinated water and their global share. On the other hand, countries with low income (e.g. Southern Asia and sub-Saharan Africa) contributed negligibly toward global production with less than 0.1%.

**Table 1 Top 10 countries employing desalination. Adapted from Nair, M., & Kumar, D [10], Jones et al. 2019 [8] and SWCC Report 2019 [16].**

| No. | Country | Total capacity Million (m3/day) | Per Capita %m3 (1000 people / d) | Global share % |
|---|---|---|---|---|
| **1** | Saudi Arabia | 12 | 353 | 22.0 |
| **2** | USA | 10.6 | 32.3 | 14.0 |
| **3** | UAE | 7.5 | 773 | 12.5 |
| **4** | Spain | 5.3 | 112 | 8.9 |
| **5** | Kuwait | 2.5 | 625 | 4.2 |
| **6** | China | 2.4 | 1.7 | 4.0 |
| **7** | Japan | 1.6 | 12.7 | 2.6 |
| **8** | Qatar | 1.4 | 500 | 2.4 |
| **9** | Algeria | 1.4 | 32.5 | 2.3 |
| **10** | Australia | 1.2 | 48 | 2.0 |

The public, scientists, and governments are all looking for cost-effective and environmentally safe desalination practices to save the earth from water scarcity.  Gulf countries are the leading regions to produce fresh water desalination per capita due their limited sources of fresh water and fewer populations compare to other developed countries. Since SA and the US are the top two countries employing desalination, this essay aims to examine their approaches to gain insights into applications, challenges, solutions and prospects.

## 2.0 Types of Desalination

The desalination of water is accomplished through several technologies, the two major methods that have been widely used being thermal and membrane-based [8]. Table 2 includes a synopsis of the advantages and limitations of the two major techniques available. The thermal-based process consists of evaporation of saltwater using thermal energy (heat) followed by collection of the de-salted condensate to produce fresh water [11]. For decades, thermal-based technology was widely used in Arabian Gulf countries where the abundance of fossil fuel was available to generate the required thermal energy.

**Table 2 Synopsis of advantages and limitations of thermal and membrane technologies.**

| | Thermal | Membrane |
|---|---|---|
| **Pros** | ○ Non-membrane processes<br>○ Fewer amounts of fouling<br>○ Higher water quality<br>○ Low maintenance cost | ○ High-water permeability<br>○ High salt rejection<br>○ Energy-efficient<br>○ Low energy cost |
| **Cons** | ○ Require more energy; more expensive<br>○ Lower recovery rate<br>○ Larger amount of higher temperatures brine<br>○ Require special materials to treat corrosion and fouling | ○ Pre-treatment is required<br>○ Excessive membrane fouling<br>○ High maintenance cost |

The most predominant thermal technologies are Multi-Stage Flash (MSF) and Multi-Effect Distillation (MED) [12]. The MSF works as a series of stages that uses heated steam and condensers to separate water from salt. The heated steam heats up the saline water, and the pressure decreases in multiple stages, thus the water flashes into cooled steam [13]. Brine, on the other hand, builds up after each stage and settles at the bottom.

Similarly, MED, uses a similar technique of multiple vessels that relies on heated steam and condensers to treat seawater [12]. The major difference that distinguishes MED from MSF is the evaporation and heat transferring methods. In MED, evaporation comes when feedwater contacted a heat transfer surface. While on the contrary, the MSF heating processes occur only withing the tubes.

The membrane-based technology, on the other hand, forces saltwater through the selected membrane to pass freshwater and retain suspended salts and other solids. The membrane technology for water treatment includes Reverse Osmosis (RO), microfiltration (MF), ultrafiltration (UF) and nanofiltration (NF) [8]. The separation mechanism in MF, UF and NF is mainly the size exclusion whereas RO uses a different physical phenomenon (diffusion). RO separates the feedwater into two streams using membranes, high salinity concentrate water and purified water is to retain the salt [14]. However, the major difference among these technologies are the pore size. Table 3 summarizes the differences between the common membrane processes. Hence RO, by far, known as the more selective membrane-based technology to clean up all the contaminations.

**Table 3 The difference between microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and Reverse Osmosis (RO)**

| | MF | UF | NF | RO |
|---|---|---|---|---|
| **Pore size** | 50 nm – 1 µm | 5 – 20 nm | 1 – 5 nm | Non-porous |
| **Elements retained** | Colloidal particles, bacteria and suspended solids only | Fine colloids and viruses in addition to what MF can remove | Organic matter and Ions such as sodium and chlorides | Most of the dissolved elements including ions |
| **Application** | A pre-treatment step for another water treatment facility | Mostly commercial sector for drinking water | Pre-treatment for RO | Mostly seawater desalination to produce drinking water |

RO is the most common desalination technology used for seawater and brackish water treatment worldwide due to its high-water permeability, salt rejection, energy-efficiency, and low energy cost compare to other technology [14]. The RO advantages allow for high possibilities of keeping the environment clean, reducing waste and therefore fulfilling the general public health standard. Compare to thermal processes, RO have a higher recovery rate hence produce less brine. Brine, the high concentrated salt, is being diluted before returning to the sea to avoid harming the ecosystem. More details about brine management and disposal methods are further discussed in the water desalination impact section below.

Currently, desalinated water produced from RO represents 69% of the world production followed by the two major thermal technologies MSF and MED as 18% and 7%, respectively [8]. These three technologies account for 94% of desalinated water produced in the world. Although RO has a wide range of benefits, membrane fouling remains a major challenge. Fouling is the buildup of undesired deposits on the membrane surface or when the pores of the membrane are clogged causing reduction of permeation flux and salt rejection [14, 41]. Membrane fouling could significantly affect the quality of filtration and production as well [14]. The average lifetime for a membrane is estimated to be between 2 to 5 years before disposed into a landfill or incinerated to produce energy [41]. Feedwater type, pretreatment, cleaning and maintenance are factors affecting membrane lifetime. For example, In Greece SWRO plants study suggested that the RO membrane could last 5 years if pre-treatment of feed water is chosen properly to remove contaminants from water [42]. If pretreatment is disregards, more cleaning will be needed which could reduce the membrane lifespan. Overtime, RO production decreases if fouling occur. Consequently, more energy, maintenance and cost are required to overcome the issue resulting from the membrane fouling.

## 3.0 Kingdom of Saudi Arabia

Saudi Arabia is located on the far west of Asia constituting a large proportion of the Arabian Peninsula. SA has population of 34 million within an area of 2,149,690.0 km$^2$ [15]. By 2019, approximately 33 water desalination plants larger than 1000 m$^3$/day produced 12.0 million m$^3$/day in SA [16]. For more than 100 years, SA has undertaken water desalination through distillation. A coal–actuated mechanism was invented to distill water, generating steam from the re-purposed hulls of wrecked ships. The mechanism was installed on the Red seashore and called “Al Kindasah” derived from the English “condenser” [17]. In 1928, Saudi Arabia's king ordered two separate distillation plants to be built on the west coast, near the Red sea. Each plant had to produce 230 m$^3$/day of freshwater, necessary because of the limited access to drinkable water for pilgrims and visitors to Mecca, the holy city. In 1970, another water desalination plant was built in Jeddah to produce 5 million gallons of freshwater per day. In September 1974, The Saline Water Conversion Corporation (SWCC) was established by royal decree to supply all the regions in the Kingdom with desalinated water [17]. SWCC was also assigned to consolidate natural water resources, including groundwater, and to build desalinated water plants with the best available technology.

Saudi Arabia has been successful in desalination efforts, shown by their accomplishments. In 2019, SA was awarded two certificates by The Guinness Book of World Records [16]. One for SWCC, the largest desalination company in the world producing 5.6 million m$^3$/day for freshwater. The other one for, Jubail desalination plant, the largest facility in the world with 1.4 million m$^3$/day. During these decades, SWCC has increased its water production more than 90 times to produce 1,883.6 million m$^3$/year in 2019 [16]. Figure 2 shows the annual increase of desalination production in SA by location since 2012. As illustrated in the line graph, the annual production has significantly increased from 1,070.9 million m$^3$/year in 2016 to 1,883.6 million m$^3$/year in 2019. This 64% increase in production is due to several new desalination facilities being introduced to the market.

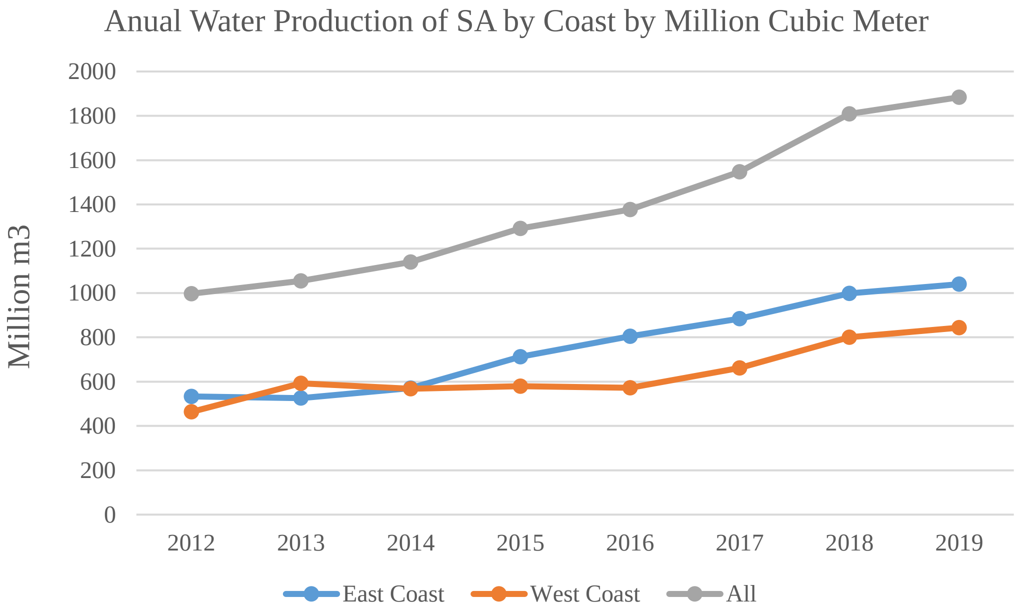

**Figure 2 The annual desalination production of SA by Coast by million m3. Data were obtained from SWCC annual report 2019 and translated from original report in Arabic (16).**

As of 2019, Saudi Arabia owned and operated 33 water desalination plants spread out over the two coasts – 8 plants on the east producing 55.2% of the overall annual output and 25 plants on the west produce the remaining 44.8% [16]. Plants that are located on the west coast, near Mecca and Jeddah, are the oldest. Recently SWCC shut down three major plants – two of them are located on the west and one on the east coast – because of their environmental impacts and the availability of better technology that will save money and energy. Like the rest of the world, SA uses RO as its major desalination technology in 53% of its facilities; however, thermal technologies like MSF and MED are still prevalent, accounting for 43% [Figure 3.A].

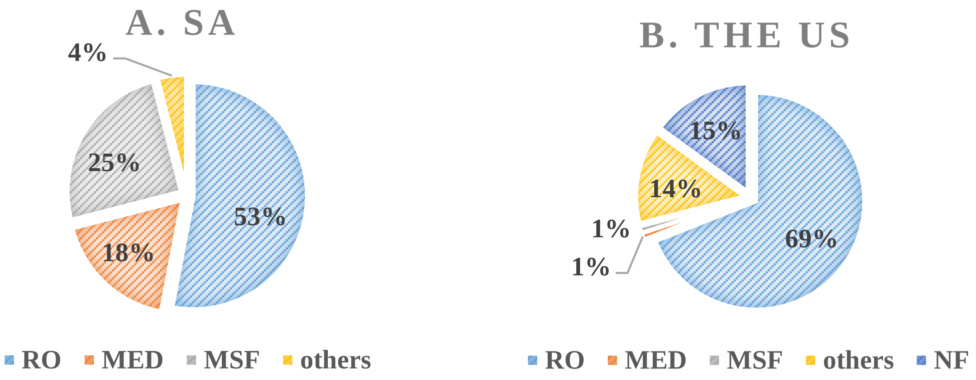

**Figure 3 A. and B. Show the distribution of the technology used in the US and SA desalination. Data were obtained from SWCC annual report 2019 and translated from original report in Arabic [16][19].**

## 4.0 The United States of America

The United States, located in the center of North America with a population of 328 million, is the fourth largest country in the world [18]. By 2018, approximately 2240 water desalination plants larger than 1000 $m^3$/day produced 10.6 million $m^3$/day in the US [8]. Since 1952, the US has utilized water desalination with Congress passing the Saline Water Conversion Act (SWCA). Nearly ten years later, John F. Kennedy expressed his endorsement to expand the use of commercial desalination. He openly said, “desalination can do more to raise men and women from lives of poverty than any other scientific advance” (Kennedy 1961) [20]. In the 1970s SWCA established the Office of Water Research and Technology to fund advanced technologies in desalination. Between 1970 and 2010, The US underwent ups and downs of funding bills to support research and development of desalination technologies. By 2010, the US government had spent approximately $2 billion [19]. Unlike the rest of the world, around 50% of the water treated in the US is brackish, compared to the rest of the world treating seawater more frequently [19]. The desalination of brackish water is significantly easier than saltwater because it is less expensive and requires less treatment to be drinkable. Like the rest of the world, the most used desalination technology in the US is RO, which accounts for around 70% [Figure 3.A].

The US coastal regions, in particular, have been relying on imported surface water and groundwater for approximately 200 years. Recently, these valuable water resources have become unreliable due to continuous drought, unstable weather conditions and saltwater intrusion into water resources [21]. To overcome the expected shortage of freshwater, state authorities have supported many desalination projects to reduce the dependence on imported and groundwater [21]. The states of California, Florida and Texas, all coastal areas in need of sustainable freshwater resources, are the leading states for desalination plants. Recently, California has experienced a shift of opinion regarding water desalination due to increasing water scarcity and improvements in desalination technology. Previously, California had limited interest in desalination until the Carlsbad desalination plant opened in December 2015, the largest in the United States by far. This project cost $1 billion to supply the San Diego County residents with freshwater [22]. The Carlsbad desalination plant produces 190.200 $m^3$/ day to cover around 30% of the total water generated in the County [22]. Since then, California has remained interested in desalination for three reasons: growing water demand, improving technology, and increasing government subsidies. The California Department of Water Resources (DWR) has approved more than $100 million grants for environmental feasible and pilot studies and proposed to build 20 more water desalination facilities across the state [19][23].

Despite opposition focused on marine environmental concerns, California leaders are looking forward to building more plants in the near future. They stand behind the continuous improvement of advanced technology that will reduce the total cost while increasing the efficiency [19]. At the same time, the cost of other water resources is climbing.

## 5.0 Water Desalination Impacts

Water desalination, while helping countries to reliably provide freshwater, remains controversial because of its potential environmental and economic impacts. Like any other industrial process, the environmental and economic impacts of desalination must be recognized, managed and mitigated. Environmental consequences stemming from both intake of seawater and disposal of more concentrated, possibly heated, brine threaten fish, benthic communities and other coastal organisms. Whereas the economic impacts include the capital cost (one-time investment), operational and maintenance cost, energy cost and brine (waste) management cost. For the purpose of this essay, the following discussion focuses on three major concerns, namely, brine, intake (feed) water and cost, which all have significant impacts before, during and after the desalination process.

### 5.1 Brine

In general, as saline water passes through the desalination process to remove the salt, the plant produces freshwater (product) and the hypersaline liquid concentrate brine (waste by-product). Brine contains a significant amount of salt (predominantly NaCl), and varying concentrations of lead, iodine and nitrates [24]. The quantity and quality of the brine are dependent on the type of feed water, the technology used and the plant's maximum capacity [8]. The water recovery rate is estimated to determine the percentage of brine production by dividing the quantity of the freshwater generated by the quantity of feed water. In other words, as the quality of the feed water increases the recovery rate increases. Therefore, smaller quantities of brine are produced. To elaborate, if a desalination facility operates with a recovery rate of 0.6, that means 60% of the feed water converted into freshwater, and by default the remaining 40% becomes brine. Considering RO as an example, recovery rates as low as 42% are obtained with seawater compared to 65% for desalinating brackish water [8]. This relationship between technology used and feed water type should play a role in deciding whether or not desalination is efficient.

In 2018, the total brine production was 141.5 million m3/day worldwide [8]. More than 70% was produced from the Middle East and North Africa (MENA) followed by East Asia and Pacific at 10.5% while North America generated only 3.9% of the global share of brine production [Figure 4]. MENA's produced brine can be as much as 50% of its processed water, which means their recovery rate is low, indicating their efficiency is also low. The brine is either disposed back into the global water system (through surface water discharge, sewer discharge, deep water injection or other land applications) or treated to have a Zero Liquid Discharge (ZLD) [25]. ZLD systems are designed to achieve as high a recovery rate as possible (less brine production as possible) with a recovery rate between 95 – 99% [25]. Despite knowing that treating brine is a better option, many regions are still disposing the rejected brine into seawater. MENA is considered a hot region because they are responsible for 70% of total brine produced, the largest contributor being the Arabian Peninsula [Figure 4].

In Saudi Arabia, where all of the desalination plant are adjacent to costal water (Redsea or Gulf) and most are coupled with a power plant, the brine is blended with the cooling water from the power plant before is disposed to the sea through pipes to be quickly diffused in the seawater [16]. Both coastal and in land (>50 km from closest coastal line) concentrate disposal are applied in the US. The seawater discharge has been used either through wastewater or power plant facilities

[38]. More desalination plants are being built in California coast that dispose brine back to the seawater after mixing with wastewater.

National Pollutant Discharge Elimination System (NPDES) permits and state/local water quality laws have set several standard to regulate that the aquatic life conditions [39]. However, several uncertainties still exist. For example, there are no specific objectives to detail how brine should be treated or controlled, nor limits for elevated saline concentrations. Research and other experiments have suggested that salinity level should not exceed 2 – 3 spu (Practical Salinity Unit) since marine and benthic communities show some adverse effect on levels more than 3 psu [38]. Globally, there is no one-size-fits-all discharge strategy that is perfect for every type, size and technology available for desalination.

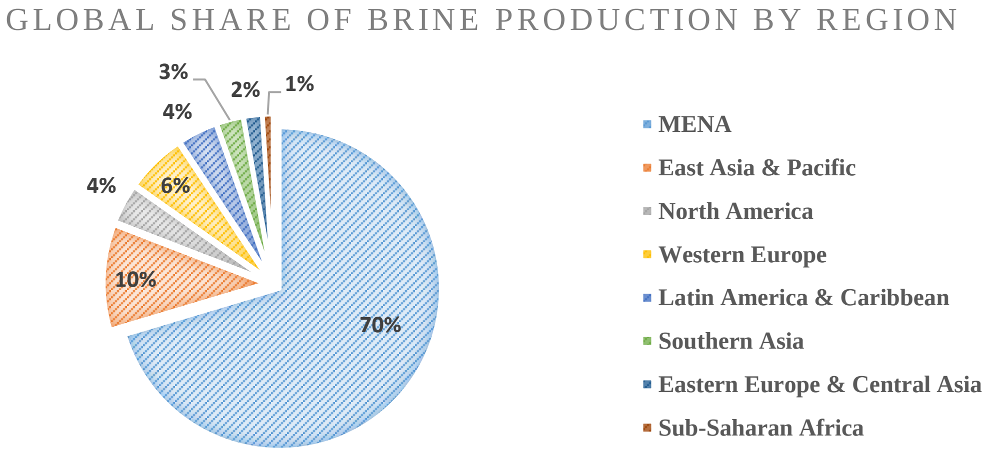

**Figure 4 Brine production by region and percentage of global share. Redrawn from (Jones et al. 2019) [8]**

The temperature of discharges is a factor that can be straightforward to manage and does not need to have uncontrollable consequences. Brine on the other hand is, without doubt, significantly toxic. Globally, this is not an issue (mixing/dilution in the ocean), but local marine environments can be impacted, with benthic ones being of particular concern because brine sinks in seawater.  For example, the Arabian (Persian) Gulf is considered a shallow semi-enclosed sea, with an average of 35 meters of depth and a maximum of 100 meters [26]. This shallowness increases the potentiality of forming salty water. If the mixing product was not appropriate and dispersed well, a bulk of saltier water can sink to the bottom resulting in killing organisms on the sea bottom due to a lack of oxygen. Other regions around the world might have less impact. Chile, for instance, is at a latitude that is subject to strong tidal action that would tend to promote mixing of brine discharges into the (bulk) Pacific Ocean [30]. As a result, coastal desalination plants install their pipes behind the tidal zones to reach maximum dilution and therefore less accumulation of salty concentrate in the benthic environment.

As discussed earlier, regions are varying on how much brine discharge could harm the local marine environment. Several research studies suggested that the discharges of brine harm aquatic life, air pollution and energy consumption [19][27][28]. They claim that an excessive amount of chemicals available could harm the benthic environment because of the accumulation on the seafloor. Another side effect is the change of the physical properties of the returning water due to higher temperature and salinity. On the other hand, fewer studies, mostly done on the Arabic Peninsula and Chile, recommended that the discharge of brine has little impact on marine ecosystem [29][30]. They have demonstrated that by; decreasing the temperature and salinity of the rejected brine with cooling water; and by reporting that most of the current technology used is Sea Water Reverse Osmosis (SWRO), and therefore, has lower temperature than thermal process. Controlling discharge salinity and temperature is doable and offset the major brine-related adverse effects. Both of the arguments have many variables to consider such as the feed water type available, the technology used, ocean/sea adjacent, dual-purpose with power/wastewater plants and cost-efficiency in order to reach a better decision. It is proven that untreated brine harm the aquatic life [8][25][36]. However, energy-rich countries who live in arid areas should make more effort on managing brine generation and treatment because they are in continuous need of desalination as a vital water source option.

## 5.2 Water Intake

The intake seawater is not just water and salt. The California Energy Commission described seawater in one of their reports thus “It is habitat and contains an entire ecosystem of phytoplankton, fishes, and invertebrates” [31]. During the intake process, two essentially unavoidable mechanisms threaten the aquatic life [19]. First, *impingement,* when larger organisms (e.g. fish or crabs) collide with intake screening mesh, they are killed. Chemical waste discharges of agents used to clean the screens represents a secondary undesirable consequence associated with impingement. Second, *entrainment,* when smaller species (e.g. algae, plankton or bacteria) pass through the intake screens to the plant during the operation, where they are also killed. Then, these remains are disposed back into the seawater to create an imbalance in the ecosystem. Several partial solutions to the effects of the impingement and entrainment on marine life have been applied in the industry.

In 2018, an environmental impact analysis was conducted by Dr. Thomas M. Missimer to address the consequences of impingement and entrainment and to propose solutions [32]. He explicitly said that the impingement and entrainment are manageable and can be reduced by several methods. Choosing the right location is crucial to reach lower ocean productivity levels because oceans tend to have lower productivity at greater depth; therefore, much less environmental disruption [32]. Moreover, subsurface intake systems are proposed to manage the impact of the impingement and entrainment, however, they cause other social effects such as reduced access to beaches and impairment of the visual landscape. Facilities that consider impingement and entrainment mitigation plans are desirable and any proposed site development plans should include assessment of local marine conditions before operation begins.

## 5.3 Cost

The cost of desalination remains unfixed. Factors contributing to the overall cost include energy demands, water distribution, environmental consequences and land use, to be balanced against the prevailing freshwater market price. One study summarizing the cost of operation for 25 RO desalination plants worldwide ranged the cost between \$0.45 and \$1.48 /$m^3$ for their first year of operation [19]. These numbers encompass the variation of operational cost due to consideration of feedwater salinity, technology used, energy demands, available subsidies, and any other environmental conditions that were addressed. Power generation is the largest single variable that contributes to the net cost of a desalination plant [19]. For instance, up to 50% of the total costs in RO installations are from energy demands. Thermal plants require even more energy, therefore, have higher costs. Since energy is a major cost burden for desalination, operators and governments have to make more efforts to reduce energy consumption. One of the current solutions that have been applied in SA and Israel is to build a power plant near the desalination facility to have dual-purpose facilities that produce freshwater and generate power at the same time [29][19]. The use of alternative energy sources (e.g. solar, wind, hydropower) in this manner is economically viable and environmentally friendly thus gained popularity. The International Desalination Association's (IDA) Global Clean Water Desalination Alliance has set a goal to reach 20% of newly or updated desalination to be powered by renewable sources by 2025 [43]. Saudi Arabia, for instance, has signed a $130 million contract to build a SWRO plant powered by solar energy producing 60,000 $m^3$/day [44]. Other countries such as UAE, Spain and India are implementing renewables large-scale trials before they completely applied.

Furthermore, other financial obligations include the cost of distribution to the end-users. RO processing, for example, leads to lower concentrations of calcium and carbonate, resulting in acidity which, in turn, promotes corrosion [18]. Post-treatment is required to ensure that any biological growth is within the range of drinkable water. Regrettably, these disinfection processes are costly. Other financial variables to consider are the final price affordability, environmental mitigation effort and management. In the end, the cost of operating desalination facilities depends on many factors, but energy production remains the largest contributor.

# 6.0 Discussion

The limitation of freshwater availability is the main driver of water desalination. The more water scarcity, the more countries are in need. The United Nations Food and Agriculture Organization (FAO) has reported 4 countries located in the Middle East and North Africa (MENA) who are experiencing more than 1000% water stress, namely, Saudi Arabia, Kuwait, Libya, and the United Arab Emirates, while the global average is only 13% [1]. According to the same report, the United States is experiencing 10 to 25% water stress. The water stress is calculated as the proportion of water withdrawal by all water resources available. Meanwhile, it is expected that the water stress will increase globally due to three main reasons: population growth, limited access to freshwater and global warming. This distress raises the high demand for desalination especially in areas that live through water stress. The top two countries who are employing desalination as a volumetric flow ($m^3/d$) are the Kingdom of Saudi Arabia and The United States of America. Although they are together producing more than 36% of the global share, they have different approaches and motivations.

In terms of water demand, Saudi Arabia is heavily dependent on desalinated water to cover almost 70% of people's needs; the other 30% comes from groundwater. The US desalinated water consumed is 4% of the total water used, mainly in the states of California, Florida and part of Texas. In terms of feed water type, seawater remains the prominent source of desalination followed by brackish water, at 61% and 21%, respectively. Much larger than the global average, SA is heavily reliant on seawater while the US uses brackish water as the major source for desalination. There is an advantage for producers to use brackish instead of seawater because of its lower salinity needing less treatment and ultimately lowering cost. Choice of feed water is mostly driven by availability of resources but ensuing sustainability can present a formidable challenge. Brackish water accounts for only 1% of the world's water whereas the oceans – saltwater – account for 97% of the water on the planet. Potential depletion, or change in salt content, of brackish water resources and the resulting impact on those particular ecosystems from which the brackish water is drawn might pose an imminent environmental threat.

In terms of technology, RO is by far the most used water desalination process worldwide. RO accounts for 53% of the applied technology in SA followed by MSF at 12%. Likewise, the US used RO for 69% of its desalination capacity, far from the second technology NF, which accounts for 15% only [Figure 3a and 3b]. RO is much better because of its overall higher recovery rate that generates less brine and, therefore, has fewer associated impacts on marine life. Unlike the rest of the world, the US uses NF as the second most applied desalination technology because of its lower operation and maintenance cost compared to RO.

SA still uses MSF and MED for 43% of its facilities mainly because they take advantage of dual-purpose installations that produce freshwater and generate power at the same time [Figure 3a]. The co-location between a power plant and a desalination facility helps to utilize the available resources. The cooling water from the power plant is used as a source for mixing water in the co-located desalination plant to reduce brine salinity before discharging. In addition, SA is transforming to RO because of its economic and environmental advantages [see table 3 above]. In 2020, SA was expected to operate 9 more desalination plants using RO to increase their RO desalination plants to represent for 62% of SA capacity.

## 6.1 Future of Desalination

By 2050, water scarcity is projected to affect 5 billion people [33]. The recent increase in the global desalination market indicates challenges and prospects. Challenges that hinder the growth of desalination include cost, energy and marine and environmental concerns. Approaches to addressing these existing challenges are centered around lowering cost and minimizing environmental consequences. One major approach to lower the cost is to lower the energy consumption or to find alternative renewable energy sources. Recently, the renewable energy prices are going down and expected to get less expensive as it gains more attention with advanced technology. Renewable energy can lower desalination cost in the long term as prices have been dropping and are likely to fall even more with advancing technology.

On the other hand, brine production is the major environmental impact-from desalination. Regrettably, most of the facilities dispose untreated brine into the ocean because brine management is relatively expensive. Adopting international environmental regulations will limit conventional disposal methods such as seawater discharge, surface water discharge, or deep well injection. The ultimate goal is to produce high quality of water with zero brine. An emerging treatment system like zero-liquid discharge ZLD can fulfil this goal [25]. Despite all the obstacles, desalination could be the most reliable source of water in the future.

## 6.2 Public Health Impacts

Water desalination has been introduced as a great alternative source of producing fresh water. However, if not treated as it should be, it might pose several risks to public health and the environment. These issues impact the finished water quality during the main processes of producing fresh water. To illustrate, the intake water is expected to have a high amount of total dissolved solids, petroleum or other microbial contaminants; the treatment stage depends on technology and is responsible for producing pretreatment and anti-fouling additives and disinfection by-products; failing to manage the distribution system could lead to an increased amount of corrosion control additives and bacterial regrowth [45]. It is critical here to ensure that each of the desalination stages is producing no potential harm to humans and the environment by implementing a regulatory monitoring system.

Drinking water is a rich source of essential chemicals that are vital to human health such as calcium, magnesium, manganese, sodium, fluoride, chloride, iodine and potassium. On the other hand, desalinated water lacks most of these elements due to the natural process of removing salts and other natural ionic contaminants [45]. The WHO has published Guidelines for Drinking Water Quality (GDWQ) and Safe Drinking-water from Desalination to establish rules for a safer desalination process. They confirmed that the desalination process removes several essential minerals (e.g. calcium, magnesium and fluoride) [46]. Yet, they have not proposed any minimum concentrations for most of them. A study compared 26 different locations in Israel pre and post implementing desalination found that half of the study population – who relied on desalinated water after – showed magnesium deficiency [47]. In addition, lack of fluoride in desalinated water is detected and linked to teeth decay [45]. Remineralization is introduced as a post desalination process to achieve desired water quality. It can be done by mixing the desalinated water with groundwater or applying carbon dioxide with limestone dissolution filters [45]. However, most desalination facilities do not add all the essential minerals. Hence more stringent regulation must be applied to ensure that finished water does no lack vital nutrients.

The main objective of desalination is to provide fresh and reliable water to people in need. Continued monitoring of the contaminants throughout the process is a key here. The ultimate goal is to minimize the contamination from the intake water, reduce or remove contaminants from the treatment process, then prevent further contamination during water distribution and storage until it reaches the consumer’s tap. WHO, EPA, and other international and local authorities should set health-based standards for contaminants of concerns such as disinfectants, bacteria and other trace metals. Post-treatment, in particular, it is important to test if the product water is demineralized and safe to drink. Moreover, community-based interventions aim to promote public health awareness of desalinated water benefits and safety. For example, home treatment technologies are used to further purify treated water. Access to safe, reliable drinking water is a human right, vital to human health and the main constituent of any public health policy and intervention.

## 7.0 Conclusion

Without necessary freshwater, we cannot survive. Therefore, in the long term, assuming there is no catastrophic population loss by other means, increasing the amount of freshwater available to us is unavoidable. As with any resource extraction (“mining”) operation, there may be no ideal method of achieving this completely free of negative environmental health and other impacts. Desalination is a powerful technology that could avoid/alleviate any potential public health crisis stemming from freshwater scarcity. Several diseases such as cholera, diarrhea, dysentery, hepatitis A, typhoid, and polio are associated with lack of access to safe drinking water resulting in 1.6 million mortality each year [36]. Other social and mental development issues have been identified among malnutritional children such as low IQ, slow learning and negative behaviors [37]. The water scarcity and its public health related issues are under increasing pressure from population growth and climate change. By 2025, more than half of the world’s population will be living in water stressed area [2]. The contribution of providing reliable safe drinking water to overall public health must be acknowledged in public and health policies.

Although desalination is tremendously beneficial, not every country can afford it. The vast majority of the countries who currently employ desalination are high-income or developed countries, because of its relatively high cost. This calls for extension of desalination to other middle- or low-income countries, specifically those who suffer from extreme water stress. Continued improvements in technology coupled with alternative renewable energy and water resources might help those countries to produce more freshwater. For example, solar-powered desalination is proving to be effective in low-income countries [34].

Most importantly, brine discharge must be addressed as it threatens the marine ecosystem if left untreated. Brine management can includes adding unpotable cool water to lower salinity and temperature, before discharge back into the ocean. The most well-known experienced practice would be to return the brine to the ocean in a manner that prevents accumulation, i.e. with efficient mixing. A much better approach is to adopt the Zero Liquid Discharge (ZLD) system of treating brine. The recovery rate of a facility that uses ZLD could reach 99%, meaning the brine production will be negligible. The ZLD process will result in solid dry product (directly disposed in a landfill or salt recover) and little amount of purified water that can be reused in the same facility for treatment purposes [40].

In countries with abundant energy sources and limited access to freshwater, desalination is vital and almost inevitable. Although the US and SA are the leading two countries employing desalination, it is difficult to compare them as they have completely different water resources, energy resources and different local demands. The lesson seems to be that new projects must be assessed on a case-by-case basis, with research needed to evaluate the whole picture of the environmental and economic feasibility of water desalination processes planned for individual locations. Most countries are hesitant to become reliant on desalination as a sustainable water source due to the high cost and associated environmental impacts. On the other hand, however, in times of scarcity, desalination could well be the most reliable water source available in many locations.

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