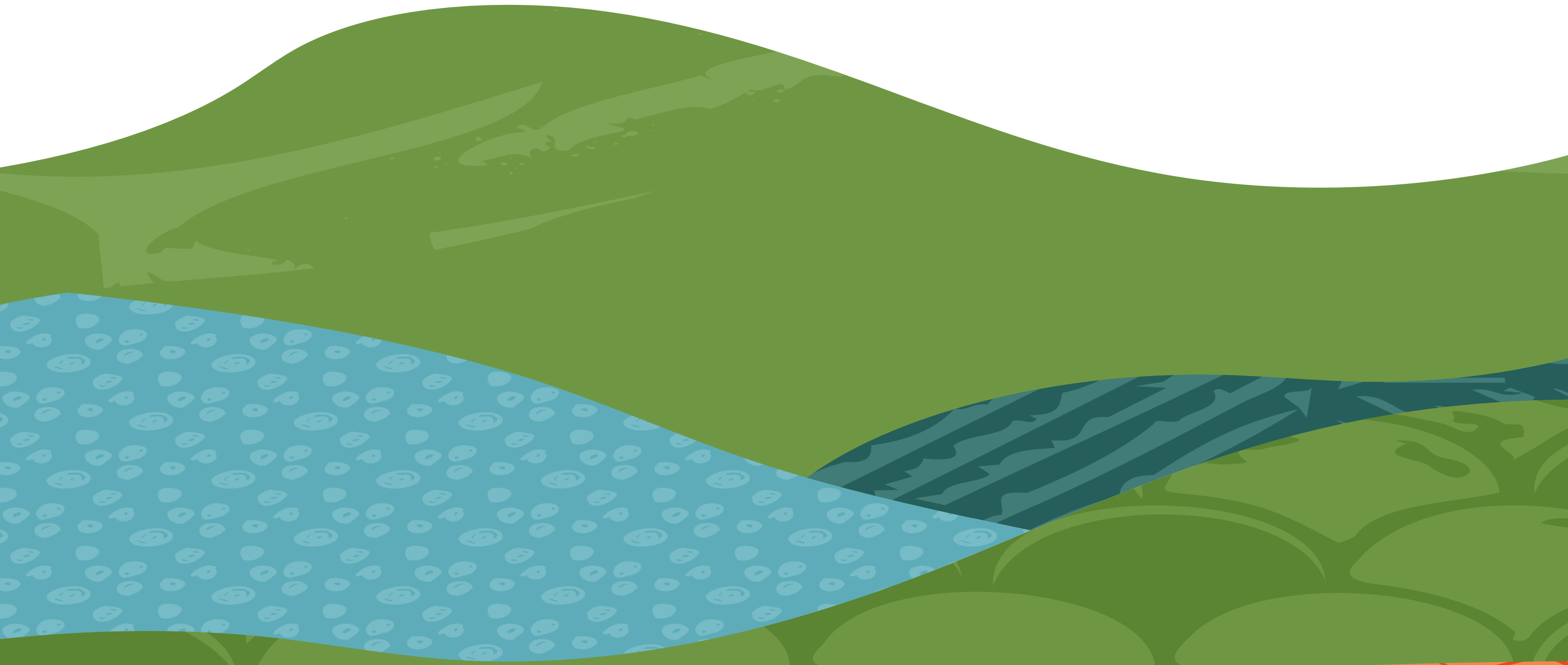
The Joint Water-Agriculture Ministerial Council

The Status, Treatment Methods, and Use of Brackish Water in the Arab Region

Draft for discussion



Food and Agriculture Organization of the United Nations

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Disclaimer

The report on "**The Status, Treatment Methods, and Use of Brackish Water in the Arab Region**" was prepared and revised by the Regional Office for the Near East and North Africa of the Food and Agriculture Organization (FAO) to support the Joint Technical Secretariat of the Joint Ministerial Council (composed of the Technical Secretariat of the Arab Water Ministerial Council and the Arab Organization for Agricultural Development) in implementing the recommendation of the High-Level Joint Water-Agriculture Technical Committee emanating from its meeting held on 18 October 2022 on the Use of Non-Conventional Water Resources in Agriculture.

Abbreviations

UN	United Nations.
FAO	Food and Agriculture Organization.
USGS	United States Geological Survey.
MCM	Million Cubic Meters.
BGW	Brackish Ground Water.
RO	Reverse Osmosis.
MSF	Multi- Stage Flash Distillation.
MED	Muti-Effect Distillation.
GCC	Gulf Cooperation Countries.
FO	Forward Osmosis.
FDFO	Fertilizer Drawn Forward Osmosis.
CP	Concentration Polarization.
DS	Draw Solution.
EDR	Electro-Dialysis Reversal
MD	Membrane Distillation
DCMD	Direct Contact Membrane Distillation
AGMD	Air Gap Membrane Distillation

Executive summary

Arab countries are located in one of the most arid regions in the world with very scarce freshwater resources. In most of the arid parts of the Arab countries, the good quality water is not available or is extremely limited. The majority of the total water supplies in Arab region are supplied from unconventional resources; brackish water and sea water, which are mostly saline, hence they require desalination to tackle the water scarcity and satisfy the increasing water demand especially for agricultural needs.

The direct link between food (agriculture) and water limits the potential of water-stressed Arab countries to promote food production. However, the prospects of using unconventional resources for irrigation, such as desalination, should be taken into consideration as a potential sustainable option for food production.

The high cost of desalination for irrigated agricultural crops is the main reason it is rarely used. It is necessary to analyze each factor (e.g. parts, chemicals, labor, membranes, and energy) influencing the costs of water desalination.

The concept of sustainability with its three pillars: economic, environmental, and social should be at the forefront of planning any food production initiative using desalinated water.

However, several adverse effects are associated with the desalination process and thus many technologies are being implemented to reduce their environmental effects. The use of renewable energy in the desalination sector is recommended as an impressive idea to reduce the environmental impacts and the associated huge energy costs.

Investments in infrastructure and R&D in innovative technologies and renewable energies can lower desalination costs and make it more sustainable in the future. While desalination can help reducing pressure on conventional water resources, they have negative environmental impacts.

Planning and developing the concept of brackish water desalination in Arab region should take into consideration the following aspects:

- Integration into the existing energy and piping infrastructure,
- Suitability of abstraction facility for providing constant quality and quantity of source water,
- Adequate pre-treatment as well as post-treatment,
- Measures to the process monitoring and maintenance,
- Corrosion and fouling prevention according to the desalination technology,
- Brine management (disposal/mineral recovery),
- Environmental concerns & environmental management
- Health & Safety (Public & occupational).
- Adequate financial and contract management.

In addition, deficiencies in planning can lead to unspecific tendering documents that increase costs due to additional claims of the plant manufacturer and time delays.

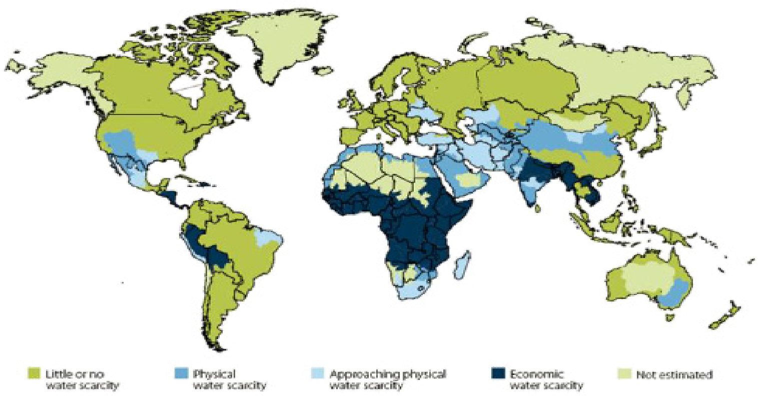
This report thoroughly discusses the brackish water desalination as a viable option of supplying fresh water for agricultural needs in the Arab region, a thorough investigation of the current situation of brackish water desalination and its uses in the Arab region is presented with future directions of utilizing emerging novel desalination technologies. The report as well discuss the socio-economic impact of brackish water desalination. Furthermore, it presents a proposed guideline for partnership between governmental organizations, private sector and all other parties of interest.

1. Introduction

1.1. Current water status in Arab Region

The Arab world stretches across well over 12.9 million square kilometers, including North Africa and parts of Western Asia. This is a region of highest water scarcity and arid climate with annual precipitation ranging from 100 mm to 400 mm. The total annual renewable water resources vary tremendously between the different Arab countries ranging between 0.1 billion m3 per year for Qatar and 75 billion m3 per year for Iraq. With a current total population of around 325 million and a very high growth rate of 2.7%; the per capita share of total annual renewable water resources has dropped well below the UN threshold for water poverty (1000 m3 per year) with most of the Arabian Gulf countries reaching per capita total annual renewable water resources below 200 m3 per year (El-Nashar et al., 2007). Moreover, Arab region suffers from physical water scarcity (Figure 1). A very promising option is to explore the possibility of using brackish water and seawater through techniques such as bio-saline agriculture. Saline groundwater is also a non-renewable resource, but it is less valuable than fresh groundwater, and more limited in its potential uses. Another viable option is desalination of the brackish water resources, either it is surface or ground water.

Figure 1: Global water scarcity.



(Source: Sewilam et al.2015)

1.2. Brackish water in Arab Countries

Brackish water is water occurring in a natural environment that has more salinity than freshwater, but not as much as seawater. Brackish water can be classified into two categories; surface brackish water and ground brackish water. The surface brackish water may result from mixing seawater (salt water) and fresh water together, as in estuaries, or it may occur in brackish fossil aquifers, as in ground brackish water. In Arab region, surface brackish examples are estuaries such as Shatt Al-Arab in Iraq and Nile Delta in Egypt, mangroves swamps, which mostly exist near coastal areas in North Africa and the Arabian Peninsula.

On the other hand, renewable groundwater resources in the Arab region are quite limited, estimated to be about 45 billion cubic meters annually, mostly in the form of shallow aquifers recharged from rainfall and different surrounding surface water activities (FAO, 2011). Non-renewable groundwater sources (or fossil groundwater) are available in relatively wide areas in the Arab region and at rather larger depths, particularly in the Sahara and the Arabian Peninsula, and are shared among many countries in the region (Al-Zubari, 2014). Due to over-abstraction, most of the groundwater reserve in the Arab region has deteriorated and has become brackish according to its salinity levels classification. Brackish water or briny water is water that has more salinity than freshwater, but not as much as seawater.

Brackish groundwater usually has dissolved solids concentrations between 3,000 and 10,000 mg/L (USGS, 2014). Brackish groundwater is directly used for purposes such as saline agriculture, aquaculture, cooling water for power generation, and for a variety of uses in the oil and gas industry such as drilling, enhancing recovery, and hydraulic fracturing. Brackish water aquaculture, also known as coastal aquaculture, is a rapidly expanding farming activity and could play an important role in the overall fisheries development and food security in the region. As such, brackish groundwater use is emerging as a high potential source of non-conventional water in the Arab water-stressed countries. Dawoud, et al (2019), summarized the brackish water reserve and use in Egypt, Tunisia, UAE and Yemen as follows:

In **Egypt**, recent studies are indicating that brackish water exist in all aquifer systems with potential of about 325 million cubic meters (MCM), however the use of this resources is still limited to small-scale agricultural activities and as drinking source for people and cattle. Recently, medium to large-scale farmers in the northern part of the Nile Delta started to transfer their agricultural land to fish farms based on brackish groundwater as a result of fresh water shortage (Attiya 2010).

In the south **Tunisia**, the authorities have been able to use reverse osmosis (RO) technology to convert brackish into drinking water. The government subsidizes the private sector to invest in desalination and considers this technology a key part of the long-term national water management strategy. Meanwhile, the government plans to increase public sector installed capacity from 44 MCM/day in 2009 to 50 MCM/day by 2030 (World Bank 2009).

In **UAE**, the brackish to saline groundwater aquifer potentially is about 650 billion cubic meters. At present the brackish groundwater use contributes with about 50% of the total water use. It is used directly for irrigation of farms and forests and for domestic sector after using membrane desalination technology (Dawoud 2014).

In **Yemen**, the usable brackish water for agriculture is about 300 MCM/year, mostly for irrigating some tolerant crops in the coastal areas. The total irrigated area by brackish water is about 38,500 ha. In highlands, brackish water is mainly used for rock cutting industry, In Taiz city, the brackish water with high salinity is used for water supply by mixing with freshwater for domestic use without any desalination (Dawoud 2019).

1.3. Water management

Water management is a process that includes planning, developing, management of available water resources, its distribution in equitable quantity and its quality. Over the past three decades, the water management in Arab countries has been strongly influenced by the idea of water resource management. This process advocated new approaches for the assessment, management, and development of freshwater resources which are represented by further development of non-conventional resources such as sea water and brackish water desalination as well as wastewater treatment (Jagannathan *et al.*, 2009). Arab countries are in either the arid or hyper-arid zone, depend on seasonal rainfall, have very few rivers some of which carry runoff from other countries and often rely on fragile (and sometimes nonrenewable) aquifers. Consequently, their economies are much more sensitive to the way that water is extracted, conveyed, and consumed than are the economies of other regions (Jagannathan *et al.*, 2009). Agriculture (which utilizes 80 percent–90 percent of water in most countries will not enjoy guaranteed water supply at past historical quantities. If there is increased variability in rainfall as has been experienced. Farmers perforce will have to change water usage patterns at a time when plant water requirements (Jagannathan *et al.*, 2009). Almost 85% of the water available in the Arab region is used for irrigation. Adopted irrigation methods are not sustainable and lead to overuse of scarce renewable water resources, which in turn results in soil salinization (Sewilam *et al*.2015*)*.

1.4. Brackish water uses challenges

There are many practical challenges facing the wide use of brackish water such as accumulation of salts in the root zone and salt impacts on the well materials and pump life time. Disposal of waste brine in case of desalination is also another challenge. Brackish water irrigation effect includes yield reductions due to salt accumulation, high cost of agricultural inputs due to the need for deeper plowing and pumping costs to cover the additional water requirement for leaching. However, in arid countries, it is not whether to use brackish/saline water to irrigate, but rather how best to use this "resource" in a sustainable manner and with as little detrimental effect as possible on the natural resource base (Dawoud, 2019).

As a first step, the feed source of the potential raw water source (brackish water) needs to be defined.

The following questions must be answered:

- Are there any available brackish water sources in the vicinity of the demand center?
- What is the quality of water, including temperature, that is planned to be abstracted from groundwater sources?
- How much water can be drawn from the wells?
- Are the capacities of existing wells sufficient, or do more wells need to be added?
- Are constant qualities of raw water provided, or do variations have to be considered?

Feed water quantity

After the amount of water to be produced has been specified, the following steps should be

carried out to evaluate the groundwater resources in the area quantitatively:

- Analyze potential sustainable yield of the aquifer to be exploited using groundwater contour maps (applying the flow-through method) and groundwater models if adequate data are available
- Conduct yield tests to verify the data and fill in gaps
- Analyze the long-term impact of water extraction by well piloting groundwater flow maps and groundwater models (the latest versions, respectively) should be used to provide an overview of available aquifers and the amounts of groundwater extracted from them.

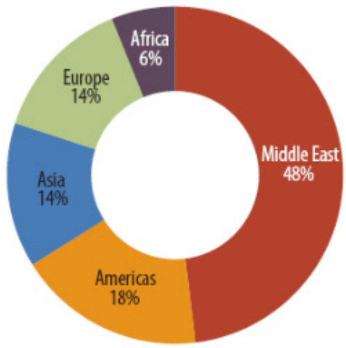
Feedwater quality

Next, the available water sources must be analyzed qualitatively. Having access to reliable water quality data is crucial in determining the treatment requirements of the plant. Existing data can often be found to get an idea of groundwater parameters in the area. However, field samples are still needed to be taken and analyzed to verify and fill in potential gaps in the data. The acquired data should then be verified by an ionic balance check. This is done to identify possible anomalies in the data of parameter concentrations.

For purposes requiring lower dissolved-salt content, especially drinking water, brackish water is treated through reverse osmosis (RO) or other desalination processes. The energy, materials and equipment used for RO desalination of brackish groundwater is far less than those used for desalinating seawater. RO desalination technology has recovery efficiency of 60 to 85% for brackish groundwater. Disposal of waste brine in case of using desalination with RO is also another challenge. Negative effects on the marine environment can occur especially when high wastewater discharges coincide with sensitive ecosystems. Improving recovery efficiencies to 90 or 95% would significantly reduce brine disposal volumes, extend the supply of brackish resources, and potentially reduce overall desalination costs. Meanwhile, with climate change, there are fears of serious impacts on social and economic stability, biodiversity and sustainable development in general. Lands and people using marginal water –brackish groundwater- are considered the most vulnerable. As the quality of this water becomes degraded, the impact on people and the environment can be dreadful (Dawoud, 2019).

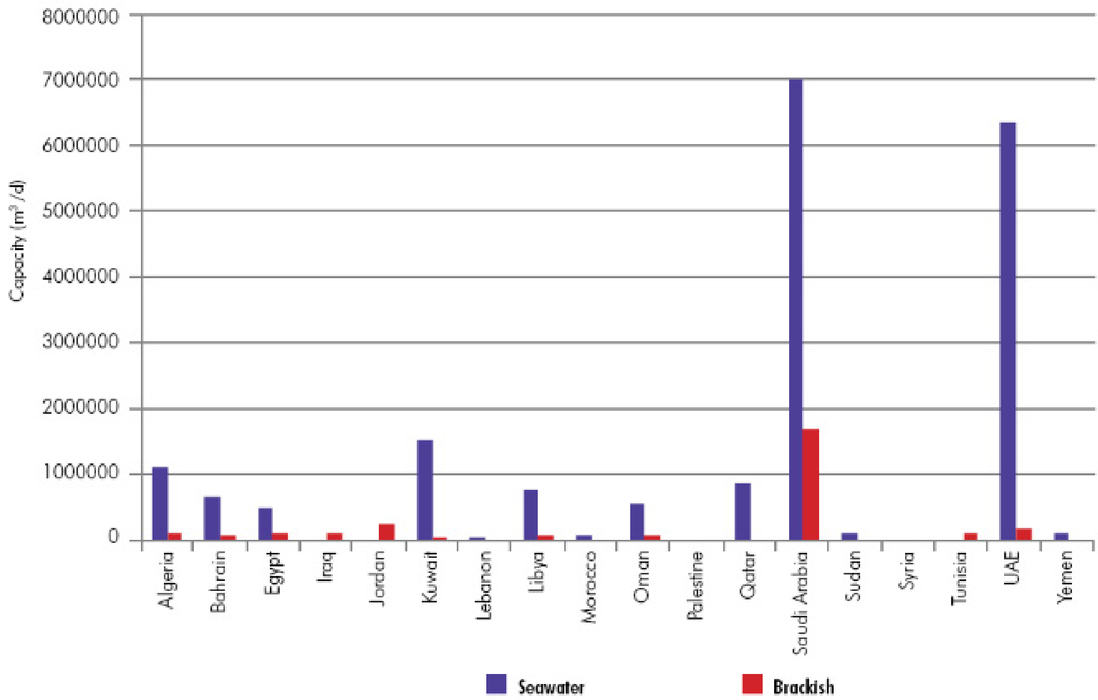
Current commercial desalination technologies have been developed through large- scale applications in a number of Arab countries (World Bank 2012). By 2007 approximately 54% of the world's desalination potential was installed in the Arab Region (Figure 2). Today, member countries of the Gulf Cooperation Countries (GCC), as well as Algeria, Libya, and Egypt are the largest users in the region, as indicated by their total cumulative contracted capacity of desalination plants (Figure 3). Worldwide production of desalinated water by 2007 was approximately 44 km^3 a year: 58% from seawater, 22% from brackish water, and 5% from wastewater (World Bank 2012). The high rate of annual increase in contracted capacity is expected to continue over the next decade. By 2016 the Arab region's share of global demand is projected to account for approximately 70% of the increased global capacity for desalination. Of the 15 countries with the largest conventional desalination installations, 9 are in the Arab region. Yet, this large expansion requires a review of present policies and practices including how to increase local capacity and knowledge.

Figure 2: Distribution of worldwide desalination capacity in 2007.



(source: World Bank 2012).

Figure 3: Contracted capacity of desalination plants since 1944 in m3/day.



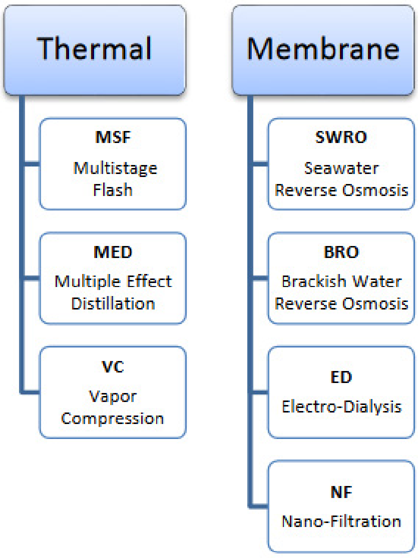
(source: Bushnak 2010).

2. Desalination technologies

2.1. Employed desalination technologies in Arab countries

Commercial technologies used today in desalination can be grouped into two categories, namely, thermal and membrane (Figure 4). Thermal technology separates water from minerals through evaporation-distillation using multi-stage flash technology; a very energy-intensive process. Multi- Stage Flash Distillation (MSF) desalinates by evaporating and condensing seawater in various stages each time functioning on lower pressure than the last. The heat required for the thermal part of the process is usually obtained from the steam from the water stream cycle of a power plant. MSF is a proven technology, even with high levels of salinity, and can be built to a very large scale. As thermal desalination technologies are most common in these countries, being the older technology, Gulf Cooperation Council (GCC) countries tend to co-generate electricity and water in large plants in order to increase fuel efficiency (Bushnak 2010).

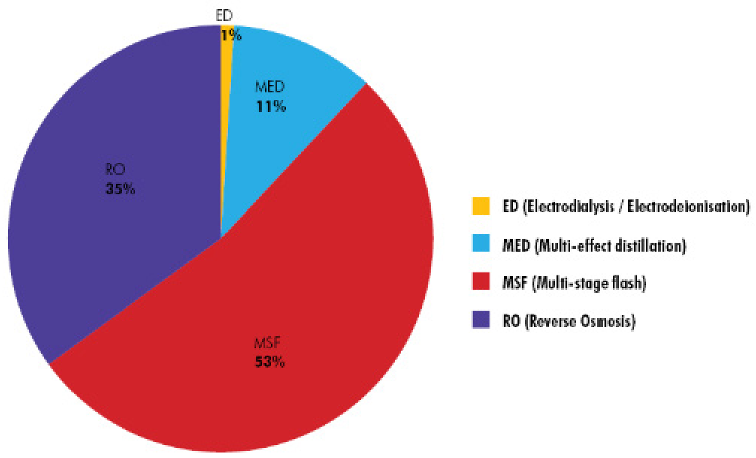
Figure 4: Categories of current commercial desalination technologies in Arab region.



(source:Bushnak 2010)

On the other hand, membrane processes, mainly, Reverse Osmosis (RO) pressurize saline water through membranes that exclude most minerals (Buros 1990). Usually, membrane technologies are used when electric power is accessible or when feed water is brackish water (World Bank 2012). In the Arab region, the MSF technology still dominates, particularly in the GCC countries, although installed capacity for RO is growing (Figure 5). RO technology is easily scalable due to its high modularity, requires no thermal energy and less or equivalent amounts of electric energy than distillation. Most GCC countries still prefer the thermal technology, however, because they use the disposed heat in cogeneration systems. More recently, hybrid RO and MSF systems are being used in cogeneration system.

Figure 5: Contracted desalination technologies in the MENA Region since 1944.



(source: Bushnak 2010).

The choice of technology used for desalinating brackish water is dependent on the level of salinity (ESCWA 2009). Reverse osmosis is used mostly for higher salinity brackish water, while electro-dialysis is more efficient for lower salinity brackish water (Krishna 2004). Figure 6 provides a breakdown of the cumulative contracted capacity by technology in the Arab region since 1944. MSF process still dominates, although installed capacity for reverse osmosis has increased recently. RO is increasingly used because of its lower cost and improved membranes (Lenntech 2014). Hybrid technologies, such as MSF/RO or MED/ RO, can be used in the future. to increase efficiency when power generation is required. Future large co-generation plants may combine NF/MSF/ MED/RO if present research and technical solutions prove to be commercially competitive (Table 1).

Table 1: Classification of desalination processes.

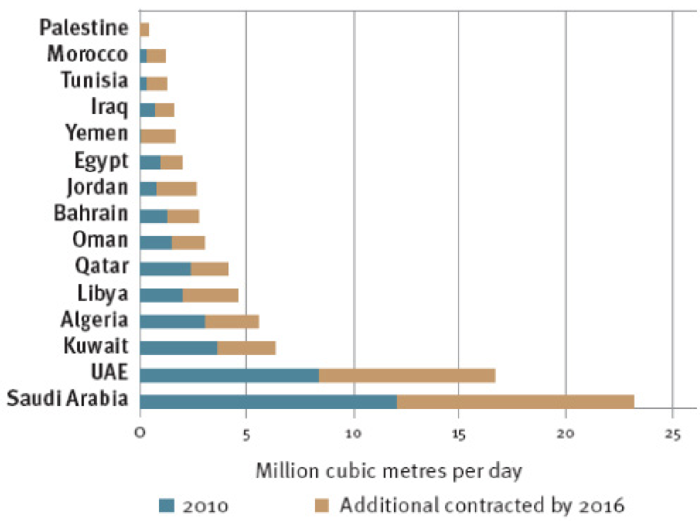
Ref#	Desalination principles with phase change		Desalination principles without phase change
Principle	Distillation	Freezing / Hydrate forming	Membrane separation
Process	▪ Multi-Stage-Flash evaporation (MSF) ▪ Multiple Effect Distillation (MED)	▪ With organic refrigerant ▪ Vacuum freeze / Vapor compression	• Reverse Osmosis (RO) • Electro Dialysis (ED)
Products	Vapor / Condensate	Ice crystals / Melt	Permeate (RO) / Dilute (ED)

2.2. Current desalination capacity in Arab countries and future forecast

Currently, desalination plants in the Arab countries have a cumulative capacity of about 24 million cubic meters per day. The highest desalination capacity (Figure 6) is in the Gulf countries (81%), Algeria (8.3%), Libya (4%) and Egypt (1.8 %) (UNDP 2013). Growth is expected to remain high for the next decade to meet escalating domestic water demand. Desalinated water will expand from 1.8% of the region's total water supply to an estimated 8.5% by 2025 (World Bank 2012). Most of the anticipated increase in capacity will be concentrated in the GCC countries, where it will be used to supply water to cities and industry. More than 55% of the water supplied to cities in the Gulf countries comes from desalinated water; used directly, or blended with groundwater. This share is expected to rise as groundwater resources continue to deteriorate.

There are a number of new desalination technologies under development. These new technologies include membrane distillation, carbon nanotubes membranes, aquaporin (biomimetics) membranes, thin film nano-composite membranes, forward osmosis, and electro-dialysis/deionization (Elimelech 2007, Kim et al. 2010, Mayer et al. 2010, Zhao, Zou, Tang, & Mulcahy, 2012). However, such technologies need further research and development so that one can claim that they hold great promise for desalination of seawater. In addition, the use of renewable energies, mainly solar and wind, are still underutilized and need more attention from Arab countries.

Figure 6: Accumulated desalinated water in selected Arab countries in the years 2010 and 2016.



(source: UNDP 2013).

Arab countries, especially gulf countries, Algeria, and Libya, plan to increase desalination capacity from 36 million m3/day in 2011 to about 86 million m3/day in 2025 (Bushnak 2010). By the year 2025, needed investments are estimated at $38 billion, 70% of which are in the Gulf area.

UNDP (2013) claims that although costs will vary with interest rates and energy prices, the energy costs of the expected expansion in desalination capacity by the year 2025 can be projected using the cost breakdown of a typical RO desalination plant (Table 2). Assuming a 10% interest rate, the cost of a unit cubic meter of desalinated water would be $0.62 (UNDP 2013).

Arab countries desalinated around 19 billion m^3 in 2016 and that is expected to increase to about 31.4 billion m^3 in 2025, at an average cost of $0.525 per cubic meter. The annual desalination costs are estimated at $10 billion in 2016 and it is predicted to be $15.8 billion in 2025, of which energy costs was almost $4 billion in 2016 and will be around $6.4 billion in 2025.

Table 2: Cost breakdown for typical reverse osmosis desalination plant in the Arab region (UNDP 2013)

Cost breakdown for typical reverse osmosis desalination plant* in the Arab region	
Parameter	Cost ($ per cubic meter)
Annualized capital cost (at 5% interest rate)	0.180
Energy Cost (at $ 0.06 a kWh)	0.210
Membrane replacement cost	0.035
Labour and Chemical	0.100
Total Cost	0.525

* *for 800 cubic meter per day capacity and 3.5 kWh energy consumption per cubic meter.*

2.3. Criteria for desalination technology selection

For desalinating brackish water in the desalination plant all possible concepts need to fulfill the requirements according to the Plant Design Data Sheet:

- Production of the specified amount of water.
- Compliance with the specified limit values and other properties of product water.

To develop a desalination concept, the introduced treatment technologies for abstraction/ intake, pre-treatment, desalination, post-treatment and brine treatment need to be combined appropriately.

For the exemplary concept development, the following assumptions have been made:

- The site identification is completed.
- The chosen site is suited for thermal and membrane desalination (for this example).
- The site area is sufficient for the chosen technologies.
- The feed source can constantly deliver the needed amount of brackish water.
- The desalination plant will have a sufficient thermal and electrical energy supply.
- Brine disposal is possible without further brine treatment (surface discharge).

In the following example, two different concepts for brackish water desalination are developed:

- Concept 1: Thermal desalination (MED) with all necessary technologies for abstraction, pre-and post-treatment, and brine treatment.
- Concept 2: Membrane desalination (RO) with standard technologies for abstraction, pre-and post-treatment, and brine treatment.

Concept 1:

- Abstraction including pumping/piping, screening, and chlorination.
- Pre-treatment including sedimentation,

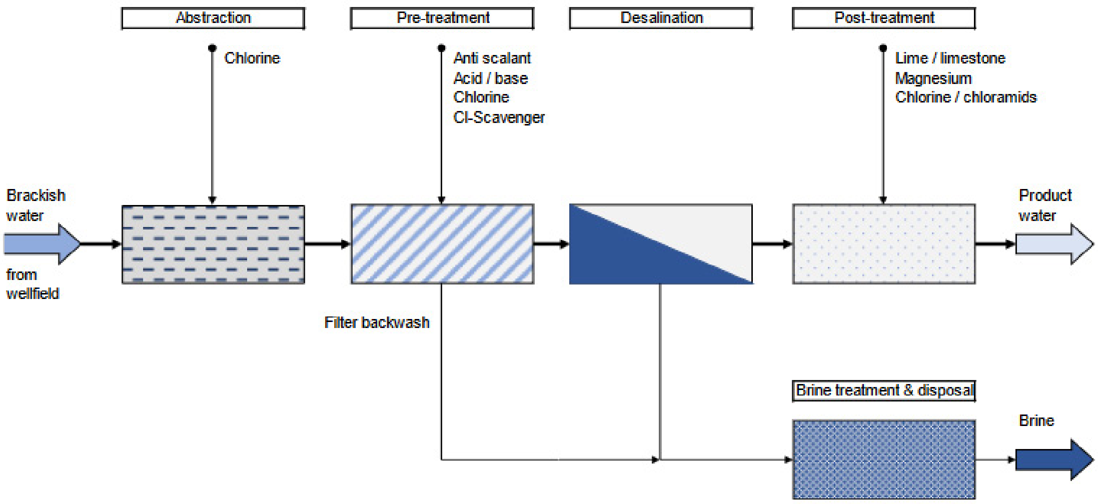
media filtration, cartridge filtration, the dosage of antiscalant, acid, chlorine, and chlorine scavenger MED desalination

- Post- treatment including remineralization (limestone & dolomite) and disinfection (chlorine or chloramines).
- Brine disposal via surface discharge.

Concept 2:

- Abstraction including pumping/piping, screening, and chlorination.
- Pre-treatment including sedimentation, coagulation/flocculation, media filtration, cartridge filtration, the dosage of anti-scalant, acid, chlorine, and chlorine scavenger.
- RO desalination.
- Post-treatment including remineralization (limestone & dolomite), disinfection (chlorine or chloramines), granular activated carbon filtration, and air stripping.
- Brine disposal via surface discharge.

Figure 7: Brackish water desalination concept 1



Abstraction
- [x] Pumping/Piping
- [x] Screening
- [x] Chlorination

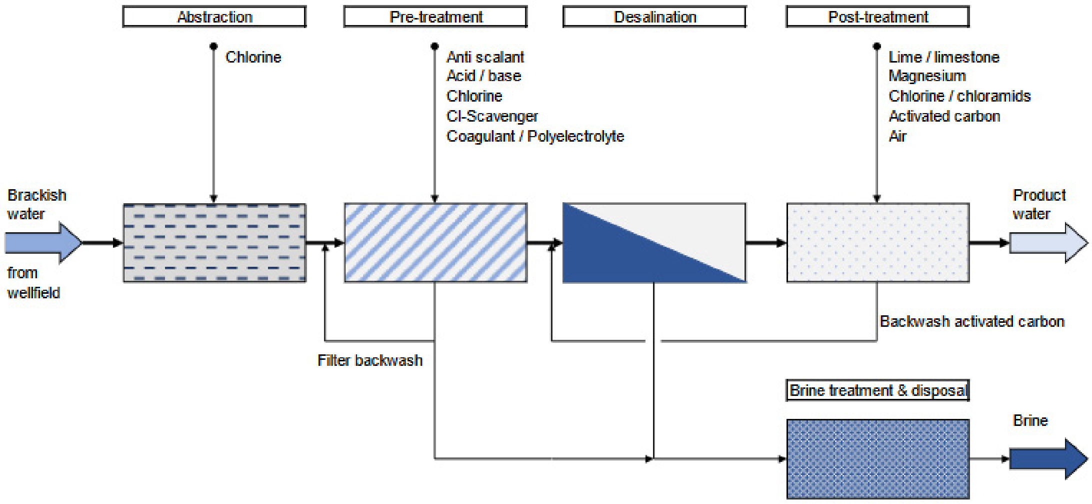
Pre-treatment
- [x] Sedimentation
- [ ] Coagulation / flocculation
- [ ] Dissolved air flotation
- [x] Media filtration
- [ ] Precoat filtration
- [x] Cartridge filtration
- [ ] Microfiltration
- [ ] Ultrafiltration
- [ ] Nanofiltration
- [x] Anti scalant dosing
- [ ] Antifoam dosing
- [x] pH adjustment
- [x] Chlorination
- [x] Scavenger dosing

Desalination
- [x] BW MED
- [ ] BW RO

Post-treatment
- [x] Remineralization
- [x] Disinfection
- [ ] Enhanced post-treatment

Brine treatment & disposal
- [x] Surface discharge
- [ ] Deep well injection
- [ ] Thermal brine treatment

Figure 8: Brackish water desalination concept 2



Abstraction
- [x] Pumping/Piping
- [x] Screening
- [x] Chlorination

Pre-treatment
- [x] Sedimentation
- [x] Coagulation / flocculation
- [ ] Dissolved air flotation
- [x] Media filtration
- [ ] Precoat filtration
- [x] Cartridge filtration
- [ ] Microfiltration
- [ ] Ultrafiltration
- [ ] Nanofiltration
- [x] Anti scalant dosing
- [ ] Antifoam dosing
- [x] pH adjustment
- [x] Chlorination
- [x] Scavenger dosing

Desalination
- [ ] BW MED
- [x] BW RO

Post-treatment
- [x] Remineralization
- [x] Disinfection
- [x] Enhanced post-treatment
  - Granular activated carbon filtration
  - Air stripping

Brine treatment & disposal
- [x] Surface discharge
- [ ] Deep well injection
- [ ] Thermal brine treatment

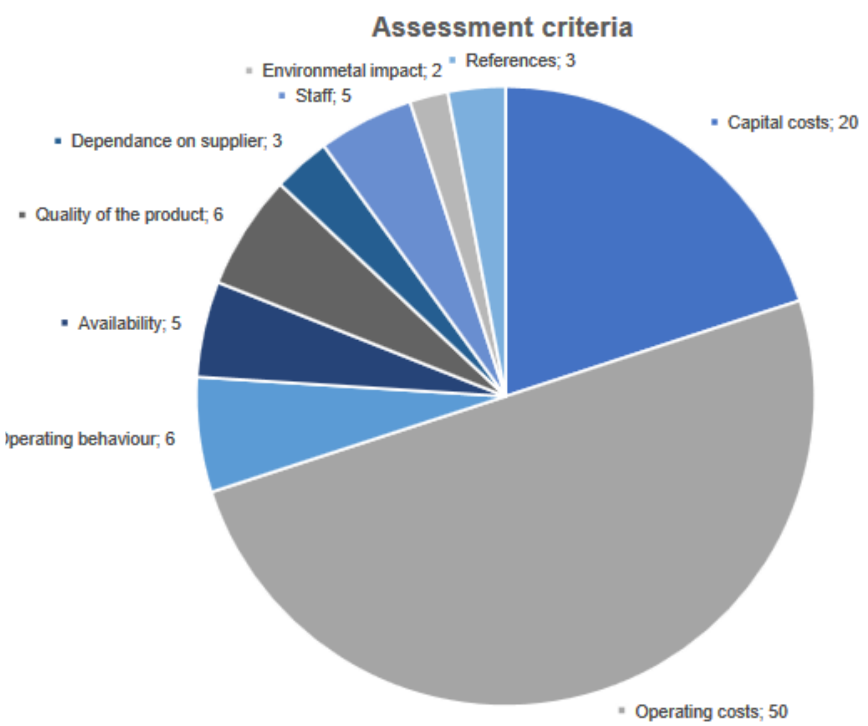
The following assessment criteria, listed in Table 3, can be established for a brackish water desalination plant. The list may be extended or modified, depending on the specific case. But most important is that all points which are relevant for the selection of the process are considered. We can see, in this case, the close tie with the project aims. No single criterion should be eliminated at this stage. If the significance of the criterion is low, this is automatically considered by the following weighting.

Table 3: List of assessment criteria for brackish water desalination plant.

No.	Criteria	Keywords
1	Capital costs	Desalination plant, civil works, energy supply, abstaction facility, pre-treatment, post-treatment, brine treatment, brine disposal, infrastructure
2	Operating costs	Depreciation, interest, energy, chemicals, additives, personnel, water transport, brine disposal, waste disposal, spare parts
3	Operating behaviour	Normal mode, start-up, shutdown, malfunction, overhaul, standstill period
4	Availability	Reliability, robustness, complexity, redundancy, susceptance to failure
5	Quality of the product	boiler feed water, drinking water, process water, irrigation, dangerous chemicals
6	Dependance on supplier	Tubes, membranes
7	Staff	Number, necessary qualification
8	Environmetal impact	Coloured rejects, brine, wastes
9	References	Large, medium and small units, test plants

As shown in Figure 9, it may be recognized that the Capital Costs and Operating Costs comprises of about 70% of the total points of assessment.

Figure 9: Assessment criteria



Desalination is energy-intensive, so energy efficiency is important in developing new plants, as well as upgrading old ones. Saudi Arabia uses a quarter of its oil and gas production to generate electricity and produce water in cogeneration power–desalination plants. Assuming water demand continues to grow at the current rate, this share will increase by at least 50% by the year 2030 (UNDP 2013). Likewise, in Kuwait, cogeneration power desalination plants consume more than 50% of total energy generated. The energy required to meet desalination plant demand is expected to be equivalent the country's current fuel oil production by the year 2035 (UNDP 2013). This means that the Arab countries cannot keep relying on fossil fuels to cover their energy demand in the future. Serious plans and investments need to be considered to integrate desalination with renewable energy sources (solar, wind, tidal, thermal, and waste bio-fuel).

However, as stated previously, desalination requires a considerable amount of energy. Using fossil fuel in desalination is not environmentally friendly. Coupling renewable energy sources with membrane technologies are recommended in Arab countries in the future. These energy sources include:

- Solar energy
- Wind energy
- Geothermal energy
- Waves and tidal energy
- Hydro-electric

The economics of using the renewable energy sources in desalination depends on the cost of energy as the cost of desalination is largely determined by the energy costs, which contribute by more than 30%. Feasibility studies done by researchers or developers in Egypt indicated that in general, the cost of desalination using renewable energy is still higher compared to the cost of conventional desalination based on fossil fuels. However, the costs of renewable energy technologies are quickly decreasing and renew- able energy-based desalination can compete with conventional desalination in remote areas, where the transmission cost of energy and distribution is higher than the cost of distributed generation. Solar power is a great source of energy, for example, although desalination plants are already extremely costly, solar panels are becoming more and more affordable. Offshore wind power plants provide clean energy and should be considered a viable power source for desalination plants. The best way for desalination plants to minimize their energy consumption is by using renewable energy to power the facility. Although it carries a huge cost, desalination benefits people by providing them with freshwater. High-speed electrical pumps on desalination plants consume more energy than is needed. If desalination plants focused on sustainably using renewable energy, it would be a major step toward a greener environment.

3. Emerging technologies in brackish water desalination

Water desalination has evolved from the traditional systems of water distillation, with high energy consumption, to the most modern membrane technologies, especially reverse osmosis (RO), which is more energy efficient and requires lower investment costs. Although distillation technologies were predominant in the past, the appearance of RO membranes in the 1970s has completely changed the desalination scene in the world, and especially the application of desalinated water for agriculture.

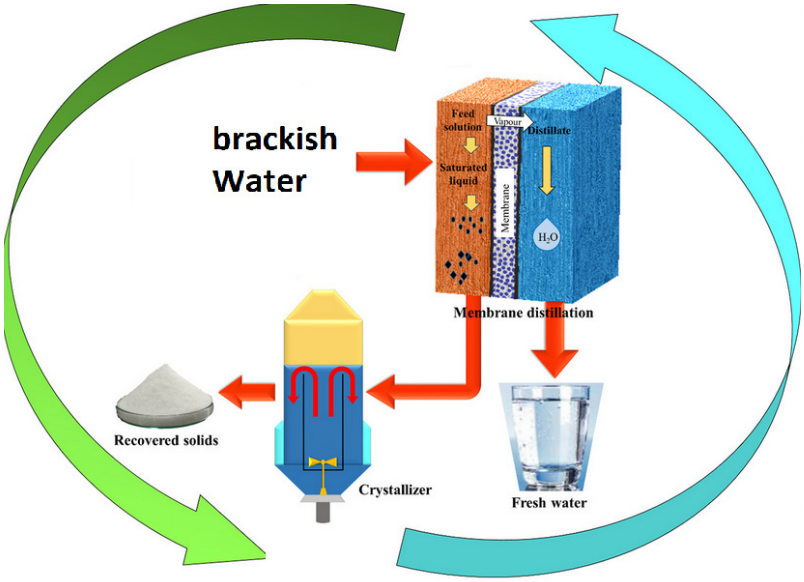
Water desalination relies on energy consumption, which is the main cost of desalinating water. Distillation technologies consume considerable energy regardless of the level of water salinity. However, energy consumption with membrane technologies depends on the salt content of the feed water and of the product water. RO can be adapted to different water salinity contents. This flexibility has enabled the extension of the use of RO to new applications. Electrodialysis reversal (EDR) is less flexible than RO, and should only be used for special brackish water applications in agriculture (Buros 1990).

In recent years, there was a drastic development and interest on new technologies that are considered to be very promising in solving the ever-pending water desalination challenges. There are two technologies with great potential in fulfilling the desalination requirements at very low cost, these technologies are Membrane Distillation (MD) and Forward Osmosis (FO).

3.1. Membrane Distillation

Membrane Distillation (MD) is a new high-efficiency membrane separation technology with broad application prospects. Depending on the method used to treat the vapor with a membrane, MD can be subcategorized into direct contact MD (DCMD), vacuum MD, air gap MD (AGMD), and sweeping gas MD. The main factors that hinder the development of MD are the availability of the membranes for membrane distillation, and membrane wetting. In DCMD, the solution is in direct contact with the hydrophobic membrane on both sides and it is considered one of the most promising membrane desalination methods because of its various advantages, such as a simple structure and large membrane flux, MD can evaporate water at very low temperature in at atmospheric pressure which make it a non-energy-intensive technology. (Ali *et al. (2017))* studied the energy efficiency of a DCMD device during the desalting of brackish water with geothermal energy and other low-temperature heat sources. (Zho *et al*. (2021)) considered the feasibility of desalinating brackish groundwater using the DCMD method and investigated the effects of the feed temperature, flow rate, and salt concentration on the performance of the DCMD process. MD process is being investigated to replace reverse osmosis or thermal distillation for brackish water desalination in Arab world. Figure 10 summarizes MD technology in desalinating brackish water.

Figure 10: Membrane distillation technology



MD has the advantages of a low operating pressure (i.e., low pumping power demand), low operating temperature (heat source: 50–90 ˚C), and a 99.99% possibility of separating solutes and non-volatile substances.
MD is more sensitive to heat and it is the most economical and feasible thermal desalination technology for low cost thermal conditions. Furthermore, the consumption of energy needs to be reduced by applying effective energy recovery systems and implementing multistage MD effect units.

3.2. Forward Osmosis

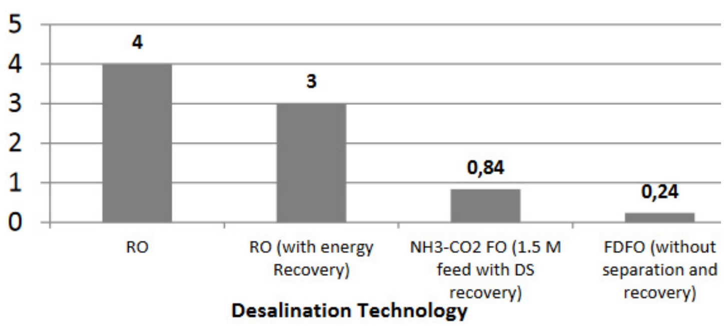
Forward Osmosis (FO), can be used to produce water for irrigation. This type of FO application is Fertilizer Drawn Forward Osmosis (FDFO), as demonstrated in Figure 11. As Phuntsho (2012) clarifies, two different solutions are used in the FDFO process: saline water (as the feed water) on one side of the membrane, and highly concentrated fertilizer solution (as the draw solution) on the other side of the membrane. The two solutions are always kept in contact with the membrane through a countercurrent flow system, where fresh water flows from the saline feed solution towards the highly concentrated fertilizer draw solution. After extracting the water by the FO process, the fertilizer draw solution becomes diluted, and can be used directly for fertigation, provided it meets the water quality standards for irrigation in terms of salinity and nutrient concentration avoiding the need for separation and recovery of the draw solution (Phuntsho *et al.* 2012). Although the potential for such an idea is very promising, research on this model has not received much consideration until recently due to the lack of suitable membranes.

Figure 11: Typical FDFO setup

(*Source: Phuntsho et al. 2012*).

FDFO is a remarkably low energy desalination process. The only energy required in the FDFO process is for sustaining the cross-flow of the feed and draw solutions in contact with the membrane surface and providing sufficient shear force to minimize the Concentration Polarization (CP) effects. Figure 12 shows the relative energy requirements for different desalination technologies. The total energy saved, when compared to other current desalination technologies on an equivalent work basis, can be between 72% and 85%. The performance of NH_3-CO_2 as a draw solution (DS) could vary from the fertilizer draw solutions (Phuntsho, 2012). Yet, given the fact that the recovery of draw solutes from the diluted draw solution is not necessary, the estimates in Figure 12 signal that the energy required for FDFO will be significantly lower.

Figure 12: Comparison of average energy requirements for different desalination technologies



(Source: Phuntsho, 2012).

4. Current use of brackish water in agriculture

4.1. Direct use of brackish water without treatment in agriculture in Arab region

Earlier this year, FAO presented a report (FAO 2023) that thoroughly investigated guidelines and summary of the Arab countries experience in direct use of brackish water without treatment for irrigation of agricultural corps. The Arab region is faced with a wide range of salinity problems and there are a number of examples in the region of the successful use of brackish water for agricultural production. It is important to emphasize, however, that successful practices avoided the sustained accumulation of salts through adequate leaching, drainage and amendment applications.

The region's agricultural practices have evolved through the experience of farmers growing crops under their particular situations of water availability, prevailing agricultural conditions and economic factors. Each country has its own experience in producing crops under its local conditions and each country has its own crop varieties, developed through research and farmers' experiences. There was a wide variety of successful crops production in the Arab world using saline brackish water as an irrigation sources including key cereal, fibre, vegetable, fruit and forage crops. The salinity of the irrigation water used to grow the crops varied widely, from 1.1 to 14 dS/m, albeit with different yield potentials. Sesbania, a halophytic forage crop, was even grown in Syrian Arab Republic with irrigation water that was over 75 percent the salinity of seawater (FAO 2023).

The information provided clearly demonstrates that brackish water has been used successfully in arid and semi-arid climates around the world, including the NENA region, and that there is potential for further successful use of brackish water.

The Arab region faces two important limitations in the successful use of brackish water for agricultural production. One is that many places in the region lack the infrastructure (namely, state-of-the-art irrigation and drainage networks) needed to apply the good management practices necessary for brackish water use. Without investment in the necessary infrastructure, good irrigation management practices cannot be implemented. Drainage, in particular, is a key issue in the region as many areas suffer from waterlogging, and, in fact, the guidelines presented in (FAO 2023) can only be applied in those areas where adequate leaching and drainage are feasible for only in areas with adequate drainage can a salt balance be achieved. Another important limitation is that many countries lack the knowledge and understanding of good agricultural practices for brackish water use.

4.2. Status of brackish water desalination in the Arab region

Because of high costs, desalination technologies are not simply used for agricultural purposes. A thorough cost analysis is essential in order to determine whether water desalination may be feasible to produce a water resource that could be used to complement or substitute natural water resources in areas with water shortages. Yet, the current situation is quite different from that of decades ago, when brackish water desalination started its development. However, more experience is still needed in order to determine whether water desalination is a solution to water scarcity and especially whether desalinated water should be used in agriculture. That being said, it is necessary to analyze the factors influencing the water desalination costs of the different desalination technologies. Desalination technologies have evolved in the last few years, from being little used in the world, limited to some oil rich countries where energy costs are low, to now being used globally. At the beginning, desalination was only used to provide domestic and industrial supplies. However, once this technology had been improved and its costs decreased, its application was extended to other sectors, especially to agriculture. To obtain an average cost of desalinated water, it is necessary to consider three factors:

- desalination technology and energy requirement.
- feed water quality.
- product water quality.

First: Desalination technology and energy requirement.

As agriculture is by far the largest consumer of fresh water in the Arab region, small savings in agricultural water use through improved techniques will provide immense quantities of water available for the community and the environment. Besides making irrigation water available using lower energy from saline water sources, nutrient-rich water for fertigation (Phuntsho, *et al*., 2012). Fertigation has several advantages in comparison to the application of water and fertilizers separately:

- minimum loss of irrigation water due to leaching
- optimum nutrient balance by supplying the nutrients directly to the root zone
- control nutrient concentration in the soil solution
- saving on labor and energy costs
- offering flexibility in fertilizer application timing
- suitable for application in mixtures with other micronutrients such as pesticides
- accommodating and flexible technology as it can be easily integrated in any already-existing fertigation scheme

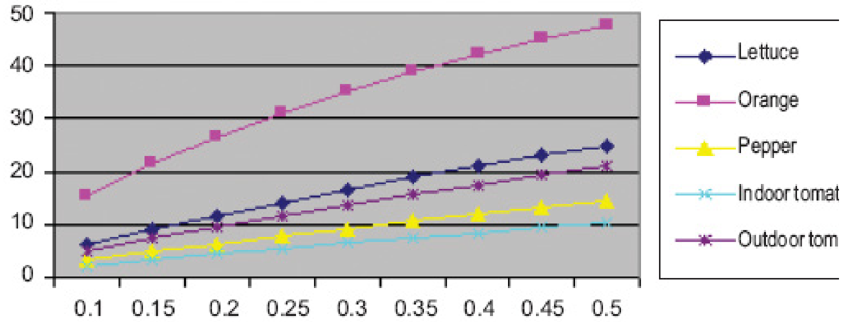
Second: Feed Water Quality.

For highly profitable out-of-season crops, desalinated seawater could be considered as an alternative source of irrigation water. Generally, seawater is seen as the most promising resource for desalination in the future. This is because of the enormous volume that this natural water resource represents and its availability. However, brackish water desalination is also applied in many areas. The economic feasibility of brackish and seawater desalination for agricultural applications needs to be assessed. The World Bank (2007) forecasts that more than 200 million people will encounter the problem of water scarcity by the year 2025 and that most of this population will be living within 50 km from the sea coast. In addition, technologies to desalinate seawater and brackish water are available and their efficiency is continuously improving, permitting desalinated water to cover the agricultural demand in these areas. Distillation technologies can only be used for desalination of seawater at a very high cost. The flexibility of RO to the salt content of the product water makes it possible to reduce costs, an advantage that is not feasible with the other technologies

Third: Product Water Quality

The required salinity of the irrigation water used to achieve sustainable agriculture depends on a number of factors, such as climate, crops, soils, and water management. Therefore, the design of desalination plants has to carefully consider the agricultural needs, so that production costs can be optimized. In order to reduce the Leaching Requirement and the quantity of water applied, desalinated water could be used for specific and profitable crops, such as lettuce, orange, and pepper. In this way, the cost of desalination would be less than that of typical irrigation water. Figure 13 shows irrigation water costs in relation to the total costs for some crops. This information could be used when deciding whether or not to use desalinated water in agriculture.

Figure 13: Irrigation water costs as a percentage of total costs as a function of the water price.



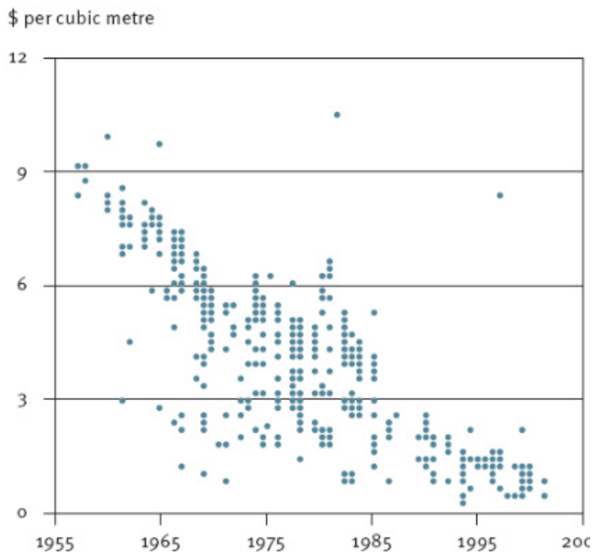
(*source: Beltran and Koo-Oshima 2004*)

Saudi Arabia is currently the world leader in desalination with approximately 26% of global production capacity, followed by the United States (17%). In Saudi Arabia most of the desalination plants are based on the thermal process (newly constructed plants are different) and the source water is seawater. In contrast, in the United States 69% of the desalination plants are based on RO and only 7% is seawater desalination plants. While only 20% of the total number of the desalination plants world-wide use thermal process, 50% of the total production capacity is based on the thermal processes. The United Arab Emirates (UAE) opened its Fujairah desalination plant in 2005 with a combined MSF and RO production capacity of 454,000 m^3 /day (Matsuura *et al.* 2011).

For Arab countries to make desalination a suitable source of brackish water, the high financial and energy cost challenges must be appropriately addressed. As currently practiced, desalination is capital and energy intensive especially when using brackish water as a feed water. Costs per delivered cubic meter of desalinated water are as high as $1.50 and even $4 in some cases (UNDP 2013). The water is subsidized, however, and sold for as little as 4 cents/m^3 in some Arab countries. With improvements in desalination technologies, production costs are continuously dropping.

Technologies such as RO, electrodialysis and hybrids are more energy efficient and better suited to different types of water. As shown in Figure 14, the price of multistage flash over 1985–2004 dropped from $4.0– $2.0/m^3 to $0.50–$0.80 (UNDP 2013). Similarly, the current price of RO is estimated to be $0.99/m^3 for seawater and $0.20–$0.70 for brackish water (UNDP 2013). The World Bank (2012) confirms that energy requirements vary from 3.5–5.0 kwh/m^3 for RO seawater to 4–8 kwh/m^3 for multi-stage flash technology. This downward trend in the cost of desalinated water indicates that desalination technology is becoming more viable.

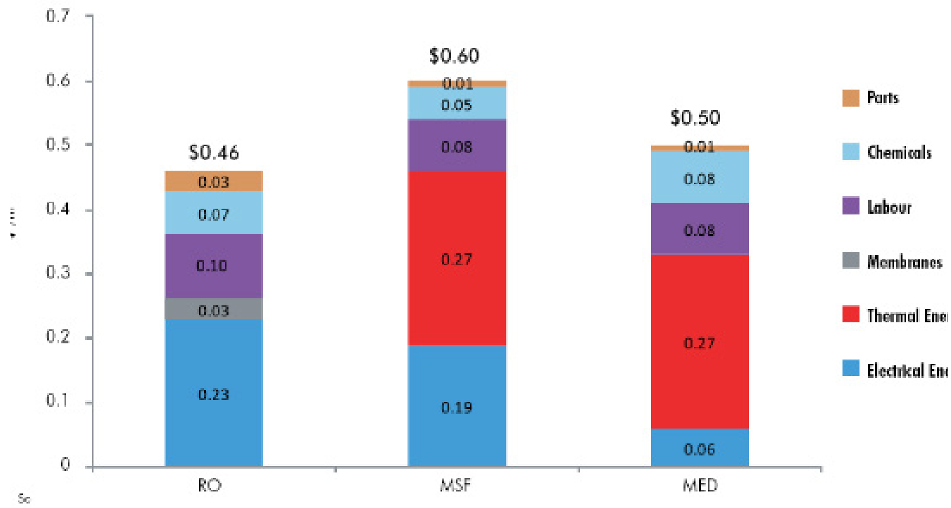
Figure 14: Reduction in the unit cost of multi-stage flash desalination plants, 1955–2003



(source:UNDP 2013).

While the unit capital cost in 2010 for seawater desalination plants ranges between $1000 to $2000/m3/day of installed capacity (Bushnak 2010), the unit capital cost for brackish water plants is estimated to be 25%-45% of the above unit cost for seawater plants (Bushnak 2010). The relative operating costs (parts, chemicals, labor, membranes, thermal energy, and electrical energy) of the three main desalination processes (RO, MSF, and MED) for cogeneration plants are illustrated in Figure 15.

Figure 15: Operating costs of desalination processes in cogeneration plants.



(source: Bushnak, 2010).

5. Impact of the use of brackish water

The salinity of water and soil is a problem present on all continents, impacting ecosystems and agricultural activities, notably in arid and semi-arid regions. However, the growing demand for food, the scarcity of water resources, and the overuse of groundwater under the ongoing scenario of global climate change have created the need to tap into salt water resources to maintain food production and generate jobs and income for farmers in dry lands. Therefore, it is necessary to use appropriate management techniques and salt-tolerant species, both aspects being part of bio saline agriculture (Ma *et al*. (2008)). Research also proved that irrigating with brackish water will not result in serious crop yield reduction. However, brackish water irrigation also carries the risk of causing soil salinization and affecting the normal growth of crops (Selim *et al*. (2012)), since the salinity at the soil surface increased as inter-plant emitter distances and emitter depth increased. (Rahil *et al*. (2013)), recommended to use a short irrigation interval (one day interval) when highly saline water is used. To reduce the damage to the soil associated with brackish water irrigation, many researches have concluded that adopting an effective irrigation system (such as drip irrigation, sprinkler irrigation) and strategy (such as high frequency irrigation) can control the degree of soil salinity accumulation and reduce the influence of high salinity on the soil environment. Moreover, brackish water can alter the soil environment and affect the soil capillary action, resulting in changes to the soil permeability and water retention. It can also lead to the accumulation of salts in the soil, which will restrict crop growth and cause physiological drought, affecting water uptake by crop roots, inhibiting photosynthesis, and altering the physiological characteristics of crops. Therefore, the effect of brackish water on soil and crops should be fully considered, when using brackish water for irrigation.

6. Capacity building and technology localization propositions

Brackish water resources represent a complementary source of the current and future water supply in the Arab region. Brackish water development requires careful planning and management to ensure their longevity in serving socio-economic development in the region. The following are recommendations for policy actions:

6.1. Capacity building

The increase in desalination capacity needs to be matched by an increase of the capacity to develop, implement and operate desalination facilities. Capacity to deal with desalination projects is the bottleneck to the development of the brackish water desalination.

Capacity building includes making efforts to find and support local community groups, so that they can assist in identifying and prioritizing problems and opportunities, in assessing possible ways forward, and in planning and delivering an implementation (AL-Mutaz, 2001)

Particular capacity problems with regard to the desalination sector in Arab Region are:

1. Inadequacy of information and data resource assessment specially related to desalination technology;

2. Lack of know-how and limited technical capabilities;

3. Lack of financial resources for research;

4. Lack of appropriate national policies regarding desalination in long-term planning and the necessity of establishing adequate institutional infrastructures for the management of the operation of desalination systems.

The initiation, formulation and implementation of desalination plants need organizational structures for managing required activities at the governmental level as well as within the utilities, industry, research and development, and educational institutes involved. The distribution of tasks, functions and responsibilities among involved organizations is required. The function of these organizations will be to ensure their design, manufacture, construction, commissioning and operation of desalination plants. Qualified human resources are an important factor to maintain successful of operation of desalination plants. A plan for developing manpower must also be established at the earliest stage to develop highly qualified human resources.

6.2. Role of Research and development (R&D) and technology localization

Research and development (R&D) and innovation are a central area of individual national and international policies and innovative strategy. Principally, it is related to R&D policies' connection with education, innovation, employment, information, and business policy. Research and development play a key role in generating new knowledge, products, and technological processes, which are a necessary condition for stable and sustainable social growth. If Arab countries want to become a more competitive knowledge-based economy, not only the production but also the spread and use of knowledge need to improve. It is essential to manage use and effective transfer of knowledge among research organizations, universities and public organizations in particular, and industry small- and medium-scale businesses which transform it into products and services.

The rapid pace of technological developments played a key role in the previous industrial revolutions. However, the fourth industrial revolution and its embedded technology diffusion progress are expected to grow exponentially in terms of technical change and socioeconomic impact. However, academics still struggle to define its approach appropriately.

Science, technology, and innovation represent a successively larger category of activities which are highly interdependent but also distinct. According, science contributes to technology in different ways:

- new knowledge, which serves as a direct source of ideas for new technological possibilities;
- source of tools and techniques for more efficient engineering design and a knowledge base for evaluation of the feasibility of designs;
- the practice of research as a source for development and assimilation of new human skills and capabilities eventually useful for technology; creation of a knowledge base that becomes increasingly important in the assessment of technology in terms of its wider social and environmental impacts or knowledge base that enables more efficient strategies of applied research, development, and refinement of new technologies.

However, a number of experiences involving the private sector since the 1990s have fallen short of expectations for all parties involved and led in some cases to highly politicized debates and international arbitration. In particular, the expected surge in the flows of private investment did not materialize. The causes were often a poor understanding of the opportunities and risks involved by private sector participation in a complex sector, as well as inadequate framework conditions. This contributed to catalyzing public attention on the role for private sector participation in developing and managing water systems, as well as more generally on the conditions under which water services can be provided safely, affordably and sustainably. It also led to rapid changes in the forms of private sector involvement, towards less risky contracts (service, management contracts and greenfield projects), the emergence of new actors (local and regional), and a growing recognition of alternative small-scale and very often informal private providers.

Past difficulties have contributed to revealing the complexities of the water sector:

i) High fixed costs coupled with long-term irreversible investments and relatively inelastic demand tend to make it a monopolistic sector in which competition is difficult to introduce and regulation plays a central role.

ii) Water is a basic need. Water quality and access have important externalities affecting health, gender equality and the environment. These justify a public policy interest.

iii) The responsibility for water and sanitation service provision often rests with local authorities. Nevertheless, the importance of the externalities, of taking into account the full water cycle and of optimizing economies of scale requires an integrated approach to development and management of water infrastructure and service provision.

iv) The sector involves numerous stakeholders and suffers from segmentation of responsibilities notably across government tiers and public agencies.

v) Investors in the water and sanitation sector are faced with commercial risk. contractual risk, foreign-exchange risk, sub-sovereign risk, arbitrary political interferences, and complex pricing policies with multiple objectives, such as cost recovery, economic efficiency, environmental objectives, equity and affordability.

vi) Long-term relationships, limited competition and irreversibility of infrastructure and technology may expose the sector to risks, particularly of capture by vested interests.

Focusing solely on the private vs. public dimension of operators might be misleading for two main reasons. First, the obstacles to water and sanitation infrastructure development are largely unrelated to ownership. Secondly, the "private sector" accommodates a large variety of actors. These include, not only the large networked utilities run by international corporations, but also local and small-scale actors and a continuum of partnerships between private operators, public actors and communities. Most systems are increasingly hybrid and rarely either purely public or purely private. The partnerships are also in effect multi-stakeholder arrangements as they involve, in addition to the "private" entity, different tiers of governments, the consumers and the communities. Consequently, they can hardly be reduced to a face-to-face relationship between a homogenous public entity and a single private actor, but can rather be seen in practice as tripartite partnerships.

The R&D of the business enterprise (private) sector includes all resident corporations, including companies incorporated under the laws and all other types of quasi-corporations that would make a profit or any other profit for their owners.

Developing local capacity and implementing state-of-the-art desalination technologies through providing financial and logistical support are required. Arab Governments should provide generous support to help develop and pilot test new desalination technologies, such as Forward Osmosis powered by solar and wind energies. This can be done by awarding local and regional universities with funds and generous scholarships to research and test the applicability of the new technologies. Some countries (e.g., Saudi Arabia) have large allocations for science and technology initiatives. It is still a challenge to see how local universities will be able to convert their intellectual research ideas to high-value economic assets. Arab Governments should offer financial support to allow the establishment of desalination training centers. The governments in partnership with local companies should build and equip such centers. The Saline Water Conversion Corporation (SWCC) in Saudi Arabia has the only desalination focused training center in the region. In addition, the Arab Water Council is spearheading capacity building by

establishing the Arab Water Academy (AWA) and the Arab Desalination Technology Network to facilitate networking, capacity building, and cooperation among desalination experts in Arab countries (Bushnak, 2010).

7. Conclusions and future directions

7.1. Conclusive Remarks

In this report, a thorough investigation of current brackish water status, treatment methods and use are demonstrated. It is well known that the region is a water stress region so looking at every opportunity for sustainable water supplies is the utmost priority considering the food security problem as well, so the region can be sustainable in terms of water and food security. This study discussed the direct use of brackish water for irrigation as well as the possibility of desalination brackish water for agricultural and drinking purposes. A detailed presentation of the current desalination technologies is presented together with the selection criteria of the appropriate technology for a given challenge. Both energy requirements and environmental impact played a role in hindering the wide use of brackish water desalination, however the report presented membrane distillation and forward osmosis as a promising solution that can overcome the traditional drawback of the well-established desalination technologies especially in terms of energy saving as well as brine disposal.

Furthermore, the report provided some guidelines for proposed policy directions in terms of capacity building, technology localization and partnership between private sector, public sector and other parties of interest.

7.2. Future directions

The following actions are suggested to make brackish water a more sustainable source of irrigation water:

1. It is recommended for the governments to consider brackish irrigation as good agricultural practices. Brackish water therefore can be part of the governments' national policies and strategic integrated lands and water resources development plans.
2. Government might as well perform area mapping for high brackish water potential identifying their economic feasibility and considering different hydrological and environmental factors. This should be coupled with developing knowledge base and technical and institutional capacity building.
3. Concerted efforts by regional organizations are needed to strengthen regional cooperation and applied research in brackish water development. Possible areas of cooperation include capacity building activities, data and information sharing, and establishing knowledge hubs to support individuals and organizations working in brackish water management and utilization.
4. Pilot scale brackish water projects could be financed and constructed at potential areas to demonstrate new technologies utilizing indigenous regional knowledge.

5. It is recommended for new desalination plants to reduce energy consumption and reduce carbon footprint per unit water produced. Arab Governments might set a maximum limit on water carbon emissions to achieve this.

6. Implement newly developed solar powered desalination technologies for small and large systems. Arab based technical solutions and products for solar desalination and cogeneration can provide a strong economic base for many countries in the region. Arab countries need to plan for exporting solar power for their future prosperity as much as they rely on oil and gas exports today.

7. It is recommended that the Governments provide generous support to private investments in R&D, training, high technology venture capital, and knowledge based local industries. Such support should be integrated to achieve desired national local economic outcomes and meet export targets in strategic industries like desalination and solar power.

8. Arab countries might develop joint R&D programs in desalination and renewable energy such as wind, solar, and possibly wave and tidal power. Such programs would maximize the value of new ideas and research findings emerging from new institutional knowledge centers.

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