Desalination: a water supply augmentation option for Pakistan

Adnan Ali

Research Associate, NUST Institute of Policy Studies

Ra.nips@nust.edu.pk

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I. Introduction

Water scarcity and management have been a boiling issue in Pakistan for the last couple of decades. Multiple local and international reports pointed to the year 2025. It will be the year when Pakistan will hit the most water-scarce point. Pakistan crossed the water stress line in the 1990s and it crossed the water scarcity line in 2005. The growing population added by the poor management pushed Pakistan towards water scarcity. Pakistan is slowly sliding down into the pool of water-scarce countries with few water supply augmentation options. The per capita availability of water was above 5650 cubic meters per annum in 1951 and at present it is below 1000 cubic meters[1], accelerated by unbridled population growth and poor water management. The population numbers are still uncertain because the censuses have been made controversial because of discrepancies. The digital census will hopefully bury the regional reservations. Correct population numbers will assist policymakers in drawing policies essential to developing and providing basic facilities. Water is such an essential facility that promotes city development and farming. However, historical neglect, poor maintenance of existing facilities along with ballooning population has made access to water a daunting task.

For water supply, Pakistan relies on surface and underground water. Glacial melt forms the major source of water supply in the country. The Indus River system primarily relies on the annual glacial melt. However, after the introduction of water tube wells, the agriculture area has gone up because of the use of underground water for farming and supply for cities. Multiple research outlets have designated Pakistan as one of the most vulnerable countries to climate change[2]. Pakistan's water supply is particularly at risk because of global warming. If global warming continues at the current rate, Pakistan would be left with no glaciers by the turn of the century. In addition, the over-extraction of underground water is alarming because underground is not regulated in the country.

[11] "Per Capita Water Availability May Fall to 860 Cubic Metres." 2019. The Express Tribune. June 28. https://tribune.com.pk/story/2002420/per-capita-water-availability-may-fall-860-cubic-metres.

[2] Global Climate Risk Index 2021

Unregulated underground water makes a recipe for disaster when commercial giants fight for water against community needs. For instance, Tucson, Arizona has its underground water regulated in active management areas, but in non-active management areas, the extraction of water puts a strain on the supply of water because underground aquifers are connected. Pakistan is steering aimlessly with no water policy and implementation.

A. Significance of addressing water scarcity through supply augmentation strategies

Water scarcity in Pakistan becoming a core issue that would require a multi-partisan national-level strategy to address it. The vertical and horizontal authorities working in the water sector must be greased to work smoothly. The Indus Water Treaty (IWT) is turning into a bane because of poor handling[3]. To ensure a continued supply of water, the two major dams were built following the IWT, but nothing substantial has been achieved beyond that.

For water supply augmentation, policymakers had historically relied on building huge dams to store and distribute water. Dams not only store water for usage but they are used to produce power and control floods despite their ecological impacts[4]. In addition to dams, other water supply options include underground water, rainwater harvesting, recycled/reclaimed water, stormwater, and others. In Pakistan, dams are the primary focus, but the country has failed to build mega dams to control perennial floods and to store water for scarce periods.

The Pakistan Council of Research in Water Resources (PCRWR) and the International Water Management Institute are working on different measures like underground aquifer recharge through wetlands and recharge units[5]. Rainwater harvesting has been

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[3] NIPS Report, 2019: Managing the Waters: Appraisal of Pakistan's Problems and Ways Forward
[4] Dams, World Commission on. Dams and Development: A New Framework for Decision-making - The Report of the World Commission on Dams. United Kingdom: Taylor & Francis, 2016.
[5] "Media Briefing Organized to Highlight the Artificial Groundwater Recharge Site in Kachnar Park, Islamabad." 2022. International Water Management Institute (IWMI). July 4. https://www.iwmi.cgiar.org/local-media-

more in the policies and little on the ground. It is effective and cheap, yet it ranks very low in the government-endorsed strategies. Similarly, there is little focus on the treatment of wastewater or grey water. On a daily basis, thousands of gallons of water are wasted which if treated or recycled, it would help increase the supply options for the country.

As the deadline for sustainable development goals approaches, the focus is on SDG 6: clean water and sanitation. The focus has not been on cheap viable solutions, but on grand-scale systems that would also be sold as political wins. In addition to all the above options, Desalination is another strategy that is getting traction around the world as water supply problems aggravate. Seventy percent of the earth is water, yet humanity struggles to make it clean for drinking. Communities and desalination proponents believe that desalination will be a huge force in the achievement of SDG 6.

B. Purpose of the research paper:

Pakistan has meddled with desalination only slightly because of its capital-intensive nature and the lack of technology. There are no homegrown companies or industries which focus on clean water production at a city scale. There have been small-scale projects in different pockets of the country, but nothing at scale has been focused and built. This research paper will explore desalination as a potential solution for water supply augmentation in Pakistan. It will look into the technologies of desalination, global applications, and case studies for Pakistan if the country can shift towards desalination to expedite its sojourn towards achieving SDGs related to water.

II. Overview of Water Scarcity in Pakistan

A. Current water supply challenges in Pakistan

Water supply has increasingly become a basic issue as cities have grown exponentially and the water management infrastructure has not caught up. The inland water issues

releases/media-briefing-organized-to-highlight-the-artificial-groundwater-recharge-site-in-kachnar-park-islamabad/.

mostly revolve around poor management, not the unavailability part. Pakistan relies on surface and groundwater to meet its agriculture, domestic and industrial demands. Interestingly, according to the Pakistan Council of Research in Water Resources, 93 percent of drinking water comes from groundwater and almost 100 percent of industrial water comes from groundwater and 93 percent of total water goes to agriculture[6].

Some of the compelling water supply challenges that Pakistan faces are declining water availability, inefficient water use, climate change, and water pollution. The declining water availability is worry situation for the country and it has been talked about in the media and conferences. The emphasis is put on the construction of reservoirs to store flood, waters, particularly monsoon waters. Large construction projects are politically motivated which makes water storage and provision a political issue instead of treating it as a human rights issue.

Inefficient water use is the least focused challenge, but its dividends are huge. Pakistan's water demands are skewed towards agriculture which employs 37 percent of the workforce in the country and generates 19 percent of the GDP[7]. The seepage losses in canals amount to 45.5 and 66 percent for lined and unlined watercourses respectively[8]. The use of new methods like sprinklers and drip irrigation is slowly taking space against the traditional flood irrigation system.

Climate change is becoming an existential threat to Pakistan. It is one of the most vulnerable countries to climate change. It is causing intense drought situations and also accelerating the melting of glaciers in the north of Pakistan[9]. Moreover, the country is already facing frequent floods that are damaging infrastructure and polluting water

[6] PCRWR Report on Water Resources
[7] Pakistan Economic Survey 2021-22
[8] Shah, Z., Gabriel, H., Haider, S., and Jafri, T. (2020) Analysis of seepage loss from concrete lined irrigation canals in Punjab, Pakistan. Irrig. and Drain., 69: 668– 681. https://doi.org/10.1002/ird.2474.
[9] Rasul, Ghulam, Qin Dahe, and Q. Z. Chaudhry. "Global warming and melting glaciers along southern slopes of HKH range." Pak. Jr. of Meteorology 5, no. 9 (2008).

sources[10]. In addition, water pollution is a huge water supply challenge. Industrial waste, sewage discharge, agricultural runoffs, and urban water runoffs make water harmful for consumption. Access to clean drinking water is becoming a challenge.

B. Causes and consequences of water scarcity

The causes of declining water availability are primarily linked to two factors: population and mismanagement. Pakistan has seen huge population growth in its 75 years of independence[11]. It was 38 million in the 1950s and now it stands close to 250 million in 2023[12]. The exploding population has stressed available resources and decreased the per capita availability of water. As mentioned, the per capita availability of water was above 5650 cubic meters per annum in 1951, and at present it is below 1000 cubic meters[13]. According to hydrologists, an area experiencing water stress is when annual water supplies drop below 1,700 m3 per person. When annual water supplies drop below 1,000 m3 per person, the population faces water scarcity, and below 500 cubic meters "absolute scarcity"[14].

The irrigation system is out of maintenance and the annual seepage losses make around 65 percent. Water management is equated with supply management instead of focusing on both aspects: supply and demand. The demand control mechanisms and efficiency gadgets will reduce the demand for water and will help to direct where it is needed the

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[10] Fahad, S., Wang, J. Climate change, vulnerability, and its impacts in rural Pakistan: a review. Environ Sci Pollut Res 27, 1334–1338 (2020). https://doi.org/10.1007/s11356-019-06878-1

[11] Rana Waqar Aslam, Hong Shu & Andaleeb Yaseen (2023) Monitoring the population change and urban growth of four major Pakistan cities through spatial analysis of open source data, Annals of GIS, DOI: 10.1080/19475683.2023.2166989

[12] John Bongaarts, Zeba A. Sathar, Arshad Mahmood, chapter two, Population Trends in Pakistan, Capturing the demographic dividend in Pakistan

[13] "Per Capita Water Availability May Fall to 860 Cubic Metres." 2019. The Express Tribune. June 28. https://tribune.com.pk/story/2002420/per-capita-water-availability-may-fall-860-cubic-metres.

[14] "Scarcity, Decade, Water For Life, 2015, UN-Water, United Nations, MDG, Water, Sanitation, Financing, Gender, IWRM, Human Right, Transboundary, Cities, Quality, Food Security." 2023. United Nations. United Nations. Accessed May 24. https://www.un.org/waterforlifedecade/scarcity.shtml.

most. The lack of emphasis on demand-side management makes water management more difficult.

The over-extraction of underground water is another ticking bomb. Underground water is not regulated in Pakistan and as surface water fails to reach villages and towns, the extraction of underground water has taken a steep rise. The lack of regulations will do more damage in the long run as the water tables will go beyond replenishment levels.

Climate Change, however, is the biggest threat to water availability. With changing weather patterns, increased temperatures, and altered rain patterns and droughts, the country might grapple with water scarcity for a long time. Other main causes include pollution and contamination, deforestation, conflict, political instability, and economic factors. Pakistan is in poor economic conditions. The country rarely invests in basic infrastructure projects. The examples of big cities like Karachi, Lahore, and Islamabad are good examples that are suffering from basic infrastructural deficits.

C. Need for alternative water supply options

Since the sole focus of water management is on the supply side, and on the supply side only one or two options are explored because of traditional approaches. The construction of large dams has been a huge priority to store and direct water. In addition, canals are built from areas of water surplus to water-scarce towns or for agricultural purposes. The current reliance on underground water and lack of structures to properly use surface water is backfiring already. Surprisingly, there is no emphasis on desalination and the treatment of wastewater on a large scale. Pakistan must push for waste and grey treatment at a large scale to be used for lawns and parks in the country. A huge amount of water is wasted in prayer areas and in service stations[15].

[15] "Water Recycling in Car Wash Stations: Prototype Demonstration: United Nations Development Programme." 2019. UNDP. March 15. https://www.undp.org/pakistan/news/water-recycling-car-wash-stations-prototype-demonstration.

Desalination and water treatment are both energy and technology-intensive ventures which have helped countries overcome their water supply challenges. In the case of Pakistan, the cost-effectiveness of the alternate water supply options is essential.

The case of wealthy Arab countries and Israel are wonderful case studies for desalination projects. They have successfully overcome their water supply challenges. The story of Israel is fascinating. Israel successfully gets 55 percent of its domestic water requirements from seawater and brackish water[16]. The advancement in desalination technology is considered a game changer because it brought the cost of clean water production to bearable levels. Israel has signed a memorandum of understanding with Jordan on a water-energy swap deal where Jordan will supply 600 megawatts of electricity for 200 million cubic meters (mcm) of desalinated water[17].

The Middle East is a hub of desalination plants to provide safe drinking water to the growing population. According to one research, Saudi Arabia and UAE account for 25 percent of global desalination production. Both heavily rely on desalination water to meet their daily demands. The high cost of desalination discourages a lot of countries, but the shifting of desalination plants to renewable energy outlets is considered a good sign for water-scarce countries.

Pakistan has an extended coastline with a total length of 1046 kilometers. There have been deliberations on installing desalination plants, but the planning does not translate into physical action because of a lack of funds. The cost-effective solutions are prioritized over desalination, however, improvement in the technology has rendered it cost-effective in some parts of the world. It would be insightful to take a look at the existing desalination units in Pakistan and how they compete with other water utilities in the country.

[16] "How Desalination Came to the Rescue in Israel." 2017. ISI Water. March 14. https://isi-water.com/desalination-rescues-israel/.

[17] "Israel and Jordan Move Forward with Water-for-Energy Deal." 2022. Reuters. Thomson Reuters. November 8. https://www.reuters.com/business/cop/israel-jordan-move-forward-with-water-for-energy-deal-2022-11-08/.

III. Understanding Desalination

A. Definition and principles of desalination

Desalination is not a new concept. It happens in nature all the time. The water cycle is a good example of it. The sun evaporates water from the sea leaving behind salt, they form clouds then condense and turn into rain. The modern definition of desalination focuses on removing salts and minerals from seawater to make it suitable for human consumption and industrial use. The process has been in use for centuries. People have used distillation and evaporation to get clean drinking water from salty water. The sailors used evaporation during their sailing journeys to get clean water from the sea and so did the travelers using distillation. The new methods of desalination still predominately use distillation and evaporation.

B. Different desalination technologies

There are two dominant desalination technologies used around the world: thermal desalination and membrane desalination. Thermal desalination is evident from the nomenclature that salt water is heated changed into vapors and condensed to get clean drinking water. In membrane desalination, instead of using heat, the salty water is pressed to pass through a membrane that extracts salts and another harmful minerals from the salt giving fresh water. Both technologies are emission positive because of the huge energy required for functioning. There are two main types of membrane processes: reverse osmosis (RO) and electrodialysis (ED). After decades of iterations, the technology has matured in three different methods: multi-effect distillation (MED), multi-flash distillation (MSF) and reverse osmosis (RO), albeit there are many other processes. MSF and MED are both thermal technologies that are in the advanced growth phase and rapidly approaching saturation point and their usage is likely to peak before 2050[18].

[18] Mayor, "Growth Patterns in Mature Desalination Technologies and Analogies with the Energy Field."

MED and MSF technologies are often applied to seawater desalination. Both methods consume a lot of energy. MED is the oldest method to be applied. Its penetration rate has gone down because of the high energy and electricity requirements. MED plants require both thermal energy for the distillation process and electrical energy for the water pumping system, with typical value ranges of 45 - 230MJ/m3 (12-19 kWhe1 /m3 assuming power plant conversion efficiencies of 30%) and 2 – 2,5 kWh/m3 respectively[19].

MSF is an alternative method that also uses energy and electricity however, MSF pants are bigger in size and operation making them less cost-effective and optimal. Typical MSF thermal and electric energy requirements are in the order of 190-282 MJ/m3 (16 - 23 kWhe/m3) and 2.5 – 5 kWh/m3 respectively[20]. Both technologies require water for cooling after the process which is why these plants are often located near the coastline.

Out of the different membrane technologies, RO has been very successful because of its advanced technological efficiency and cost-effectiveness. The most common type of membrane technologies applies external pressure to overcome the intrinsic osmotic pressure of seawater and reverse the natural flow direction across a membrane, leaving the dissolved salts behind. This process requires only electric energy to power the pumps, with typical values ranging between 0.5-1.5 kWh/m3 for brackish water and 2.5-5 kWh/m3 for seawater depending on the feedwater salinity[21].

[19] Mayor.
[20] Mayor.
[21] Mayor.

RO-based desalination plants have been in work since the first RO plant in 1962 in Kuwait. According to research, in 2016, RO plants made up 73 % of the global desalination market share[22]. The success of RO is because of three different factors: RO plants require less energy as compared to MSF and MED, the advancement in membrane technology has lowered capital and operation costs, and RO plants do not require water for cooling which gives them an advantage over MED and MSF[23].

C. Advantages and limitations of desalination

There are certainly advantages and disadvantages of desalination and it comes with its own limitations that will hamper its optimal functionality. The biggest advantage of desalination is its low vulnerability to climate change. Climate change is set to disturb conventional water supply options since they are vulnerable to climate variations. Glaciers will be lost to increasing global temperatures, rainfall patterns will shift rains to

Figure 1 Comparison of different desalination methods, Source: Beatriz Mayor, Ph.D. (International Institute for Applied Systems Analysis (IIASA))

Feature	MED	MSF	RO
Number of stages	4-31	19-28	NA
Recovery ratio	30-38%[3]	30-38%[3]	35-45% SW[1] 75-90% BW[2]
Tolerated feedwater salinity	No restrictions	No restrictions	<60,000 mg/L
Output water salinity	<10 mg/L	2-10 mg/L	<500 mg/L SW[1] <200 mg/L BW[2]
Brine temperatures	70°C	90-120°C	Same as input
Thermal energy consumption	12-19 kWhe[4]/m^3	16-23 kWhe/m^3	None
Electric energy consumption	2-2.5 kWh/m^3	2.5-5 kWh/m^3	1.5-5 kWh/m^3

[1]SW: Sea water

[2]BW: Brackish water

[3]The recovey ratio for thermal technologies refers to the "blowdown" factor or ratio between the distillate produced and the seawater make up flow rate [25]. When the additional cooling water volume is considered, the ratio between distillate and total water use is lower with typical values ranging 15-25%.

[4]kWhe: Kilowatt hour equivalent applying a heat conversion efficiency of 30%

other places, and underground water tables will be affected. In contrast, desalination is a non-conventional water supply-it is resilient to a lot of external climate change influences.

[22] Mayor.

[23] Mayor.

During drought season or floods, the desalination plant will produce fresh water as per requirement. This gives desalination plants an advantage over conventional water supply options. As the world grapples with uncertain climatic events, desalination would be prioritized as a reliable water supply option.

However, desalination plants are highly energy intensive emitting large quantities of greenhouse emissions into the atmosphere. According to estimates, it takes two gallons of seawater to make one gallon of freshwater leaving behind an extremely salty solution called brine[24]. The recovery ratio (RR) is the processing efficiency of a plant[25]. It indicates the proportion of intake water that is changed into high-quality water.

The disposal of brine is of great concern because of its harmful impacts on aquatic life. The brine is often discharged without dilution risking coral reefs and other aquatic life. According to a study the total daily brine production is at 142 million cubic meters per day[26]. Brine production in UAE, Saudi Arabia, Qatar, and Kuwait accounts for 55 percent of global production[27]. Another problem with desalination plants is the risk of harming aquatic beings because of the suction intake. As water is pulled into the desalination plant using pipes, different aquatic species and other organisms are sucked into the system.

Therefore, capital intensiveness, energy consumption, and brine are considered three key barriers to desalination expansion. As research continues to bring down the cost, and energy consumption and finds solutions to brine disposal and water suction, desalination plants will thrive across the globe irrespective of the rich or poor countries because water scarcity is turning into a global phenomenon because of climate change.

[24] Jones et al., "The State of Desalination and Brine Production."
[25] Jones et al.
[26] Jones et al.
[27] Jones et al.

IV. Desalination Projects around the World

Desalination has been increasingly implemented in developed regions to increase water supply. Different studies have quoted desalination as an important element in achieving sustainable development goal 6: clean water and sanitation. As the world grapples with frequent drought spells, desalination is proving essential to bridge the supply and demand gap. According to different estimates, there are more than 19000 desalination plants around the world spread over 177 countries[28]. The total water production is more than 93 million cubic meters per day and 48 percent of this water is produced in the Middle East and North Africa[29]. The majority of these desalination plants are concentrated in the energy-rich Middle East and some of them are in the small island states. The installation of desalination plants is on the rise as countries look towards more reliable, climate change-independent water supply options.

A. Case studies of successful desalination projects in countries facing water scarcity

Most of the world's desalination plants are concentrated in the Middle East and so are the success stories. The Kingdom of Saudi Arabia has long relied on desalination plants to provide clean drinking water to its increasing population. Also, UAE, Qatar, and Israel have been successful in using desalination to their advantage. Some of the successful desalination plants are the world are:

1. Ras Al Khair located in the north-west of Jubail and serving Riyadh has a production capacity of over one million cubic meters per day. It is a hybrid project that uses thermal MSF and RO technologies and it also produces 2400 MW. In addition, Shuaiba 3 with production capacity of .88 million cubic meters per day, and Jubail Water and Power Company plant with 0.8 million

[28] Jones et al.
[29] Jones et al.

cubic meters per day are rated third and fourth largest desalination plants in the world[30].

2. DEWA station M plant located in Dubai has a production capacity of .6 million cubic meters per day and a total power capacity of 2885 MW[30].
3. Sorek plant located 15 kilometers from Tel Aviv in Israel has a total production capacity of .6 million cubic meters per day. It is considered a prime example of a membrane-based plant. In addition, an extension of Sorek 2 has been established as well which along with Hadera, Ashkelon, Palmachin, and Ashdod provide water to Israel[30].

As mentioned, desalination plants are operating in 177 countries. All major arid regions have invested in desalination plants to avoid water supply shocks. These plants operate in major western states of the US like California, Arizona, and Texas. The Lewis Carlsbad Desalination Plant in San Diego is another example of California diversifying its water supply options as the region perpetually remains in drought spells and receives less rainfall[31].

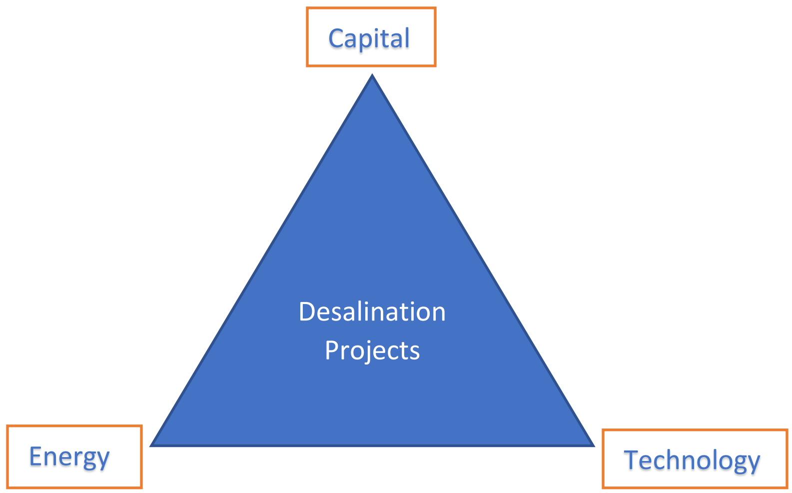
The story of Israel is pertinent here because Israel was considered water scarce in the seventies and eighties as it had few water options and it was in a fistfight with Jordan on the sharing of the Jordan River. When Israel turned towards desalination, it decided to master the technology and it did. It turned itself into a water exporter using its extensive seawater and brackish water desalination plants.

B. Lessons learned from these projects and their applicability to Pakistan

Over 20,000 projects around the globe in 177 countries with many lessons and learning that could help other countries plan well and execute these projects to take maximum

[30] “Desalination Plants: Ten of the World’s Largest.” 2021. Aquatech. April 21. https://www.aquatechtrade.com/news/desalination/worlds-largest-desalination-plants.
[31] Robbins, Jim. 2019. “As Water Scarcity Increases, Desalination Plants Are on the Rise.” Yale E360. Yale School of the Environment. June 11. https://e360.yale.edu/features/as-water-scarcity-increases-desalination-plants-are-on-the-rise.

benefits. The technology has made wonderful strides and if projects are given ample time to function and achieve economies of scale then these technologies will help countries avert water shortages. On a greater level, these projects require three essentials: capital, energy, and technology.



The desalination plants are built at the confluence of these three essentials.

Here is a global distribution of desalination plants[32].

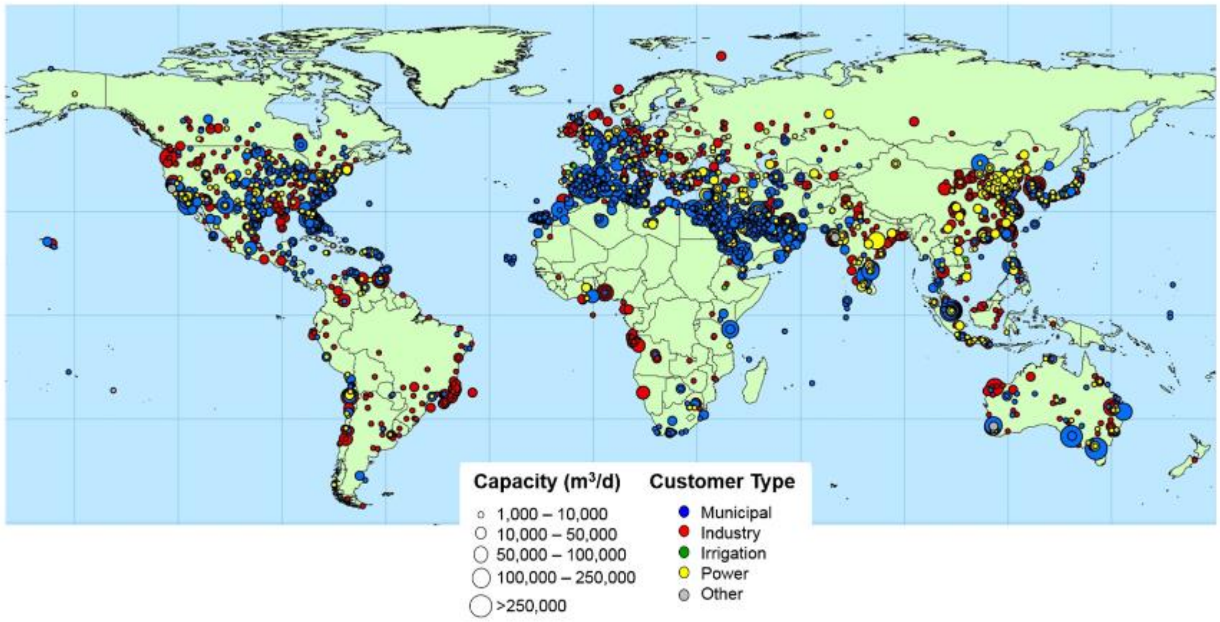


Figure 2 Global distribution of Desalination Plants, Source: Jones et al., "The State of Desalination and Brine Production

Pakistan is an agriculture-based economy that relies on the Indus River system to cultivate and provide safe drinking water to its denizens. The prospects of desalination are immense, but the government has not placed desalination on the priority list because of the cost-effective management techniques. Most experts working in the water sector emphasize more on the management of water resources because most of the water loss in the country is because of poor management. However, the National Water Policy 2018 mentions desalination as a potential source of water supply augmentation, and it acknowledges its importance for water-deprived communities[33].

[32] Jones et al.
[33] National Water Policy 2018

V. Feasibility of Desalination in Pakistan

A. Evaluation of Pakistan's coastal regions as potential desalination sites

With a coastal line stretching up to 1046 km, the country holds huge potential for desalination sites. Corporations working in the mining and energy sector have established small brackish desalination plants to meet their water demands, but nothing substantial has been planned in Pakistan.

Figure 3 Pakistan Coastal line, source: BBC

One of the first desalination plants based on RO method was built in 1987 in Saindak Copper Mines in Balochistan and later a plant based on MSF technology was built in 1996 in the HUBCO station in Karachi base[34]. The country had minor experiments with desalination in different pockets, but no national-level project has been carried out.

At present, there are only a handful of desalination plants functioning in Pakistan. Under the China-Pakistan Economic Corridor, the city of Gwadar is getting a desalination plant. With a total cost of 12.7 million dollars, the plant is expected to produce 1.3 million gallons per day[35]. The government of Sindh has established a desalination plant on Manora Island to provide its residents with water[36]. However, there are many failed attempts as well. The Defence Housing Society (DHA) and Cogen Limited collaborated on a desalination plant that stopped working after starting to produce water[37]. Since, the confluence of capital, energy, and technology is essential for a functioning desalination plant, Pakistan lacks in all three spheres. When capital, energy, and technology are managed, the lack of trained humans resource makes desalination a lackadaisical proposition.

C. Technological and infrastructural requirements for implementing desalination projects in Pakistan

Desalination plants are capital-intensive and technologically driven, requiring highly trained human resources to run and maintain. In both cases, the country fares behind. The capital-intensive nature and maintenance issues make desalination a worrisome affair. The conventional projects are tried and tested and the workforce feels confident in their implementation.

[34] 2023. SLMDC Limited. Accessed May 23. http://slmdc.com.pk/knowledgebase/desal.html.
[35] “1.2 MGD Desalination Plant: China-Pakistan Economic Corridor (CPEC) Secretariat Official Website.” 2023. 1.2 MGD Desalination Plant | China-Pakistan Economic Corridor (CPEC) Secretariat Official Website. Ministry of Planning, Development, & Special Initiatives. Accessed May 23. https://cpec.gov.pk/project-details/92.
[36] Siddiqui, Tahir. 2022. “Desalination Plant at Manora to Be Ready in July, Murad Told.” DAWN.COM. January 1. https://www.dawn.com/news/1666966.
[37] Sahoutara, Naeem. 2014. “Cogen Plant: Dha Residents’ Dream Goes Sour.” The Express Tribune. April 5. https://tribune.com.pk/story/691919/cogen-plant-dha-residents-dream-goes-sour.

VI. Economic and Environmental Considerations

A. Cost analysis of desalination compared to other water supply options

The cost analysis of desalination compared to other water supply options is essential to understand the barriers and benefits of desalination. The established water supply systems have achieved economies of scale rendering their comparison with desalination useless because the initial investments have been made in the past. Comparing the cost of a new desalination plant with an established supply system will not be helpful. However, once the desalination plants run for a long period of time achieving scale, then it would be wise to compare the costs. For example, the San Diego County Water Authority spends nearly $1,200 for each acre-foot of water that is pumped hundreds of miles to Southern California from the Sacramento San Joaquin River Delta and Colorado River. A year's worth of supply for a family of five from the Carlsbad desalination plant costs roughly $2,200. The San Diego County Water Authority spends nearly $1,200 for each acre-foot of water that is pumped hundreds of miles to Southern California from the Sacramento San Joaquin River Delta and Colorado River. A year's worth of supply for a family of five from the Carlsbad desalination plant costs roughly $2,200[38].

In Pakistan, there is no pricing mechanism or cost accounting that can tell the cost of providing water to communities and businesses. The water metering system does not function properly as the majority of people in cities do not pay their water bills. The lack of regulations on underground water has made it easy for families and commercial units to bore their water. The lack of water billing works as another barrier for desalination plants. This supports the experts' findings that Pakistan does not have a water scarcity issue, but rather a management issue.

The increasing cost of capital, energy, and technology has put desalination beyond the government's possible strategies. Secondly, the lack of supply structures will also hamper

[38] Robbins, Jim. 2019. "As Water Scarcity Increases, Desalination Plants Are on the Rise." Yale E360. Yale School of the Environment. June 11. https://e360.yale.edu/features/as-water-scarcity-increases-desalination-plants-are-on-the-rise.

any attempts to connect desalination output. The existing water supply structure is poorly managed and maintained without any overhauls.

B. Environmental impacts of desalination and mitigation strategies

The environmental impacts of desalination are huge, but concerted research and development is focused on dampening and mitigating the negative impacts of desalination. As mentioned earlier, the desalination plants are energy intensive resulting in huge emissions, damaging the aquatic life while water intake and brine disposal. These environmental impacts are pertinent while venturing desalination plants.

C. Economic benefits and long-term sustainability of desalination in Pakistan

A comprehensive feasibility assessment and complementary network will usher in desalination's economic benefits and will ensure the long-term sustainability of the desalination. However, existing cities in the country do not have adequate supply lines to get benefits from a desalination facility. In case, the government decides on building new cities along the large coastline providing water to the cities through desalination plants, only then the true economic benefits of desalination plants can be calculated. However, these out-of-the-box ideas must be debated and consulted otherwise cities are already overpopulated and resourced-burden and they will turn into a monster in the coming years.

VII. Social and Cultural Factors

A. Social acceptance and community engagement in desalination projects

There are no comprehensive studies looking at the social acceptance of desalination projects in the country because there are only a few small-scale projects. In land Brackish water small RO plants are increasingly becoming a regular phenomenon in rural Sindh and Southern Punjab[39]. The study of the Gwadar desalination facility will provide insights into community engagement and social acceptance of the desalination projects. Historically, there are no cultural or social barriers to desalination technology because there have been no attempts at providing drinking water through desalination. Most projects around water are top-down projects that hardly account for community perception and considerations. Public goods are shoved down without any community consultations. There are no projects or studies on people's perceptions regarding desalinated water. These will be interesting findings. Community awareness and education regarding desalination will help the community realize the benefits and drawbacks of the projects.

VIII. Policy and Governance

A. Government policies and regulations related to desalination in Pakistan

The National Water Policy (NWP) 2018 acknowledges the importance of desalination for water supply. It emphasizes creating desalination as a mainstream mechanism for water supply in the country. Since NWP only provides a guiding framework and does not implement the said regulations. The building of infrastructure is open to public and private ventures. The desalination plant in Gwadar is a public venture as part of the CPEC projects and the failed Cogen facility in DHA Karachi was a private venture which failed.

B. Institutional frameworks for planning, implementing, and managing desalination projects, challenges, and policy interventions

There are no national projects on desalination. Since water is a provincial matter after the 18th amendment, the provincial governments are titled to lead any desalination projects in their respective provinces. Since the coastline is in Balochistan and Sindh, there have

[39] "Water for Thar: New Ro Plant in Mithi Supplying 'Brackish Water.'" 2015. The Express Tribune. February 1. https://tribune.com.pk/story/831266/water-for-thar-new-ro-plant-in-mithi-supplying-brackish-water.

been multiple attempts in building desalination plants, but nothing substantial has been achieved.

The adoption rate of desalination is on the rise globally, but in the case of Pakistan, these major-scale projects are not considered feasible[40]. The environmental concerns overshadow the ambitions and plans because the desalination technologies recovery ratio is low and it takes extra energy and effort to dispose of the hypersaline brine that is produced as a result. However, Sindh should promote desalination as a viable strategy because desalination technology has made progress and it can provide dividends in the long run if maintained properly. Scale is important for these projects.

IX. Conclusion

Desalination projects are increasing globally and they are operating in over 177 countries. As the water scarcity issues continue, the need for technologically-advanced and environment-friendly desalination plants will continue as well. The developed world is already benefitting from desalination plants, but environmental and energy concerns are still there. The disposal brine and the high energy costs make desalination an unviable option, but its stability to climate change impacts makes it a wonderful proposal. As climate change continues to impact water resources, desalination plants provide water irrespective of climate change impacts. Therefore, it holds great value for Pakistan. Pakistan is a water-scarce country with per capita water availability dropping. The regulations and policies are conducive for desalination plants, but the capital and energy-intensive nature and technology requirements are barriers to its adoption in Pakistan. The lack of investment strength has kept desalination out of the solutions to fight water scarcity. The extensive coastline has places where desalination plants can be built at a greater scale and the water burden on the conventional supply lines can be shared. Gwadar and Karachi are two major coastal cities that lack water for their denizens.

[40] Mughal, F.H. 2019. "Seawater Desalination Isn't Feasible." DAWN.COM. October 28. https://www.dawn.com/news/1513253.

Desalination plants can be answers to their water woes. The NWP emphasizes desalination, but the lack of essential elements is hampering Pakistan from benefitting from the facility.

X. Recommendations for future research and policy initiatives

Since research and development in the water resources sector blame poor management for water scarcity in the country, therefore, embarking on the expensive desalination plants, other cost-effective options must be tried and exhausted. Some recommendations for future research and policy initiatives.

1. Pakistan is vulnerable to climate change and so are its water supply options. Desalination should be considered for megacities because of their stability and resilience to climate change.
2. There is a need for a comprehensive feasibility plan and environmental impact assessment for desalination plants on the coastline.
3. Desalination should be pursued in small steps before scaling it. Technology and trained human resources are essential to run these mega plants.
4. There is a need for assessment studies comparing desalination costs with already established water supply infrastructure costs.