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Water import and transfer versus desalination in arid regions: GCC countries case study

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ABSTRACT

The scarcity of water resources and the increasing gaps between demand and available supply in the Gulf Cooperation Council (GCC) countries is a major challenging issue facing the development sectors. GCC countries have extremely dry climates with rare rainfall, high evaporation rates and limited non-renewable groundwater resources. At present all GCC countries except Oman fall in the critical water scarcity category which is about 500 m^3 of renewable water/cap/year. In addition, governmental policies with regard to increasing the level of food self-sufficiency through subsidies and other incentives, have contributed to a major expansion in and unrestricted use of non-renewable groundwater resources. This coupled with a lack of defined policies and strategies geared toward optimizing and managing the scarce water supplies within the GCC region, have contributed to wasteful and uneconomic practices, as well as to the inefficient mining of non-renewable supplies. To meet the present and future water demands of the region the available options are limited to either long distance water transfer and import from other countries or investing in large scale seawater desalination installations. In this paper the economical, technical, sustainability and the political criteria affecting the two alternatives have been evaluated. Economic analysis revealed that the cost of long distance water transfer can escalate to more than 0.83 US$ per cubic meter. When sustainability considerations are taken into account this figure may reach up to 2.35 US$ per cubic meter. While these figures were competitive with the cost of seawater desalination 20 y ago, the situation has been recently shifted in favor of seawater desalination which dropped from 5.5 US$ in 1979 to less than 0.55 US$ in 1999 using the RO technology. It is concluded that sustainable development of GCC countries will depend in the future on large scale desalination. This fast growing technology should replace or at least be considered a viable alternative to presently planned water transfer projects. Expanding desalination capacity in the next 20 y will be possible by building new plants or upgrading the existing facilities in GCC countries. This process, however, will require high economic investment.

Keywords: Water transfer; Desalination; Water demand; Water management; Cost analysis; Decision making

1. Introduction

Water is essential for all forms of life and is a fundamental resource for human survival and socio-economic development in addition to maintaining healthy ecosystems. Consequent to rising demands, water is rapidly becoming a scarce resource for most of countries in the arid and semi-arid regions which requires new methods and innovative approaches for water conservation and judicious use. The dependence of rapidly growing development sectors on water in these regions holds a special place in the water scarcity and management debate [1]. The increased pressure on water resources due to (1) population growth – demanding not only more water for food, but also inducing changes in hydrological cycle,

(2) changes in life style and urbanization and (3) climate change, lead to water scarcity and increased competition for water between agriculture, industries and the rapid growing cities. Water tables are now falling in most of the arid and semi-arid region of the world.

GCC countries are a part of water competitive world and water deficit grows larger with each year, making it potentially more difficult to manage. Conventionally available water supplies from renewable sources in these countries are simply insufficient to meet the increasing water demands of the present modes of economic activities and resource exploitation. The six counties that comprise the GCC occupy a total land area of 2.7 million km² and their combined population is currently over 30 million and is expected to top 40 million by 2010. Over the last quarter of a century there has been a three- and four-fold increase in population and total water use respectively as shown in Fig. 1. At the start of the third Millennium, all GCC countries, except Oman (583 m³/cap/year) fell in the critical water scarcity category; <500 m³ renewable water/cap/year. Total water demands are expected to increase 36% over the next decade. Today 91% of the combined total water demand is abstracted from groundwater, 7.2% by desalination of ground and seawater and the remainder from treated effluent and surface water. On average, agriculture accounts for 85% of all water used and the current deficit of water resources is estimated at 15 Bm³ [2]; a detailed summary of water resources of GCC states is not discussed here but can be found elsewhere [3]. All GCC countries are becoming increasingly dependent on the non-sustainable mining of local groundwater aquifers that are presently threatened by pollution and depletion. This makes it essential to start giving serious consideration to non-conventional water resources for their full potential development. The search is on for alternative water supplies that are economically viable, environmentally sound and socially equitable [4]. Many researches indicate that in order to meet the present and future water demands of the region, the available options are limited to long distance water import and transfers from neighboring countries or to investing in large scale seawater desalination technology [5–7]. In this paper the proposed projects for water import and transfer will be analyzed and discussed.

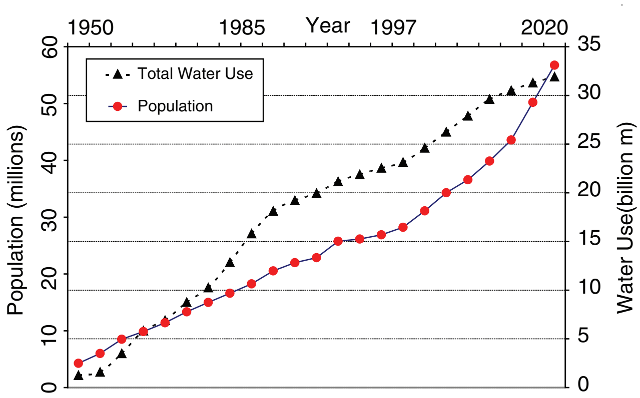

Fig. 1. GCC countries population and water use 1950–2025.

2. Present status of water resources

2.1. Groundwater resources

Many groundwater aquifers in GCC countries are being mined in an uncontrolled and unplanned manner, either because it has not been possible to regulate the access to these aquifers and/or they are non-renewable. Unplanned groundwater mining erodes the economic and social sustainability of the communities that depend on the depleting storage. Whether the groundwater mining is inadvertent or planned, there is a need for guidelines to make the concerned communities better prepared economically and socially to cope with the increasing water stresses as the storage is depleted.

Table 1 shows that the annual groundwater recharge in GCC countries is about 4875 MCM. Groundwater

Table 1
Renewable water and groundwater use in the GCC countries (2009)

Country	Population (× 1000)[a]	Renewable resources (MCM)			Groundwater use (MCM)	GW significance, in terms of:	
		Surface water	Groundwater	Total		% of renewable GW to total renewable water	% GW use to total demand
Bahrain	1106	0.25	100	100.25	260	99.7	68.5
Kuwait	2500	0.15	160	160.15	415	99.9	62.5
Oman	2900	918	550	1468	1750	37.5	79.0
Qatar	1450	1.60	85	86.60	210	98.1	50.0
Saudi Arabia	25,200	2350	3850	6200	15,230	62.0	78.5
UAE	4800	190	130	320	2800	40.6	70.0
Total	37,956	3460	4875	8335	20,665	58.5	68.0

[a]Based on the 2010 GCC council statistics.

abstractions during 2009 exceeded the annual replenishment of about 15,790 MCM. Thus, considerable groundwater mining takes place, mainly for irrigation use. Because of the overexploitation, the actual contribution of groundwater to the total use in the region is about 68%. At country level, groundwater abstractions are currently the main source of water in the GCC countries. Overall, the contribution of groundwater abstractions to total demand ranges from less than 50% (in Qatar) to more than 78% (in Saudi Arabia).

As a consequence, the groundwater quality has been threatened by increasing levels of depletion and pollution and the salinity in many local areas increased from less than 500 to more than 10,000 ppm or even more. Moreover, using such poor quality water has negative environmental impacts.

2.2. Desalinated water production

In order to meet both the qualitative and quantitative requirements for drinking water standards, domestic water supplies in the GCC countries rely mainly on water produced in desalination plants, which is used either directly or blended with groundwater. Rural areas have been provided with water from a number of desalination plants where water is transferred over long distances from coastal areas to interior regions. Desalination of seawater and brackish groundwater will continue to be a viable water supply augmentation option for large number of urban centers in GCC countries. Considering recent cost-cutting innovations in the desalination process, this alternative may prove to be a relatively inexpensive supply option in comparison to the development of conventional sources located in remote areas. The availability of desalinated water at relatively low cost may also be an attractive means of meeting industrial water demand because industries have been willing to pay for water at rates higher than domestic and agricultural rates. In 1990 the GCC countries together produced 1557 MCM annually with a daily rate of about 4.26 MCM or 30 l a day per capita at the national average [8]. In 1990 the total annual desalinated water capacity was about 2012 MCM with a total of about 1548 MCM water produced as shown in Table 2 [9].

In order to meet domestic water demands, which is a function of population and urbanization growth, the GCC countries are going ahead with the construction of desalination plants, despite their relatively enormous costs, which range between 1 and 1.5 US$/m^3. The total annual desalination capacity of the GCC countries in 2009 was about 3924 MCM. Many types of desalination processes are used such as multi-stage flash distillation (MSF), reverse osmosis (RO), multi effect desalination (MED), and others. MSF is mainly used to treat seawater and dominates the desalination market by more than 74% while RO is used mainly for brackish groundwater treatment. A growing trend is toward the application of RO in the desalting of seawater due to the advanced development in membrane technology. Limited numbers of MED plants are currently in use [10–12].

2.3. Reuse of treated wastewater

Introduced in the early eighties in most of the GCC countries, treated wastewater represents one of the most important alternatives that can be used to meet some of the present water requirements and to lessen the long-term supply vs. demand imbalance faced by these countries. Due to completion of sewage water treatment facilities and the expansion of urban sewage networks in most of the GCC large cities, relatively large volumes of treated wastewater have become available, and because of environmental considerations, have been treated completely or partially regardless of their source. Some of the issues encountered in wastewater treatment and usage in some GCC countries are the low rate of wastewater treatment

Table 2
Past and present desalination schemes in GCC countries [12]

Country	1990			2009		
	Desalination production (MCM)	Domestic demand (MCM)	Desalination to domestic demand (%)	Desalination production (MCM)	Domestic demand (MCM)	Desalination to domestic demand (%)
Bahrain	56	103	54	204	222	92
Kuwait	240	303	79	545	502	108[a]
Oman	32	86	37	163	582	28
Qatar	83	85	98	172	291	59
Saudi Arabia	795	1700	47	1340	5059	26
UAE	342	540	63	1500	964	155[a]
Total	1548	2817		3924	7620	51

[a]Production of desalination is more than the domestic demand in UAE and Kuwait. Part from the desalinated water is used for irrigation and landscaping.

Table 3
Present and future treated wastewater production and use in GCC countries

Country	2009			2015
	Treated wastewater production (MCM)	Treated wastewater use (MCM)	Used to production ratio (%)	Additional capacity planned by 2015 (MCM)
Bahrain	81	76.2	94	102
Kuwait	254	226.0	89	290
Oman	39	29.3	75	84
Qatar	104	98.8	95	160
Saudi Arabia	712	320.4	45	812
UAE	352	228.8	65	587
Total	1542	979.5	63.5	2034

due to the limited sewage network coverage (around 60% in the main metropolitan areas) as a result of the rapid rate of population growth; treatment capacity constraints in the major urban centers that require high investment costs; and the high proportion of wastewater that is treated but not used. Table 3 displays the current treated volumes of wastewater and the reused volumes in the GCC Countries.

At present, all the six GCC countries are operating modern treatment facilities with tertiary and advanced treatment capabilities. The total designed treatment capacity of the major facilities is more than 1600 Mm^3/y, with a present total treated wastewater volume of more than 1542 Mm^3/y. However, the recycled volumes of these waters are about 979.5 Mm^3/y, which is about 71% of the total treated wastewater. Recycled water is used mainly for urban uses (irrigating gardens, roads ornamentals, etc.), for irrigation of fodder crops, and for highway roadside landscaping. In 2009–2015, more than 2034 Mm^3/y of new treatment capacity is expected to be added in the region [13]. Fig. 2 shows the percentage of water use by source (Year 2009) which indicated that groundwater spite its deterioration is still the main source of water use by about 79% and the desalinated water contribute by about 16% and the treated wastewater is only 6% with future potential for increase.

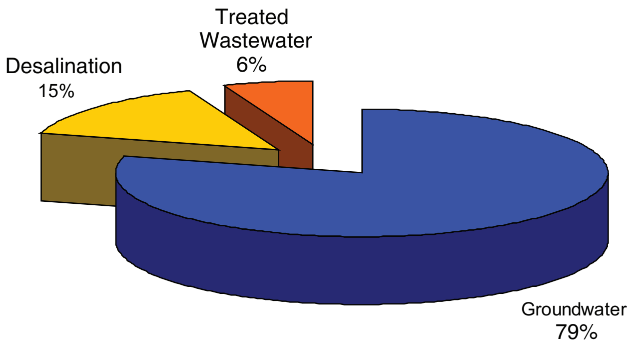

Fig. 2. Percentage of water use by source (2009).

3. Water demand

Population growth and rapid development in the agricultural and industrial sectors in GCC countries are major issues affecting all sustainable socio-economic development [14]. The estimated population in 2009 was 37.95 million with an average growth rate of 3.70% [15]. Population projections for GCC countries over the period 1995–2025 are given in Table 4.

The total renewable water in the GCC countries in 2009 amounted to 8335 MCM. The high population growth rate in the region exceeds by far the rate of water

Table 4
Past and projected population in GCC countries

Country	Population (× 1000)			Projected population (× 1000)				Percentage ration (2025/1995)
	1995	2000	2009	2010	2015	2020	2025	
Bahrain	557	618	1106	1115	1310	2041	2366	325
Kuwait	1691	1966	2500	2590	3003	4678	5423	221
Oman	2027	2717	2900	3150	4020	8358	10,667	426
Qatar	548	599	1450	1530	1953	4060	5181	845
Saudi Arabia	18,255	21,661	25,200	26,222	31,903	57,456	69,904	283
UAE	2210	2410	4800	4950	6022	10,846	13,196	447
Total	25,288	29,597	37,956	39,572	48,211	87,438	106,736	322

resource development. Consequently, the annual per capita share of water resources is decreasing, and at an increasing rate. Five countries in the region have a per capita water use of less than 500 cubic meters a year, half the benchmark of 1000 cubic meters a year which indicates chronic water scarcity. The national economy of most countries depends on oil and oil-related industries, commerce, light industries, and agriculture, in this descending order. Due to the fast increase in population and urbanization, domestic water and industry needs are escalating at rates with which available water resources cannot keep pace. Furthermore, the adopted policy of food self-sufficiency imposes continual constraints on the allocation of water resources, which would otherwise reduce the share for agriculture in favor of increased domestic and industrial demand [16]. Currently the agricultural sector takes 85% of available water resources followed by domestic water use at 14% and 4% for commercial and industrial use as shown in Table 5 [17].

The water stress experienced by the GCC countries in 2009 is expressed in Table 6 as the percentage of available water resources actually used [11]. The index reaches values of over 100% in five of the six countries and critical values in the remaining one. This indicates that these countries have already exhausted their renewable water resources and are now exploiting non-renewable reserves. The overall value of the water stress index is 252%. From this deteriorating water stress index, it is clear that current water resources cannot satisfy future water demand unless positive steps are taken soon to rationalize water demand management, increase and augment supply, and impose realistic controls on use. The negative impacts include fast depletion of aquifer reserves, possible conflicts arising from differential use of aquifers shared between states, deteriorating water quality and salinisation of agricultural lands. Furthermore, existing wastewater treatment facilities can cope with only 75% of urban and industrial waste. Pollution from inappropriate disposal of untreated wastewater will create health hazards through the contamination of shallow groundwater aquifers. These issues are all aggravated by a general weakness among the institutions dealing with water affairs. This is due to inadequate technical capabilities and unsatisfactory coordination between concerned water authorities [18].

4. The available mitigation measures and options

Escalating water demands during the past 20 y in the GCC countries has led to severe pumping and overdraft of the local groundwater aquifers with limited

Table 5
Past and projected water demand in GCC countries (MCM) [17]

Country	1995			2000			2025		
	D[a]	A[a]	I[a]	D[a]	A[a]	I[a]	D[a]	A[a]	I[a]
Bahrain	86	120	17	117	124	26	169	271	169
Kuwait	295	80	8	375	110	105	1100	140	160
Oman	75	1150	5	151	1270	85	630	1500	350
Qatar	76	109	9	190	185	15	230	205	50
Saudi Arabia	1508	14,600	192	2350	15,000	415	6450	16,300	1450
UAE	513	950	27	750	1400	30	1100	2050	50
Total	2553	17,009	258	3833	18,089	676	9679	20,466	2229

[a]D: Domestic; A: Agriculture and I: Industrial.

Table 6
Water stress index in GCC countries (2009)

Country	Population (× 1000)	Renewable water resources (MCM)	Exploited water resources (MCM)	Per capita water resources (m^3/y)	Water stress index (%)
Bahrain	1106	100.25	287	255	250
Kuwait	2500	160.15	538	280	160
Oman	2900	1468	1841	750	85
Qatar	1450	86.60	439	500	180
Saudi Arabia	25,200	6200	21,155	390	310
UAE	4800	320	3112	350	393
Total	37,956	8335	25,872	420	230

extent and limited annual recharge. These aquifers have been exposed in several locations to unacceptable levels of piezometric declines and seawater intrusions with disastrous environmental and socioeconomic impacts. However, since there are no available surface water supplies to remedy the resulting deteriorating situation, the only available options are limited to the following:

(1) Expanding groundwater exploitation in newly developed, previously untapped, aquifers
(2) Investing in large scale seawater desalination technology; and
(3) Importing and transferring water from neighboring countries

The first option is considered as a short-term mitigation measure and cannot be considered as long-term due to the limited extent of these aquifers which have a limited potential. Expanding groundwater exploitation will lead to severe environmental, health and economic problems. The cost of groundwater pumping will increase dramatically due to the drop in the water table and the effect of increasing groundwater salinity on pumps and wells which will shorten their life time and increase rehabilitation and maintenance costs. Therefore the other two options are discussed in terms of technical, economical, environmental and political issues in this paper.

4.1. Large scale seawater desalination

Seawater desalination has become a major water supply component in the GCC countries as a result of groundwater salinity problems and the remote locations of potential groundwater sources that exist far from major urban areas. The GCC countries, by necessity, have become the world leaders in sea and brackish water desalination. However, the cost of water production remains high, ranging from 0.5 to 1.5 US$ per cubic meter, which is substantially higher than what the public is charged. Desalination technology in the region has been clouded with several misconceptions and lack of understanding its multifarious aspects. Top level decision makers usually associate desalination with international companies of imperialist tendencies that monopolize this technology to extract the highest possible price for its products. These misconceptions should be immediately corrected since all available facts and information, as will be demonstrated later, clearly indicate that desalinated water is no longer as expensive as it has been thought and desalination technology is not monopolistic.

4.1.1. Projection of future potential in desalination growth

The current per capita desalination capacity Q_{2003} m^3/cap/day can be calculated from seawater and brackish water desalination for municipal use and attributed to the current urban population in each country according to Eq. (1)

$$Q_{2003} = \frac{(Q_{sw} \cdot Y_{sw} + Q_{bw} \cdot Y_{bw})}{N_{2003} \cdot U} \quad (1)$$

where Q_{sw} and Q_{bw} are seawater and brackish water desalination capacity (m^3/day), Y_{sw} and Y_{bw} are the share of municipal water from sea and brackish water desalination, respectively, N_{2003} is the current population in each country, and U represents the share of the population in urban centers [19].

To estimate the potential growth in the municipal water desalination industry, the following assumptions were made:

- Growth in desalination is determined based on the rate of population increase in the GCC countries in the next 25 y.
- Only the population in urban areas will use desalination to augment their current water supply.
- By the year 2025, water for municipal (domestic) supply will be met completely from desalinated water and no surface water or withdrawals of groundwater will be used for municipal use in any of GCC countries.

The potential growth in desalination in each of GCC countries was calculated by the difference between the present desalination capacity at year 2003 and the required demand for domestic water supply by the year 2025 and can be expressed by Eq. (2).

$$\Delta Q_{2025} = Q_{2025} - Q_{2003} = (N_{2025} \cdot U \cdot WW_{2025}) - \left[\frac{Q_{sw} \cdot Y_{sw} + Q_{bw} \cdot Y_{bw}}{N_{2003} \cdot U}\right] \quad (2)$$

where N_{2025} is the projected population of each country by 2025 and WW_{2025} is the per capita municipal domestic water use by 2025 in (m^3/cap/day).

The development of desalination for municipal use between 1990 and 2002, and the projected growth in desalination capacity in the GCC countries for the next 20 y is summarized in Table 7. The driving force determining the need for the desalination development is assumed to be the increase in population. However, due to limited potential of brackish groundwater, there will also be a need for using desalinated water in agriculture, parks, gardens and forests. This will most probably increase the desalination production by the year 2025 if there is no reform to the agricultural policies in these countries to stop the expansion in, or even reduce the area under irrigation.

Table 7
Estimated future development in the desalination market

Country	1990		2009		2025	
	Population (× 1000)	Desalination production (MCM)	Population (× 1000)	Desalination production (MCM)	Population (× 1000)	Estimated desalination production (MCM)
Bahrain	404	56	1106	123	1483	162
Kuwait	1292	240	2500	589	4744	750
Oman	1503	32	2900	68	5517	115
Qatar	358	83	1450	194	1312	253
Saudi Arabia	13,090	795	25,200	1063	48,051	1690
UAE	1459	342	4800	813	5355	1357
Total	18,086	1548	37,956	2850	66,391	4327

4.1.2. Desalination costs

Cost is a primary factor in selecting a particular desalination technique for fresh water production. Desalination costs have decreased markedly in the last few decades as shown in Fig. 3. The recent studies and analysis indicate that the cubic meter production cost of desalination for seawater based on the Gulf seawater quality having a TDS of 45,000 ppm in GCC countries ranges from 0.86 to 1.06 US$ depending on the ratio of recovery [20]. The total cost including the production and transfer of the water to the end users (at household levels) ranges between 1.7 and 2.1 US$ [21]. Table 8 summarizes the cost elements included in a seawater desalination plant. However the cost for desalinating brackish groundwater will be less than these figures using RO technology. For example, the costs of desalinating brackish groundwater in GCC countries using RO have reduced from 2.5 to 0.38 US$/m^3 and this will continue decreasing in line with improved membrane plant performance (e.g., decreased water pressure requirements, increased rejection of salt, longer operating lifetimes, improved energy recovery, and plant automation) and improved economics associated with large scale production of membranes. Also it is very important to mention that in any evaluation of desalination costs it is important to consider the hidden costs associated with using water with a high salt or mineral content.

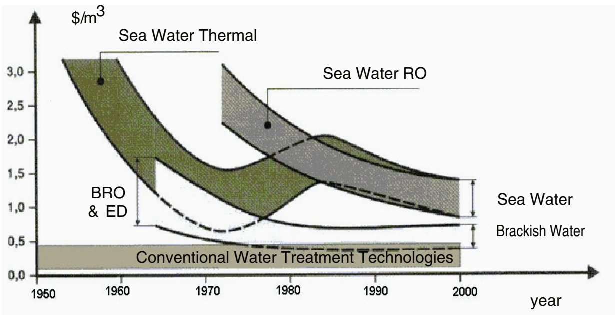

Fig. 3. Reduction in desalination costs in last 40 y.

Table 8
Costs for seawater desalination production

Cost item	Cost in US$/m^3 (35% recovery)	Cost in US$/m^3 (45% recovery)
Capital costs	0.35	0.29
Operation staff	0.048	0.048
Chemicals	0.10	0.08
Energy	0.43	0.33
Maintenance	0.138	0.11
Total (US dollars)	1.06	0.86

4.1.3. Effect of energy cost on desalination

Energy costs represent a significant contribution to the cost of produced water from the different desalination systems, with an average that varies between 20% and 30% and up to 50% for MSF. As a result, energy costs could become prohibitive for the MSF and it would far exceed the membrane replacement unit cost. In this case, the economic advantages of the RO system would be very significant. Fig. 4 illustrates the effect of fuel prices on the cost of desalinated water using MSF and RO systems. The figure shows the slight impact of energy prices on RO systems and the remarkable impact on MSF systems and that this would also vary with the capacity of these systems as shown by the range of prices [20].

4.1.4. Approaches for desalination cost reduction

One way to reduce the cost of desalinated water is to improve the desalination technology and increase the performance ratio (the ratio of fresh water to the amount

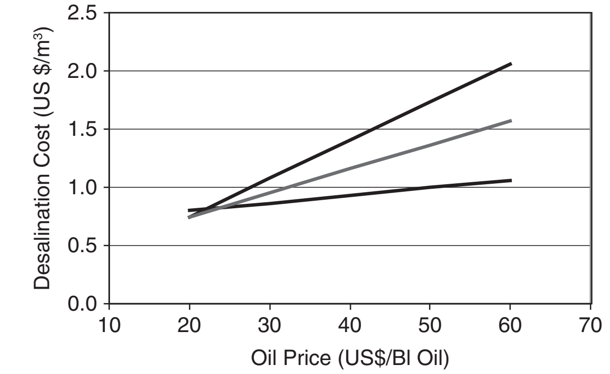

Fig. 4. Effect of energy cost on the cost of desalinated water using MSF and RO.

of energy consumed). There are a wide variety of water production costs, depending on plant size and energy prices. Usually, costs decrease with increased plant capacity [22]. Costs reported by the GCC countries are usually less than for countries in the rest of the world because of subsidized energy charges. For example, the cost of producing 1 m^3 of water in Saudi Arabia ranges from $0.48 to $2.00; from $1 to $1.45 in the United Arab Emirates; $1.14 to $1.64 in Qatar and $0.56 in Bahrain. Over the past 15 y, major advances have been made in certain desalination technologies, which have resulted in notable cost reduction [23]. Several approaches were proposed by different experts in the field for reducing the cost of desalinated water from conventional desalination plants [24–27].

4.2. Water import and transfer

Due to the severe shortage of renewable water resources in the GCC countries and the cost of using non-conventional resources such as desalination, various projects to import and transfer water from neighboring countries have been suggested.

4.2.1. Turkish peace water pipelines

The concept of exporting Turkish water to promote regional peace and economic development in the Middle East has been a constant in Turkish foreign policy since the late President Turgut Özal in 1986 proposed an extensive "Peace Water Pipeline". This was a $21 billion project to bring vast quantities of water from the Seyhan and Ceyhan Rivers via two pipelines with a length of about 6500 km to supply the major cities in Syria, Jordan, and the GCC countries. The pipelines could convey 10 million cubic meters of water every day, which was estimated as sufficient to meet the needs of 15 million persons. Table 9 shows the water share of each country from the proposed two pipe lines [28].

Table 9
Water share of each country from Turkish peace water pipelines [28]

Western pipeline		Eastern pipeline	
Country	Water share (m^3/min)	Country	Water share (m^3/min)
Turkey	300	Kuwait	600
Syria	1100	Saudi Arabia	400
Jordan	600	Bahrain	200
Saudi Arabia	1500	Qatar	100
		UAE	600
		Oman	200

4.2.2. The Nile option

In theory, another potential source of water for GCC countries is the Nile River. Some years back, an arrangement was proposed for importing and transfer water from the Nile to Saudi Arabia and then to the other GCC countries from either Sudan or Egypt passing through the Red Sea. The Nile River runs through 10 riparian countries in northern and eastern Africa: Burundi, Egypt, Eritrea, Ethiopia, Kenya, Rwanda, Sudan, Tanzania, Uganda, and Zaire. It is expected that due to Egypt's and Sudan's high population growth, increased irrigation activity, and worsening water quality, the two countries will not have sufficient water to meet their demand by the turn of the century. The primary agreement, the 1959 Nile Waters Agreement between Egypt and Sudan, dictates allocations from the Nile. This agreement basically allocates 66% of the flow to Egypt, 22% to Sudan, with the remainder to losses [29]. In practice, Egypt and Sudan would not be able to provide any Nile water to GCC countries. To do so would arouse fierce opposition and would undermine the water sharing agreements that Egypt and Sudan has so painstakingly negotiated with the other nine upper riparian states [30].

4.2.3. Importing water from the Karkheh Dam to Kuwait

In 2003, an agreement was signed between Iran and Kuwait to export water from the Karkheh Dam to Kuwait. The plan to transfer Iran's water to Kuwait was brought to public attention in the year 2000 and a consortium made up of British, Kuwaiti and Iranian companies took responsibility for drawing the plan and the executive operations.

According to the proposed plan, Iran's water will be transferred to Kuwait via a 540 km long pipeline. A 330 km pipeline will carry the fresh water to the farthest point on the bank of the Arvand River, located in Abadan, the capital of the province, and will be extended about 210 km toward the coast of Kuwait under the sea. This pipeline will supply Kuwait with 900,000 cubic meters of fresh water per day (10 cubic meters per second) from the Karkheh Dam, which is located in the southern oil rich province of Khuzestan, through the projected pipeline for 30 y. Based on the preliminary estimations, the project will cost 1.5 billion dollars and the revenue gained by Iran will apparently be spent on the construction of new dams and water installations in the country [6].

4.2.4. Importing water from India

One of the alternatives is to import and transfer water from India through the Omani Gulf to the northern Emirates in UAE. Then, a large dam will be constructed to reserve and pump the water into two pipelines to the other GCC countries. The eastern pipeline will divert the water to Oman while the western one will divert the water to Bahrain, Qatar and Kuwait. However, preliminary studies have indicated that the construction of this project is not feasible due to the complex physical environment the pipeline is expected to pass through.

4.2.5. Importing water from Pakistan

It was also proposed to import and transfer water from India through the Omani Gulf to the northern Emirates in UAE with the water then pumped into two pipelines to the other GCC countries. The eastern pipeline will divert the water to Oman while the western one will divert the water to Bahrain, Qatar, Saudi Arabia and Kuwait. Preliminary studies have again indicated that the construction of this project is not feasible due to the complicated physical setting the pipeline will pass through.

5. Sustainability and cost comparison

The only available example of mass water transfers that has been implemented in arid regions is the Libyan Great Man-made River project. After its completion the project will transfer and redistribute a total of more than 2 billion cubic meters per year. Whenever large-scale mass water transfers are considered, the financial resources available for investment in these projects and the expected cost of the transferred water are of prime concern. It is essential to compare the average unit cost of transferred water with the other potentially available alternate supplies. The economic analysis performed during project conception estimated the average unit cost of transferred water at about 0.25 US$ per cubic meter, which was highly competitive with other alternatives such as seawater desalination estimated at 2.5–3.0 US$ per cubic meter at that time. Actual economic studies performed after the completion of the first stage [9] revealed that the average unit cost of water to the user's gate, with the cost of capital set at 7% interest, is 0.83 US$ per cubic meter at 1991 prices. It is generally believed that this figure has been dramatically exceeded for the remaining stages of the project since that time.

While there is a clear trend of increasing costs of transferred water with time, the cost of desalinated seawater has witnessed a dramatic revolutionary trend in the opposite direction during the last two decades. The average price of desalinated seawater is today only one-tenth of what it was 20 y ago. It dropped from 5.5 US$ per cubic meter in 1979 to less than 0.55 US$ in 1999, including interest, capital recovery and operation and management. A Tampa Bay seawater desalination plant in Florida, USA, was contracted in 1999 at a cost of 0.45–0.49 US$ per cubic meter in the first year of operation. However, researchers always raise the issue of the vulnerability of desalination plants to pollution and emergency conditions.

In terms of cost comparison, it seems that mass water import and transfer projects in GCC countries at the moment have lost their economic advantages compared with the rapid development and cost reduction of new desalination technologies. When the questions related to sustainability considerations are raised, the advantages of the desalination option become more positive. Beyond the relative costs of desalination versus water imports from neighboring countries, the GCC countries were weighing the political risks. However, the Kuwaiti experience also pointed out the vulnerability of desalination plants. When the retreating Iraqi forces set many Kuwaiti oilfields on fire, large quantities of oil spilled into the Arabian Gulf affecting the production of the desalination plants. Some political commentators in the GCC countries have since questioned the sustainability of the giant multibillion dollar water import and transfer projects to GCC countries.

6. Conclusion and recommendations

From the previous analyses of the technical, economical, social, environmental, and political issues for the desalination and importing and transferring water to GCC countries, the following can be concluded:

- In the GCC countries, the need for more water is crucial to the goals of economic, social, industrial and environmental development. The available renewable water resources in the GCC countries have been fully utilized with extensive mining of the non-renewable groundwater resource, resulting in deterioration of the groundwater quality.

- It is clear that the water desalination industry is currently at an important stage, where the need for water availability and quality is increased in many places especially GCC countries. The production cost is declining due to healthy competition, while performance is improving along with production efficiency. No arguments are needed with respect to the quality of the water; the main struggle is still the cost of production. It is clear, however, that the cost of water is steadily declining so that more people can afford desalination.
- Expanding desalination capacity in the next 20 y will be possible by building new plants or upgrading the existing facilities in GCC countries. This process, however, will require high economic investment.
- The driving force determining the need for desalination development in municipal domestic water supply is assumed to be the population growth from 18 million in 1990 to 37.96 million in 2009 and to the projected 66 million by 2025. This will cause a continuous decline in the non-renewable groundwater resources.
- Depending on import and transfer of water from neighboring countries in the main developing sectors at GCC countries has many social, environmental and political constrains.
- Economic analysis revealed that the cost of long distance water import and transfer can escalate to more than 0.83 US$ per cubic meter. When sustainability considerations are taken into account this figure may reach up to 2.35 US$ per cubic meter. While these figures were competitive with the cost of seawater desalination 20 y ago, the situation has been recently shifted in favor of seawater desalination which dropped from 5.5 US$ in 1979 to less than 0.55 US$ in 2000. It is concluded that sustainable development of GCC countries will depend in the future on large scale desalination as a strategic resources. Presently planned water transfer projects should be substituted by this fast growing technology as the best option.
- Some argue that the best long-term solution is to build a network of large-scale desalination plants. However, even if additional desalination plants are approved quickly, these would take several years to be constructed. During these years, groundwater can be still used as short term solution.
- Though the construction of water import and transfer projects is technically possible, high costs and environmental and political impacts and several other serious problems remain to be solved. Moreover, imported water should not be used indirectly by the development sector (e.g., aquifer recharge).

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