Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2017.20864

81 (2017) 1–18
June

An overview of the GCC Unified Water Strategy (2016–2035)

Waleed Al-Zubari[a,*], Abdulaziz Al-Turbak[b], Walid Zahid[b], Khalid Al-Ruwis[b], Ali Al-Tkhais[c], Ibrahim Al-Muataz[b], Ahmed Abdelwahab[d], Ahmed Murad[e], Meshari Al-Harbi[f], Zaher Al-Sulaymani[g]

[a]*Water Resources Management Program, College of Graduate Studies, Arabian Gulf University, PO Box 26671, Manama, Bahrain, Tel. +973 17239880/+973 39433811; email: waleed@agu.edu.bh*
[b]*King Saud University, Riyadh, Saudi Arabia*
[c]*Shura Council, Riyadh, Saudi Arabia*
[d]*Texas A&M University, Doha, Qatar*
[e]*United Arab Emirates University, Al Ain, UAE*
[f]*Kuwait University, Kuwait City, Kuwait*
[g]*Oman Water Society, Muscat, Oman*

Received 2 April 2017; Accepted 2 May 2017

ABSTRACT

The Gulf Cooperation Council (GCC) countries are situated in one of the most arid regions in the world, with extremely poor endowment of freshwater resources. Despite the water scarcity, the GCC countries have done well in providing water for their ever-increasing population and rapidly expanding economic base. However, this has been achieved only by resorting to relatively very expensive and costly investments in water supply sources and infrastructures manifested by desalination, water treatment, dam constructions, as well as groundwater overdrafting. Being an important vector for socioeconomic development, there is a need for the establishment of an efficient and sustainable water management system to ensure that the water sector can continue to serve the countries' development needs. However, currently the GCC countries are facing several major challenges that are threatening the water sector sustainability. These include increasing water scarcity, increasing costs for infrastructure and service delivery, resources deterioration, increasing environmental and economic externalities, and many others. The main driving forces of these challenges are population growth and changing consumption patterns, low supply efficiencies, lower rates of water reuse and recycling, and low energy efficiency in the water sector. The intensity of these challenges is expected to increase in the future due to the additional driving force of the impacts of climate change. Realizing these challenges, the GCC Supreme Council has issued in its 31st summit (2010) the directive of "serious and speedy steps should be taken and endorsed by the GCC Supreme Council toward a long-term comprehensive Gulf water strategy". In 2016, a GCC Unified Water Strategy, 2016–2035 (GCC UWS) has been finalized by the GCC Secretariat General and approved by the GCC Supreme Council. This paper presents the main challenges facing the sustainability of the water sector in the GCC countries, the formulated GCC UWS (main themes and strategic objectives and their policies, key performance indicators and targets), the potential financial, economic, and environmental benefits from its implementation, and its expected overall contribution to the water sector sustainability in the GCC countries.

Keywords: Groundwater; Desalination; Wastewater; Municipal; Agricultural; Industrial; Security; Governance

* Corresponding author.

1. Introduction

Over the past four decades, the GCC countries have witnessed an unprecedented economic and social transformation characterized by increasing population (Fig. 1), high rates of urbanization, and accelerated industrialization. During this period, human development indicators, such as life expectancy, literacy rates, per capita income, and many other well-being indicators have substantially increased, and have reached developed countries standards, with some indicators in some GCC countries considered among the highest in the world.

As it is well known, oil plays a major role in the economies of the GCC countries, accounting for about a third of total gross domestic product (GDP) and three-fourths of government revenues and exports. A significant share of these revenues has been used to modernize infrastructure and improve the living standards of the population. Water supply and sanitation services have been made accessible to a large percentage of the population, reaching levels considered as the highest in the world.

However, such fast-paced socioeconomic development and its associated rapid population growth has been associated with substantial increases in water demands; sustainable water provision to the various development activities has grown to be one of the most challenging tasks faced by the GCC countries. This challenge is expected to grow with time due to many pressing drivers, including population growth, changing lifestyle and consumption patterns, increasing food demand, prevailing general subsidy system, anticipated climate change impacts, and many other drivers, forcing these countries into more expensive and costly investments in water supply sources and infrastructures (i.e., desalination, water treatment, dams, and groundwater wellfields). The heavy financial, economic, and environmental costs, as well as social costs associated with the provision of water supply cannot be overemphasized.

The GCC countries are experiencing a future of increasing water scarcity and water supply costs, which might not only threaten their future development, but also the preservation and sustainability of their past economic and social achievements. Therefore, the means and approaches to face the challenges of the water sector, as a strategically vital resource and essential input in the development process, will have a significant impact on the sustainable growth of these countries in the coming decades.

In this paper, the overall water resources conditions (i.e., resources and uses) and the main challenges facing the sustainability of the water sector in the GCC countries are presented. Then, an overview of the newly formulated GCC Unified Water Strategy is illustrated, and by using a number of key performance indicators (KPIs) and set targets the anticipated major benefits of its implementation are indicated.

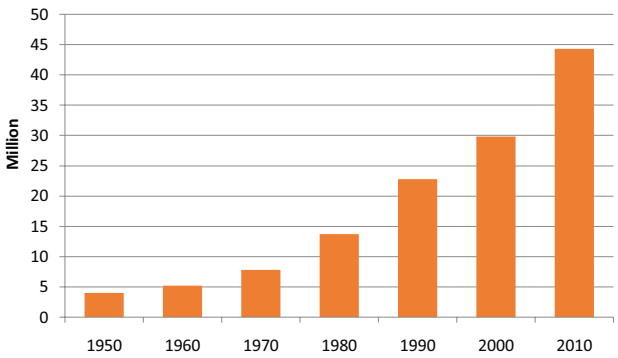

Fig. 1. Trends in GCC countries population, 1970–2010.[1] Data source: World Population Prospects, The 2015 Revision, UN Department of Economic and Social Affairs, United Nations Population Division (UNPD), available at: https://esa.un.org/unpd/wpp/.

[1]In 2012, the population has increased to about 49 million (Bahrain = 1.3, Kuwait = 3.8, Oman = 3.6, Qatar = 2.1, Saudi Arabia = 29.2, and UAE = 8.9 millions.

2. Water resources

The GCC countries are located in one of the driest regions of the world. With the exception of coastal stripes and mountain ranges, the region is essentially desert with harsh environment. It is characterized by low and erratic rainfall (70–150 mm/year), as well as high evaporation rates exceeding 3,000 mm/year, creating impossible conditions for a perennial surface water system to exist.

Under such extremely poor endowment of water resources and the ongoing trends in population growth, the region is increasingly becoming one of the most water-stressed regions of the world. It has one of the lowest per capita renewable freshwater resources in the world that continue to decline rapidly due to escalating population growth (Fig. 2). Overall per capita freshwater availability in the GCC countries has been rapidly declining from 678 m^3/year in 1970 to 176 m^3/year in 2000, and is currently at about 120 m^3/year,[2] considerably below the absolute water poverty line of 500 m^3/year.

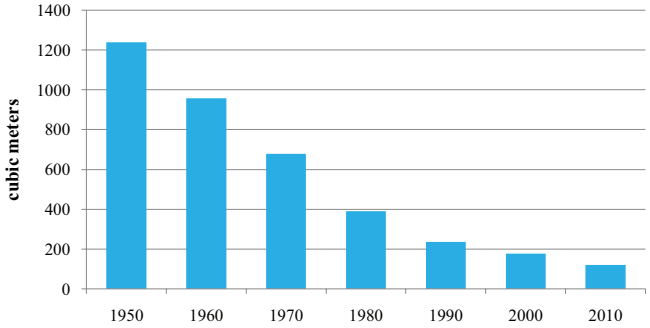

Fig. 2. Average annual per capita renewable freshwater in the GCC countries, 1950–2010.[3] Graph data sources: population data: UNPD, World population prospects, The 2015 Revision; conventional water resources data: UNESCWA [1]; WB and AGFUND [2]; and Al-Alawi and Abdulrazzak [3].

[2]Per capita renewable freshwater for the countries varies. Bahrain = 83, Kuwait = 44, Oman = 321, Qatar = 28, Saudi Arabia = 142, and UAE = 24 m^3/year.

[3]This calculation is based only on renewable "natural" water resources. However, it is customary in the GCC to add to the renewable groundwater resources the available non-conventional water resources, that is, desalination capacity and available wastewater. Adding these resources would increase the per capita water share and would give a better picture of the availability of water resources in the region.

Despite the rapid increase in water demands and the limitation of its conventional freshwater resources, the GCC countries have done well in providing water for their expanding municipal sector by resorting to desalination since 1970s. Furthermore, reuse of treated wastewater, particularly for irrigation, has started to become an important part of the water supply sources in many GCC countries since the late 1990s. Currently (2010/2012), the GCC countries water requirements, amounting to about 13.5 BCM are met mainly by groundwater abstraction and surface water harvesting (78%), desalinated water production (19%), and to a lesser extent by treated municipal wastewater (3%). Other water sources, such as irrigation drainage water, treated industrial wastewater, and fog harvesting, are being used/produced at relatively very low rates compared with other water sources and at localized small-scale.

2.1. Surface water and groundwater resources

Due to their locations, topography, and limited areal extent, Bahrain, Kuwait, and Qatar either have no surface water or it is too small to be utilized. However, for Oman, Saudi Arabia, and UAE, which have relatively vast areal extents and mountainous areas, there are good sources of surface water. Major efforts and investments are made in Saudi Arabia, Oman, and UAE to capture surface runoff by dam constructions reaching a total capacity of about 2.4 BCM, which serve multiple purposes: flood control, water supply, groundwater recharge, and irrigation. However, the fill rates in some countries show major fluctuation due to variation in precipitation.

The GCC countries depend primarily on groundwater to meet their water requirements, which is divided into two types. The first is the shallow aquifers, developed in the alluvial deposits along the main wadi channels and the flood plains of drainage basins. Shallow aquifers are the only renewable water source in the GCC countries. The second groundwater source is the non-renewable fossil groundwater stored in the sedimentary deep aquifers. These store significant amounts of groundwater that is thousands of years old laid down during the rainy Pleistocene and Pliocene geological periods, the majority of which are located in Saudi Arabia and Oman. However, these have a finite life as well as quality limitations. The quality of the deep aquifers varies greatly, being suitable for domestic consumption in only few areas. Most of the water from these deep aquifers is used for agricultural purposes. Table 1 summarizes the available water natural resources in the GCC countries as well as the current (2012) groundwater abstraction levels.

In all the GCC countries, a prolonged overdrafting of groundwater (Table 2) has resulted in a considerable decline

Table 1
Available conventional water resources in the GCC countries and groundwater abstraction, in million cubic meters (MCM)

Country	Annual rainfall[a] (mm)	Annual evaporation[a] (mm)	Available surface runoff[b] (MCM)	Groundwater (MCM)		
				Groundwater recharge[c]	Abstracted (2012)	Non-renewable reserve[d]
Bahrain	80	1,650–2,050	–	110[e]	103 (2010)	Negligible
Kuwait	110	1,900–3,500	–	160[e]	496 (2011)	N/A
Oman	20–300	1,900–3,000	102	900	1,216	102,000
Qatar	75	2,000–2,700	–	50	250	Negligible
KSA	70–500	3,500–4,500	3,695/2,400[f]	3,850	15,450	428,400
UAE	89	3,900–4,050	150	190	2,300	N/A

[a]Annual rainfall and evaporation figures are obtained from Al-Alawi and Abdulrazzak [1].
[b]Data collected from countries reports.
[c]Recharge figures represent recharge to shallow alluvial aquifers.
[d]Non-renewable reserves estimates are based on WB and AGFUND [2].
[e]Recharge to aquifers occurs by underflow from equivalent aquifers in Saudi Arabia, recharge is variable depending on the hydraulic gradient between the two countries and indicated figures represent steady-state conditions.
[f]Values indicate uncertainty in numbers.

Table 2
Groundwater abstraction/mining in the GCC countries

Country	Renewable volumes (MCM/year)	Abstraction volumes (MCM)			% of renewable volumes		
		1990	2000	2010	1990	2000	2010
Bahrain	110	167	195	103	152%	177%	93%
Kuwait	160	143	393	491	89%	246%	307%
Oman	900	1,204	1,240	1,216	134%	138%	135%
Qatar	50	111	270	248	222%	540%	496%
KSA	3,850	15,505	19,680	12,340	403%	511%	321%
UAE	190	1,148	2,673	2,300	604%	1,407%	1,210%
Total	5,260	18,278	24,451	16,698	347%	465%	317%

in groundwater levels/depletion, and significant saltwater intrusion (by seawater or up-coning) into freshwater aquifers resulting in degradation of the water supplies, abandonment of wells, cessation of flows from springs, and other adverse effects on groundwater-dependent sectors, especially the agricultural sector. Moreover, fossil groundwater, which have a finite usable reserve, are being mined extensively to mainly meet agricultural water demands, without "exit strategy" that include a balanced socioeconomic choices on the use of aquifer storage reserves and on the transition to a subsequent less water-dependent economy, and the replacement water resource.

Finally, in some GCC countries, renewable shallow groundwater is a vital natural resource for potable water supply in both urban and rural population (e.g., Saudi Arabia and Oman). However, many shallow aquifers in the GCC countries are being threatened and polluted by numerous point and non-point sources of pollution generated from anthropogenic activities (agricultural, industrial, and domestic), which pose health risks to the population. Groundwater protection strategies, for example, vulnerability mapping and wellhead protection areas restricting land use from hazardous anthropogenic activities, are missing in many countries.

2.2. Desalination

Desalination technology was introduced in the GCC countries in the mid-1950s and has developed very rapidly to counteract the shortage and quality deterioration in groundwater resources and to meet the qualitative requirements for drinking/domestic water standards. At present, municipal water supplies in major cities of the GCC rely mainly on desalinated water, which are used either directly or blended with groundwater. Fig. 3 shows the increasing trends in desalination capacity in the GCC countries. The current total desalination capacity in these countries amounts to about 4.7 BCM, with the majority of this capacity installed in Saudi Arabia (35%) and UAE (33%). Moreover, all the GCC countries are embarking on major desalination expansion projects. Based on the contracted desalination plants, it is expected that the desalination capacity of each GCC country would be doubled by the year 2016 [4].

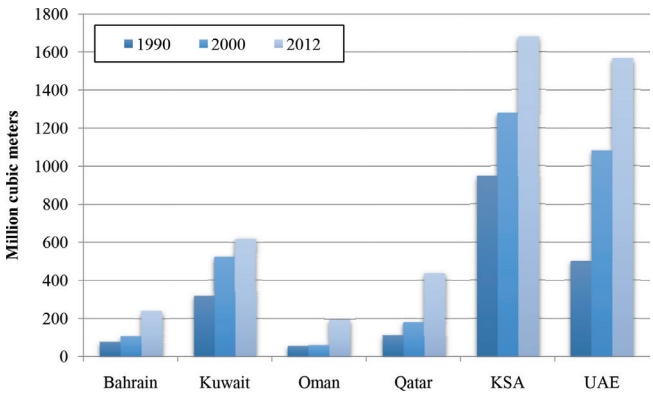

Fig. 3. Trends in desalination capacity in the GCC countries, 1990–2012, in MCM.

The primary desalination process used in the GCC countries is the thermal process, particularly the multi-stage-flash (MSF) distillation technology. This is an established technology and is combined with cogeneration of electricity, which greatly improves the economics of desalination. It also exhibits significant economies of scale which are critical for large-scale production. In addition, MSF plants have a useful life of about 25 years that can be nearly doubled through proper plant maintenance and refurbishment. An alternative thermal technology, the multiple effect distillation combined with thermal vapor compression, and more energy-efficient even for smaller desalination plants than MSF, has been increasing in the region in the past few years. On the other hand, while the GCC countries continue to rely on large-scale distillation plans, such as MSF, for bulk water supply in the foreseeable future, reverse osmosis technologies, both seawater and brackish water, have been gradually adopted with some relatively large plants now in operation in some countries, while in some countries it is still under evaluation.

2.3. Treated municipal wastewater

The GCC countries have made substantial progress in providing basic water and sanitation services to most of their population, which is a commendable effort given their rapidly increasing population and urbanization. From a water management perspective, treated wastewater in the GCC countries constitutes an increasing water source driven by escalating water consumption in urban areas.

At present, all the six countries are operating modern treatment facilities with tertiary and advanced treatment capabilities (Quaternary, e.g., Sulaibiya Water Treatment, Kuwait). The total designed treatment capacity of the major treatment facilities has increased from 1.1 BCM/year in the mid-1990s to about 1.4 BCM/year in 2008, and is currently (2011) at about 1.9 BCM/year. Most of the wastewater facilities are managed and operated by government authorities, with an emerging trend of privatization in most the GCC countries. All the GCC countries have adopted a centralized wastewater system; however, in the past few years some countries have started to move to a decentralized system.

3. Water demands

During the past four decades, total water demands in all GCC countries have increased dramatically as a result of high population growth and urbanization, improvements in the standard of living, industrial development, and efforts to increase food self-sufficiency. The total water use for all sectors in the region increased dramatically from about 6 BCM in the 1980 to about 27 BCM in 2000 (Table 3), while during the same period the population has increased from about 14 million to about 30 million. The major component of the total water demands in the GCC is the agricultural sector consumption. This period (1980–2000) has witnessed economic policies in most of the GCC countries that gave priority and support to the development and expansion of irrigated agriculture by mainly utilizing groundwater resources. Food self-sufficiency was the major economic goal

Table 3
Total water demands development in the GCC countries, 1980–2010, in MCM

Country	1980[a]	1990[a]	Growth rate (1980–1990)	2000[b]	Growth rate (1990–2000)	2010	Growth rate (2000–2010)
Bahrain	138	223	162%	269	121%	450	167%
Kuwait	186	383	206%	993	259%	1,179	118%
Oman	665	1,236	186%	1,303	105%	1,822	140%
Qatar	110	194	176%	433	223%	653	150%
KSA	2,362	16,300	690%	20,800	128%	17,446	84%
UAE	789	1,490	189%	3,506	235%	4,600	131%
Total	6,230	19,826	318%	27,304	138%	26,150	95%

[a]Al-Alawi and Abdulrazzak [3].
[b]WB and AGFUND [2].

Table 4
Water consumption by sector in the GCC countries in MCM (2010)

Country	Municipal	Industrial	Agricultural	Total
Bahrain	231 (51.3%)	29 (6.4%)	190 (42.3%)	450
Kuwait	646 (54.8%)	20 (1.7%)	513 (43.5%)	1,179
Oman	182 (10.0%)	94 (5.2%)	1,546 (84.8%)	1,822
Qatar	370 (56.7%)	22 (3.4%)	261 (39.9%)	653
KSA	2,283 (13.1%)	753 (4.3%)	14,410 (82.6%)	17,446
UAE	983 (21.4%)	477 (10.4%)	3,140 (68.2%)	4,600
Total	4,695 (18.0%)	1,395 (5.3%)	20,060 (76.7%)	26,150

and it is used to justify the expansion of certain grains and crops characterized as water intensive. Economic policies in some countries encouraged overpumping of groundwater for irrigation use.[4] These policies have resulted in substantial increases in groundwater abstraction volumes. In all GCC countries, the abstracted volumes far exceeded the renewable amounts of groundwater and the water deficit has been met by either overdrafting renewable groundwater resources, or mining of non-renewable groundwater sources.

While this trend continued with varying degrees in many GCC countries, in 2000 Saudi Arabia has made major review of its food self-sufficiency policy (phasing out wheat production) and irrigation water conservation programs,[5] which have resulted in a general decline in its irrigated areas and groundwater abstraction, which is reflected on the country's total water demands in 2010, as well as on the total GCC water demands, as shown in Table 3. However, the total water demands continued to increase in most of the other GCC countries.

Table 4 illustrates the sectoral water consumption in the GCC countries for the year 2010, as well as their share to the total water demands in each country. The overall agricultural sector water consumption constitutes about 77% of the total water demands, which is dominant in the countries of Oman (85%), Saudi Arabia (83%), and UAE (68%), while it represents about 40% of the total water demands for Bahrain, Kuwait, and Qatar. In the latter three countries, the municipal sector is the main water consuming sector (over 50%), with an overall share of about 18% in the region. In all the countries, the municipal water share has been observed to be increasing with time, which might probably hint toward competition on water resources in the future.

The water consumption of the industrial sector[6] represents the least share in the total water demands with an overall 5.3% share, varying between 10.4% in UAE to 1.7% in Kuwait. However, it should be noted that these figures do not account for the actual water use of the sector, where many industries have their own desalination plants and some are using the municipal water supply. It is expected that under the current GCC countries' plans to expand and diversify their industrial base to non-oil industries, the current industrial water consumption are much higher than the reported ones and the future would see rapid increases in demand for water in this sector. However, it is also expected that the majority of the water requirements of the industrial sector would be met by its own desalination plants.

[4]Subsidized prices of gasoline and electricity, subsidized credit for buying water pumps and irrigation equipment, exemptions of tariffs on imported fertilizers and equipment, subsidized prices of certain agricultural products, protection against foreign competition in the domestic markets, are all examples of the tools used to implement these agricultural-based economic policies. It is obvious that none of these policies have been subject to serious assessment in terms of their impact on the sustainability/longevity of groundwater resources.

[5]Since 2000, the Saudi government has taken major steps to lower irrigation water consumption such as stopping land distribution and reducing input subsidies in order to reduce groundwater depletion, encourage efficient irrigation water use and reduce fiscal burdens. It has also provided incentives for the use of water-saving technologies such as drip irrigation and soil moisture sensing equipment.

[6]There is a need for a clear and unified definition for the industrial sector in the national accounts of the GCC.

4. Main water sector challenges

The overall major challenge faced by the GCC countries is the continuous increase in water scarcity and the increasing financial, economic, and environmental costs associated with providing sectoral water supplies, which are rapidly expanding and rather competing on limited and relatively expensive water resources. This challenge is expected to grow with time and under the current policies and management approaches due to many pressing "external drivers", including rapid population and urbanization growth rates, increasing food demand, prevailing general subsidy system, anticipated climate change impacts, and "internal drivers" including unsustainable consumption patterns, relatively large water losses, inadequate water recycling and reuse, and the continuous deterioration and depletion of groundwater resources. All these driving forces are working against the achievement of an efficient water management system and its sustainability,[7] for that the financial, economic, and environmental cost are increasing with time, without any major counter driving forces, unless water policy reforms, and strong management interventions are made.

In the majority of the GCC countries, to reduce the gap between available water resources and escalating water demands, water management efforts have been primarily concentrated on the development of water supplies and addressing all water resources problems from the supply side. These are manifested by the expansion of desalination and wastewater treatment plants, expansion in dam's capacity, and increasing groundwater abstraction. Other efforts to enhance the efficiency of the supply system, such as reducing physical losses in the water distribution networks, have also been made. Demand-side management efforts, that is, directed toward influencing water demands, in the GCC countries are very few and quite limited. Demand management[8] tools[9] are generally absent in most of the GCC countries, or, if they exist (e.g., tariffs) have been ineffective in influencing demands. The followings summarize the main challenges faced by the main water-related sub-sectors.

4.1. Municipal water supply sector

Meeting the escalating water demands under the current rapid growth rates of population and urbanization and high per capita consumption patterns. The increase in water demand will require the construction of more desalination plants, and more exploitation of groundwater, which are fossil with limited recharge and are rapidly depleting and deteriorating. Currently, all the GCC countries have an established policy of providing their municipal/drinking water supply from desalination and reduced their dependence on groundwater. This has led to significantly large share of drinking water is supplied by desalination plants in all GCC countries (Table 5). The costs associated with desalination expansion would be enormously manifested by: (1) the required energy (oil and gas) for desalinated water production (including its opportunity cost and in situ value); (2) financial and energy/electricity cost of every stage in the operation of the water cycle system (i.e., production, transmission, and distribution); and (3) environmental costs in terms of thermal brine discharge by desalination plants and their impacts on the surrounding coastal and marine environment, and air pollution by burned fossil and their impacts on human health and the environment. On the other hand, expansion in groundwater abstraction means more overexploitation and further deterioration of groundwater resources.

Table 5
Trends in desalination water share in the municipal water supply in the GCC countries, 1990, 2000, and 2010

Country	1990[a]	2000[a]	2010
Bahrain	54%	66%	90.9%
Kuwait	79%	90%	84.2%
Oman	37%	33%	73.6%
Qatar	98%	100%	97.3%
KSA	47%	41%	55.1%
UAE	63%	81%	100%
Total	55%	56%	74.3%

[a]WB and AGFUND [2].

- In addition to these cost, other externalities and costs related to the municipal water consumptions itself exist, the most important of which are those related to the volumes of the generated municipal wastewater. These are manifested by the financial and energy costs of the wastewater treatment process, in addition to the environmental costs when hydraulic loading occurs, impacting treatment efficiency, and increasing carryover volumes to the coastal and marine environments.
- Generally, low water efficiency of the municipal water sector in both the supply side and demand side. On the supply side, many GCC countries experience high non-revenue water (NRW[10]) in the municipal distribution network, particularly real losses (i.e., physical leakage), while recycling in the sector is negligible. For example, the physical leakage in Saudi Arabia is estimated to be

[7]A sustainable water management system can be defined as (Al-Zubari [5]) "a system that can supply adequate amount of water with the required quality to the various development sectors, under the lowest financial, economic, social, and environmental costs, to achieve maximum socioeconomic benefits in terms of use added-value and contribution to the overall national development, on a long-term basis."

[8]The adaptation and implementation of a strategy by a water institution or consumer to influence the water demand and usage of water in order to meet any of the following objectives: economic efficiency, social development, social equity, environmental protection, sustainability of water supply and services, and political acceptability.

[9]Economic tools: price-signaling mechanism: metering, pricing, incentives/disincentives; technological tools: water-saving devices; legislative tools: building codes and bylaws.

[10]NRW is the difference between the volume of water put into a water distribution system and the volume that is billed to customers. NRW comprises three components: real losses, apparent losses, and unbilled authorized consumption. Real losses are through leaks, sometimes also referred to as physical losses. Apparent losses are through theft, metering inaccuracies, data-handling errors, etc., NRW will be discussed in detail in the next two paragraphs on cost recovery.

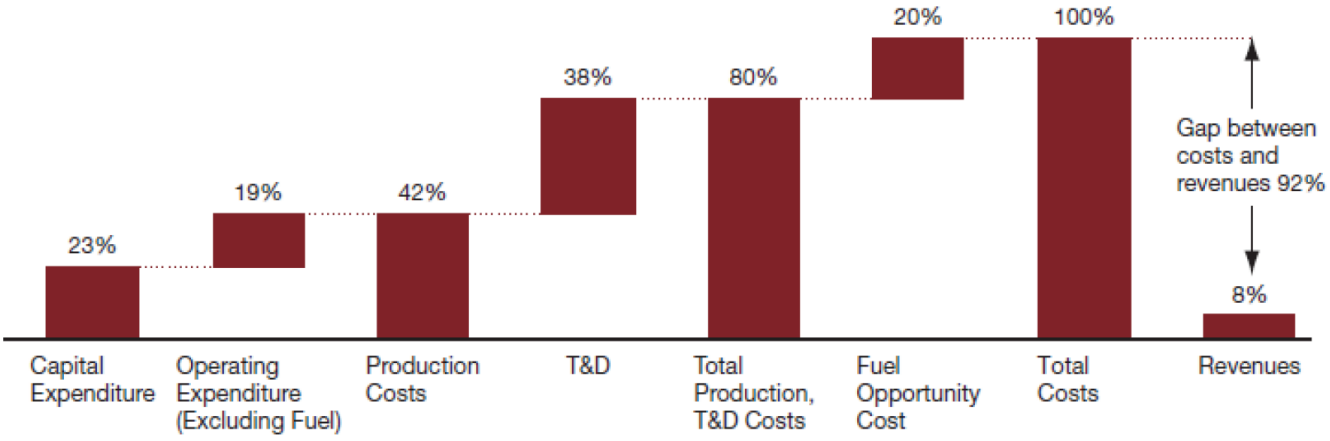

Fig. 4. Average cost of water production, transmission, distribution, and subsidies (%) in the GCC countries (Strategy& [6]).

ranging from 20% to 40%, and in Bahrain it is about 30%, leading to significant financial and economic losses.[11] On the demand side, the per capita water consumption in the domestic sector in most of the GCC countries is high. The average daily water consumption per capita in these countries ranges between 238 and 590[12] L, which at its high levels ranks the highest in the world. This volume has dramatically increased over the last three decades. Such losses represent an opportunity lost as well as use of water without an economic or social purpose.

- Non-existence of a price-signaling mechanism to influence water use in the majority of the GCC countries. The currently prevailing political economy in the GCC countries, where a general subsidy system exists, makes the use of economic incentives/disincentives difficult. Despite the existence of tariffs for municipal water consumption in all the GCC countries the current tariff is not effective in influencing water consumption and does not encourage water savings.[13]
- Moreover, the existing very high rates of subsidies for the municipal water services and consumption results in very low cost recovery percentages (Fig. 4). This creates a heavy financial burden of the municipal sector on the fiscal budget and also makes the sector captive to government allocations, which might impact its performance in some countries.
- Currently, the adopted desalination technology, that is, cogeneration power desalination plants, is energy intensive, with energy cost representing about 85% of their running cost, as well as placing strain on the environment. Desalinated water production along with the other components of transmission and distribution is claiming a sizable portion of the energy resources in the GCC countries. Available figures indicate that in Kuwait desalination consumes about 55% (Darwish et al. [7]) of the total energy used in the country, in Bahrain it is about 30%, in Saudi Arabia it is about 25% (Al-Hussayen [8]). Energy consumption by the municipal water sector is growing with alarming rates which is threatening the very source of income of the GCC countries (i.e., oil and gas).

4.2. Wastewater sector

From a water management perspective, the main challenge in the wastewater sector is the low efficiency of wastewater recovery and the large mismatch between wastewater treatment levels and treated wastewater reuse. Despite the fact that all the GCC countries have provided commendable rates for sanitation services and are operating modern treatment facilities with tertiary and advanced treatment capabilities, the reuse potential of the generated wastewater is not fully developed. The collected wastewater on average in the GCC countries does not exceed 50% of the total domestic water volumes (Table 6), which should be at least 60%, while the reuse rates are less than 40% of the treated wastewater volumes. Under the water scarcity conditions of the GCC countries, such low recovery and reuse rates represent major opportunities lost; as a substitute to the limited freshwater in the GCC countries, treated wastewater has the potential to play an important role in water resources management and lessen the present and long-term demand vs. supply imbalance. A summary of the main challenges of the municipal wastewater sector in the GCC countries are as follows.

- Hydraulic loading of the wastewater treatment systems, which occurs due to rapidly increasing municipal water consumption beyond the capacity of the treatment capacity resulting from lack of integrated planning between the municipal water supply and municipal wastewater sector, in addition to high percentage of infiltration from shallow water to the collection network. Such conditions impact both the environment (increasing carryover volumes) and the quality of treated wastewater for reuse.

[11]It should be noted that it was rather difficult to accurately estimate the actual physical losses in the distribution network due to a number of reasons, such as the reporting of NRW values without detailing its components (i.e., real losses, apparent losses, and unbilled authorized consumption), and the mixing between unaccounted-for-water and NRW. Another reason is the deficiency in water metering and billing.

[12]Bahrain = 320, Kuwait = 500, Qatar = 512, Oman = 140, KSA = 238, UAE = 520 liters per capita per day (averages).

[13]In 2016, there has been a revision of the municipal water tariff in Saudi Arabia, UAE, and Bahrain, and a similar plan is in preparation in Kuwait.

Table 6
Treated wastewater and reuse in the GCC countries, 2010

Country	Municipal water consumption	Collected WW (MCM)	Treated WW (MCM)	Reused treated WW (MCM)	% of collected to municipal	% of treated of collected	% of reused to treated
Bahrain	231	112	48	43	48	43	90
Kuwait	646	314	156	96	49	50	61
Oman	283[a]	–	60.5	60.5	–	–	100
Qatar	370	130	101	101	43	78	100
KSA	2,283	–	1,334	219	–	–	16
UAE	983	–	556	308	–	–	55
Total	4,796	–	2,256	875	–	–	39

[a]Industrial water use; WW, wastewater; data not available.

- High level of infiltration to the collection network by shallow waters results in increased salinity levels of the produced treated water which impacts the suitability of its reuse. In addition, significant volumes of industrial waste enter the wastewater collection system which impacts the efficiency of treatment and eventually reuse.
- Very low cost recovery of the wastewater sector due to the absence of an explicit wastewater tariff (collection and treatment) in the majority of the GCC countries (except for Oman), there is no explicit tariff for wastewater collection and treatment. Such cost recovery ratios increase the wastewater sector's financial burden on the fiscal budget, makes the sector captive to government allocations, and deprives the water sector from having an enforcing mechanism in water conservation. The same can be said for reuse, where providing the water free of charge does not encourage water saving, especially in the agricultural sector.
- In some countries, there is a rapid expansion in septic tanks due to lagging wastewater services behind water supply services.

4.3. Agricultural sector

Despite the fact that GCC countries are among the poorest nations in the world in terms of the availability of renewable water resources, agricultural sector is the major consumer of these resources. Agriculture consumes up to 85% of the total water supplies in some of the GCC countries, drawn mainly from groundwater (94%), even though agriculture does not contribute more than 2% of any GCC country's GDP. The main crops consuming water resources include cereals, fodder, vegetables, and fruits and dates grown mainly in open fields using traditional flood irrigation. With the exception of Saudi Arabia, which have recently implemented a major agricultural policy reform, the agricultural sector water consumption continues to grow in all the GCC countries (Table 7) leading to overdrafting of groundwater resources and their degradation.

The agricultural sector in the GCC countries faces many challenges and constraints, the most important of these are summarized as follows.

- Limited surface water resources and continuous deterioration in irrigation water quality and general deterioration of farming, especially in the coastal regions. In many GCC countries, there is a clear conflict between agricultural development policies and available water resources. While most of the natural water resources are used by the agricultural sector, groundwater resources are overexploited by the agricultural sector beyond their safe yields, leading to their quality deterioration by salt water intrusion. Degradation of the quality of irrigation water gradually leads to reduction in productivity and eventually loss of agricultural lands.
- Heavy mining of deep non-renewable aquifers leading to rapid depletion and quality deterioration, mainly by the agricultural sector, leading to dramatic declines in their water levels. In addition to the loss of these vital national strategic reserves, as drawdown increases pumping lift costs increases too.
- The absence of a national water strategy integrated with a national agricultural strategy, with unclear future agricultural vision. Certainly, there is a need for a comprehensive revision of agricultural development strategies and food security and their integration with a national water strategy.
- The economic value of the unit of water used in agriculture is not considered in the feasibility studies of large agricultural farms because groundwater is assumed to be free good. In all the GCC countries, there are no charges for groundwater consumption for the agricultural sector (as well as treated wastewater used in agriculture). Moreover, in most of the countries there are no flow meters installed on groundwater wells, which makes it

Table 7
Trends in agricultural water consumption in the GCC countries, 1990–2010, in MCM

Country	1990[a]	2000[a]	2010
Bahrain	120	137	190
Kuwait	80	221	513
Oman	1,150	1,124	1,546
Qatar	140	247	261
KSA	14,600	18,300	14,410
UAE	950	2,162	3,140
Total	17,009	22,214	20,060

[a]WB and AGFUND [2].

even harder to monitor and control groundwater abstraction. Volumetric water metering and pricing, even if symbolic, could be a powerful tool to give right price signals and value of used water to encourage farmers to improve irrigation water use efficiency and enhance agriculture production.

- Exaggeration of the agricultural water consumption due to the predominance of traditional irrigation methods (flood irrigation) leading to low irrigation efficiencies, cultivating high water consuming crops (e.g., cereals and fodders), unrestricted groundwater abstraction rights, and absence of water metering and tariff for groundwater use in agriculture. These are discussed in more details as follows.
- While there is a clear trend toward the use of modern irrigation methods and greenhouses cultivation, traditional irrigation methods, that is, flood irrigation, is still the dominantly practiced method in many GCC countries. Flood irrigation methods are used on 72% of the agricultural lands in Bahrain, 63% in Kuwait, 60% in Oman, and 75% in Qatar. The use of traditional methods leads to high water losses, resulting in low irrigation efficiencies, reported at 25%–40%.
- Major crops cultivated in the GCC countries are categorized into four categories: cereals, fodder, vegetables, and fruits and dates. Currently, there is a general trend toward cultivating fodder crops in all the GCC countries, which is attributed to two factors; alfalfa tolerates high salinity, and it is a cash crop grown all year round with high local demand, which makes it suitable for most of the GCC countries experiencing problems in soil and water quality. However, in terms of water consumption fodder crops have a high irrigation water requirement, which impacts agricultural water demand and eventually its supply source of groundwater. In addition to these two factors, areas of fodder crops cultivation has been enhanced by the policies of many GCC countries in using treated wastewater for fodder production as a barrier in their risk management plans to minimize health risks associated with the reuse of treated wastewater.
- Undefined groundwater abstraction rights and water allocations make water use in the agricultural sector water consumption uncontrolled.
- Due to lack of metering in many countries, agricultural sector consumption is based on estimates which considerably vary in some countries. Given that agriculture is the largest consumer of groundwater, determining the correct quantity of water consumption is critically important for proper water management in the sector.

4.4. Industrial sector

In the GCC countries, the industrial sector is expanding rapidly to non-oil industries due to diversification policies, and its water consumption is expected to be increasing along with diversification plans. The total water consumption in the industrial sector in the GCC countries increased from about 321 MCM in the mid-1990s, representing about 1.3% of the total water consumption of these countries, to about 1.3 BCM in 2010, and represented about 5.3% of their total water consumption. These non-oil industries include steel, mining, cement factories, food industry, and many others. However, there is a general lack of data related to the water consumption by the industrial sector (both oil-related and non-oil industries) and its quality requirements. Based on the available data the main sources for the sector are groundwater (96%) and desalinated water, with a continuously increasing trend in water utilization by the sector, which might compete with other sectors. There is a large potential for the industrial sector to use treated municipal wastewater, however, in some countries, the industrial centers are located far away from wastewater treatment plants where treated wastewater is available, which poses the problem of transportation and its cost. Moreover, large volumes of the generated wastewater by the industrial sector are not treated nor recycled/utilized. Environmental policies and regulations and enforcement in this regard are urgently needed.

4.5. Security of drinking water supply

The drinking water supply system in the GCC countries depends heavily on water supplied by desalination plants with their feed water in the Arabian Gulf. Desalination plants are highly vulnerable and at risk to a number of threats that might occur in the Arabian Gulf seawater from various activities, both land-based and marine-based activities. These could be natural or man-made, and include maritime pollution (e.g., oil spills and red tide), maritime contamination (e.g., nuclear and wastewater), natural disasters (e.g., hurricane and seawater flooding), actual combat (e.g., targeting desalination facilities), as well as pollution from agricultural and wastewater discharges to the marine environment. Other risks to the municipal water supply system are power outage, information technology, and supervisory control and data acquisition hacking. In response to these threats, the majority of the GCC countries are implementing plans that aim at increasing their strategic reserves of municipal water supply through storage reservoirs. In addition, a bilateral water grid between the GCC countries has been recently proposed within the GCC Water Grid project.

4.6. Governance, institutional and legislation

The current institutional arrangements of the water sector in the majority of the GCC countries is fragmented, which leads to the dominance of sub-sectoral water management approaches and impedes integrated management of the water sector. Moreover, interministerial coordination and coordinated planning between the water sector and other related sectors, particularly agriculture and energy are informal and limited. Reflecting institutional and policy fragmentation, water legislation in the majority of the GCC countries are also fragmented and concern specific water sectors, rather than consolidated under a comprehensive national water law that reflects the policy and strategic aspects of the whole water sector. Moreover, many legislative gaps exist and need updating.

4.7. Health and environmental issues

The life cycle of water supply to the various consuming sectors in the GCC countries are associated with a number

of health and environmental concerns, the most important of which are groundwater depletion and quality deterioration, the negative impacts of desalination on the surrounding environment and ecosystem, the negative impacts of the discharge of partially treated/untreated municipal and industrial wastes.

5. The GCC Unified Water Strategy

A brief summary of the components of the GCC UWS is presented here, including its vision, mission, values, strategic themes, strategic objectives and their policies and the targets of their KPIs.

5.1. Vision, mission, values, and principles

Based on the current conditions of the GCC countries water sector, the immense challenges and risks facing the sustainable management of the water sector in these countries, and to ensure the sector's continuation to serve the socioeconomic development in the GCC countries, the vision, mission statements, and the guiding values and principles of the GCC UWS are formulated as follows.

Vision: By 2035 the GCC countries have established sustainable, efficient, equitable, and secure water resources management systems contributing to their sustainable socioeconomic development.

Mission: To align GCC states' national water strategies and master plans with a unified GCC water management strategy that foster joint initiatives and strengthen the capacities of each country in achieving a rational, integrated, efficient, and sustainable management of their water resources.

Values and principles: The objectives, policies, and programs of the GCC UWS are guided by the following principles:

- Achieving highest international standards of service delivery in water supply and sanitation to the GCC growing population;
- Implementing effective water governance (institutions, legislation, participation, decentralization, transparency, and accountability);
- Raising water awareness of the GCC societies;
- Adopting integrated supply and demand driven approach in all water consuming sectors and focusing water efficiency, demand management, and conservation;
- Water valuation in the GCC countries;
- Integrating future impacts of climate change by integrating appropriate adaptation measures in water resources planning and management;
- Promoting R&D and innovative technological solutions in the water sector;
- Adopting a water–energy–food nexus approach in the planning and management of the water sector;
- Enhancing institutional and national human capacity; and
- Active partnership in the international and regional water agenda.

5.2. Strategic themes and objectives

The GCC UWS is founded on five strategic themes which constitutes its pillars and reflects its vision and mission statements (Fig. 5). The first three pillars are related to resources

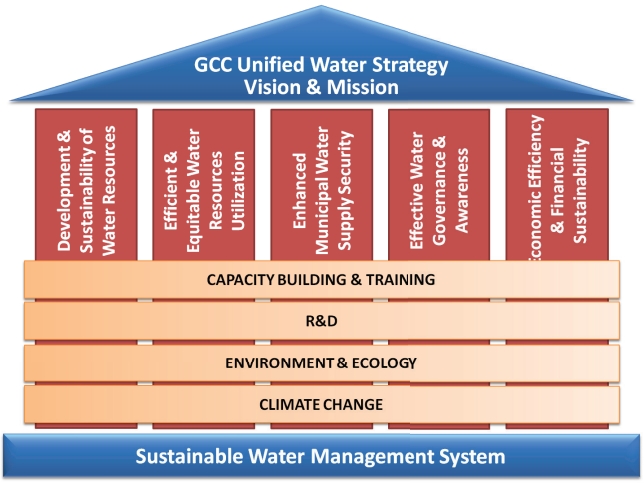

Fig. 5. Strategic themes for the GCC UWS.

sustainability under normal and emergency conditions and their efficient utilizations, and represent development, enhancement, and improvement themes, while the last two are related to establishing an enabling environment for the sustainable and effective management of the water sector in the GCC countries and represent governance, control, and incremental uplift themes. In the developed strategy, another four themes have been considered as cross-cutting themes, wherever applicable, and are related to capacity development and training, research and development, environmental and ecological aspects, and impacts of climate change.

Each one the five themes contain one or more strategic objective, as illustrated in Table 8. These strategic objectives are formulated to operationalize the mission statement and to reflect the principles and values of the strategy. They help to provide guidance on how the GCC UWS can fulfill or move toward the "high goals" in the mission and vision statements. Each of these strategic objectives consists of a number of policies (or sub-objectives), which are realized through a number of programs (or initiatives),[14] which are divided into a number of sequential activities[15] (or tasks), with each of these activities has an ownership/responsibility and a completion indicator.

5.3. Key performance indicators and targets

A detailed integrated implementation plan of the GCC UWS has been developed for each policy, program, and activity with their owners/responsibility against a specific timeline and associated KPIs for the period of 2016–2035. Milestones and targets for each KPI have been set to track future implementation progress and to monitor the success of the GCC UWS implementation with a base line established for the year 2015. Overall, the execution plan contains 82 KPIs, the most important of these are presented in Table 9.

[14]Refer to Annexure for the policies of each strategic objective (total 45 policies).

[15]Not included in this paper due to paper length limitations.

Table 8
Strategic objectives (SO) of the GCC UWS

Theme 1: Development and sustainability of water resources	
SO1:	To acquire technology development and manufacturing of desalination and water treatment plants and diversification of energy resources
SO2:	To develop and protect conventional water resources
SO3:	To maximize municipal wastewater collection, upgrade treatment and increase economic and safe use of treated wastewater and sludge
Theme 2: Efficient and equitable water resources utilization	
SO4:	To achieve the highest international standards of water and wastewater services
SO5:	To increase water efficiency and manage demands in the municipal and industrial sectors
SO6:	To establish a water-efficient and rational agricultural sector compatible with the available water resources
Theme 3: Enhanced municipal water supply security	
SO7:	To secure water supply during emergencies and disasters
Theme 4: Effective water governance and awareness	
SO8:	To improve governance in the water sector to achieve effective and integrated water resources management
SO9:	To achieve water-oriented society in the GCC countries
Theme 5: Economic efficiency and financial sustainability	
SO10:	To minimize water supply economic costs and increase cost recovery while maintaining quality of service

Table 9
Main KPIs and targets of the GCC UWS

No.	KPI	Target
1	Desalination capacity manufactured/owned locally to total desalination capacity in GCC countries	10% by 2035
2	Share of renewable energies in the water sector in each GCC country (based on set targets by GCC countries for renewable energy; COP21, SDGs)	10% at least by 2035
3	Collected wastewater to municipal water supply in each GCC country	60% by 2030
4	Reused treated wastewater to total treated in each GCC country	90% by 2035
5	Physical leakage in the municipal distribution network in each GCC country (weighted average of all regional utilities in the country)	10% maximum by 2035
6	Per capita water consumption it the municipal water sector (calculated after deducting the physical leakage)	250 L/capita/d maximum by 2035
7	Average irrigation efficiency in each GCC country	60% minimum by 2035
8	Development of national integrated emergency preparedness plan in each GCC country	By 2020
9	Establishment of a joint GCC water grid committee under the umbrella of the GCC General Secretariat	By 2017
10	Implementation of bilateral gridding between neighboring countries based on the results of comprehensive studies	By 2025
11	Conducting project study for the "General GCC Water Grid"	By 2030
12	Existence of a unified tariff framework and guideline for water sources and uses in the GCC countries	By 2018
13	Cost recovery of water supply utilities	100% of operation and maintenance costs by 2025, and 100% of total costs by 2035

6. Future scenarios and cost analysis

The water management system dynamics in each GCC country is modeled using Water Evaluation and Planning Modeling System. For each GCC country, the dynamics of the water management system (i.e., population growth, per capita water consumption, network losses, wastewater generation and collection rates, agricultural areas, irrigation efficiency, and other related parameters) is simulated under the "Business-As-Usual" scenario (BAU) to the year 2035, where these current conditions and parameters are

assumed to persist in the future. By using a number of cost indicators, the future financial, economic, and environmental costs of the reference model are quantified. The official population projections of the GCC countries are considered in this analysis.

To highlight the many financial, economic, and environmental benefits to all the GCC countries from the implementation of the GCC UWS, three "Management Interventions Scenarios" representing the policies and targets of the GCC UWS are simulated for each GCC country in the municipal water supply/wastewater and agricultural sectors. The simulation results for these different scenarios are compared with the BAU scenario and are analyzed in terms of potential savings.

6.1. Potential water savings in municipal sector and their associated costs

For the BAU scenario, the current per capita water consumption and supply efficiency (physical leakage) of the water network for each GCC country are assumed constant up to the year 2035. Under the GCC UWS in each GCC countries a target of 250 L/d/cap and a reduction in the physical leakage of the municipal distribution network to 10% (as a minimum) is achieved gradually by the year 2035. Cost and impact indicators implemented in the modeling are calculated for each country and are assumed to be constant up to the year 2035. These are:

- Costs of water supply (US$/m^3): Bahrain = 1.92; Kuwait = 2.9; Oman = 2.0; Qatar = 2.74; KSA = 2.1; and UAE = 1.
- Desalination energy requirement (kWh/m^3): Bahrain = 20; Kuwait = 13; Oman = 20; Qatar = 20; KSA = 20; and UAE = 15.4.
- Greenhouse gases (GHGs) emissions (CO_2e/m^3): Bahrain = 13; Kuwait = 13 (assumed); Oman = 21; Qatar = 11.3; KSA = 21; and UAE = 15.
- Desalination to groundwater ratio in municipal water supply in each GCC country is maintained at the same current ratio (Table 5).
- Ratio of desalination generated brines to desalinated water is assumed 1:4.

The results show that under the BAU scenario, the total municipal water supply requirements in the GCC countries are expected to increase from 5.7 BCM in 2015 to about 11 BCM in 2035, that is, to double in the next 20 years. Under

Table 10
Cumulative municipal water supply volumes and their associated costs under the BAU scenario and GCC UWS management interventions for the period 2016–2035

Scenarios	Parameter	Bahrain	Kuwait	Oman	Qatar	KSA	UAE	Total
BAU	WS requirements (MCM)	6,245	18,912	5,924	12,450	66,189	57,097	166,816
GCC UWS	WS requirements (MCM)	4,583	13,546	5,747	8,720	60,840	41,784	135,220
Savings		1,662	5,366	176	3,730	5,349	15,312	31,596
BAU	WS Financial Cost (MUS$)	11,991	54,846	12,440	34,113	138,996	57,097	309,481
GCC UWS	WS Financial Cost (MUS$)	8,799	39,283	12,069	23,893	127,764	41,784	253,592
Savings		3,192	15,562	370	10,220	11,232	15,312	55,889
BAU	DESAL requirements (MCM)	5,621	18,345	3,732	12,126	36,404	57,097	133,324
GCC UWS	DESAL requirements (MCM)	4,125	13,140	3,621	8,493	33,462	41,784	104,624
Savings		1,496	5,205	111	3,633	2,942	15,312	28,700
BAU	DESAL energy requirements (M kWh)	112,415	238,484	74,637	242,523	728,074	879,289	2,275,422
GCC UWS	DESAL energy requirements (M kWh)	82,493	170,814	72,417	169,864	669,238	643,477	1,808,302
Savings		29,922	67,670	2,221	72,659	58,837	235,812	467,120
BAU	DESAL GHGs emissions (M kgCO_2e)	73,070	238,484	78,369	137,025	764,478	856,451	2,147,877
GCC UWS	DESAL GHGs emissions (M kgCO_2e)	53,621	170,814	76,038	95,973	702,700	626,763	1,725,908
Savings		19,449	67,670	2,332	41,052	61,778	229,687	421,969
BAU	Generated wastewater (MCM)	3,124	9,456	829	4,158	29,785	28,548	75,901
GCC UWS	Generated wastewater (MCM)	2,292	6,773	805	2,912	27,378	20,892	61,052
Savings		832	2,683	24	1,246	2,407	7,656	14,848
BAU	WW Treatment Financial Cost (MUS$)	3,436	9,740	912	4,574	32,763	31,403	82,829
GCC UWS	WW Treatment Financial Cost (MUS$)	2,521	6,977	886	3,203	30,116	22,981	66,683
Savings		915	2,763	26	1,371	2,648	8,422	16,145

Note: WW, wastewater.

this management intervention scenario, the total municipal water supply requirements would increase from 5.7 BCM in 2015 to about 7.3 BCM in 2035, that is, a reduction of about 3.7 BCM in comparison with the BAU scenario water requirements (about 11 BCM in 2035).

The simulation results of the cumulative savings in terms of volumes and associated costs for municipal water supply and wastewater, desalination production, energy requirements, and emissions are presented in Table 10 for each GCC country and as a total. Considerable financial, economic, and environmental savings can be achieved by gradually enhancing the water efficiency of the municipal water sector in the supply and demand sides.

6.2. Potential water savings in the agricultural sector

One of the main causes of the exaggeration of the agricultural water consumption in most of the GCC countries is the low irrigation efficiencies resulting from the predominance of traditional irrigation methods (flood irrigation). While there is a clear trend toward the use of modern irrigation methods and greenhouses cultivation, traditional irrigation methods, that is, flood irrigation, is still the dominantly practiced method in many GCC countries.[16]

The BAU scenario for the agricultural sector assumes the continuation of the 2010/2012 trends in agricultural water use (average cubic meter per hectare) and current irrigation efficiency in each GCC country, and by assuming the stability of the irrigated area in each GCC country (i.e., no expansion or reduction in agricultural areas). Under this scenario, the total GCC irrigation sector water requirements will remain constant at about 20 BCM/year.

By implementing the GCC UWS strategy in the agricultural sector and achieving its targets in terms of increasing the irrigation efficiency from its current levels in each GCC country[17] to an average of 60% by the year 2035, the GCC countries can save significant amounts of water that would be withdrawn mainly from groundwater storage. Implementing irrigation management programs starting from 2016 to gradually achieve the set irrigation efficiency target by the year 2035 would result in that the total agricultural water requirements in the GCC countries will decrease from 20 BCM in 2015 to about 16.8 BCM in 2035, that is, a reduction of about 3.2 BCM. The cumulative savings for all the GCC countries would be about 29 BCM for the period from 2016 to 2035 (agriculture water requirements cumulative savings for the period 2016–2035 in MCM: Bahrain = 1,021; Kuwait = 2,924; Oman = 1,324; Qatar = 623; Saudi Arabia = 20,516; and UAE = 2,689). This would translate mainly into groundwater savings, and thus would support plans for extending the life of non-renewable groundwater and the restoration of renewable groundwater resources in these countries (strategic objective 2). Table 11 displays the agricultural water requirements for each country under this scenario.

6.3. Potential wastewater contribution to the agricultural sector

One of the main policies in the GCC UWS is to increase the collection rate of wastewater, treatment capacity, and treatment level (strategic objective 3). In this scenario, the current ratio of collected wastewater to municipal water supply in each GCC country[18] is increased gradually to reach the set target of 60% by the year 2030 and kept constant until the year 2035. At the same time, the target of reducing the per capita water consumption to 250 L/d in the GCC countries is implemented, for it will have implications on the dynamics of the wastewater sector and the volumes of collected wastewater in each country. Moreover, the improvement in the irrigation efficiency in the agricultural sector (target of 60%) is implemented as well. In essence, this scenario includes the above two scenarios.

The scenario results for each country are illustrated in Fig. 6 and Table 11. It is clear that for countries where the municipal sector has a large share in the total water consumption (i.e., Bahrain, Kuwait, and Qatar), generated wastewater under the dynamics of these three scenarios (i.e., reducing per capita water consumption, increasing wastewater collection rate, and improving irrigation efficiency), if treated properly has large potential to completely fulfill the agricultural sector water requirements. In fact some countries might have a surplus as we approach the year 2025 that can be used in other sectors, such as industry, or for groundwater artificial recharge.

For the two countries of Oman and Saudi Arabia, where the municipal water supply represents only 10% and 13%, respectively, compared with an agriculture sector consumption of 85% and 83%, respectively, the potential of the generated wastewater in contributing to the agricultural water consumption, at best, is not more than 15% of these requirements. Moreover, these two countries have their major urban centers, where the wastewater is generated, located at relatively far distances from agricultural areas, which poses the problem of transportation of these waters and might constrain their reuse in the agricultural locations. Nevertheless, taking into account the volumes generated, especially in the case of Saudi Arabia, they still represent a major source of water that can be reused in saving groundwater resources being utilized in other sectors, such as the industry, landscaping, and forestry, or eventually groundwater artificial recharge.

7. Conclusion

The development of the GCC Unified Water Strategy (2016–2035) represents a major milestone for the long and intricate path for coping with the water scarcity in the arid GCC countries. The overall strategy objective is to establish a "sustainable water sector management system" in each GCC country by securing long-term water supplies while meeting strict criteria for socioeconomic, financial- and environmental sustainability and public health requirements. The

[16]Flood irrigation methods are used on 72% of the agricultural lands in Bahrain, 63% in Kuwait, 60% in Oman, 75% in Qatar, and 65% in Saudi Arabia. A major achievement is made by UAE to convert to modern irrigation methods that helped in saving 40%–60% of the water used for agriculture activities, and reaching more than 90% in Abu Dhabi Emirate.

[17]Average irrigation efficiencies in Bahrain = 32%; Kuwait = 25%; Oman = 55%; Qatar = 45%; Saudi Arabia = 50%; and UAE = 55% (note: numbers are averages).

[18]Bahrain = 50%; Kuwait = 50%; Oman = 14%; Qatar = 33%; Saudi Arabia = 45%; and UAE = 50%.

Table 11
Agricultural water requirements under management intervention of increasing irrigation efficiency, and generated wastewater under increasing wastewater collection rates in the GCC countries for the period of 2016–2035, in MCM

Year	Bahrain		Kuwait		Oman		Qatar		Saudi Arabia		UAE	
	AGR water requirements	Collected WW	AGR water requirements	Collected WW	AGR water requirements	Collected WW	AGR water requirements	Collected WW	AGR water requirements	Collected WW	AGR water requirements	Collected WW
2010	218	121	513	305	1,546	32	261	123	14,410	1,028	3,140	492
2011	218	123	513	318	1,546	32	261	128	14,410	1,056	3,140	529
2012	218	125	513	330	1,546	33	261	136	14,410	1,085	3,140	567
2013	218	127	513	343	1,546	34	261	143	14,410	1,113	3,140	604
2014	218	130	513	356	1,546	35	261	149	14,410	1,142	3,140	642
2015	218	132	513	369	1,546	35	261	156	14,410	1,170	3,140	679
2016	214	135	501	379	1,546	36	259	162	14,353	1,201	3,140	732
2017	210	135	490	383	1,539	44	256	172	14,296	1,251	3,125	776
2018	207	136	479	387	1,531	53	254	182	14,239	1,300	3,110	819
2019	203	137	468	390	1,524	62	252	192	14,183	1,351	3,096	860
2020	199	137	458	393	1,517	71	250	202	14,127	1,402	3,081	900
2021	194	137	442	395	1,510	81	247	209	14,018	1,453	3,067	957
2022	189	137	427	397	1,503	92	244	215	13,909	1,504	3,052	1,012
2023	184	138	414	397	1,496	104	241	221	13,803	1,556	3,038	1,064
2024	179	138	401	397	1,489	116	238	226	13,698	1,608	3,024	1,114
2025	175	138	389	396	1,482	128	235	230	13,594	1,661	3,010	1,161
2026	166	138	366	394	1,475	139	230	234	13,442	1,715	2,997	1,231
2027	159	137	347	392	1,469	149	226	238	13,293	1,769	2,983	1,297
2028	152	137	329	388	1,462	161	222	240	13,148	1,824	2,970	1,359
2029	145	137	313	384	1,455	172	218	242	13,005	1,880	2,956	1,416
2030	140	137	298	379	1,449	183	214	243	12,866	1,935	2,943	1,469
2031	134	136	276	368	1,442	184	210	234	12,685	1,950	2,930	1,492
2032	129	136	258	357	1,436	185	206	224	12,509	1,964	2,917	1,509
2033	125	136	241	345	1,430	186	203	214	12,337	1,978	2,904	1,523
2034	120	136	227	333	1,423	187	199	204	12,171	1,991	2,891	1,531
2035	116	135	214	320	1,417	188	196	194	12,008	2,004	2,878	1,535

Note: AGR, agriculture; WW, wastewater.

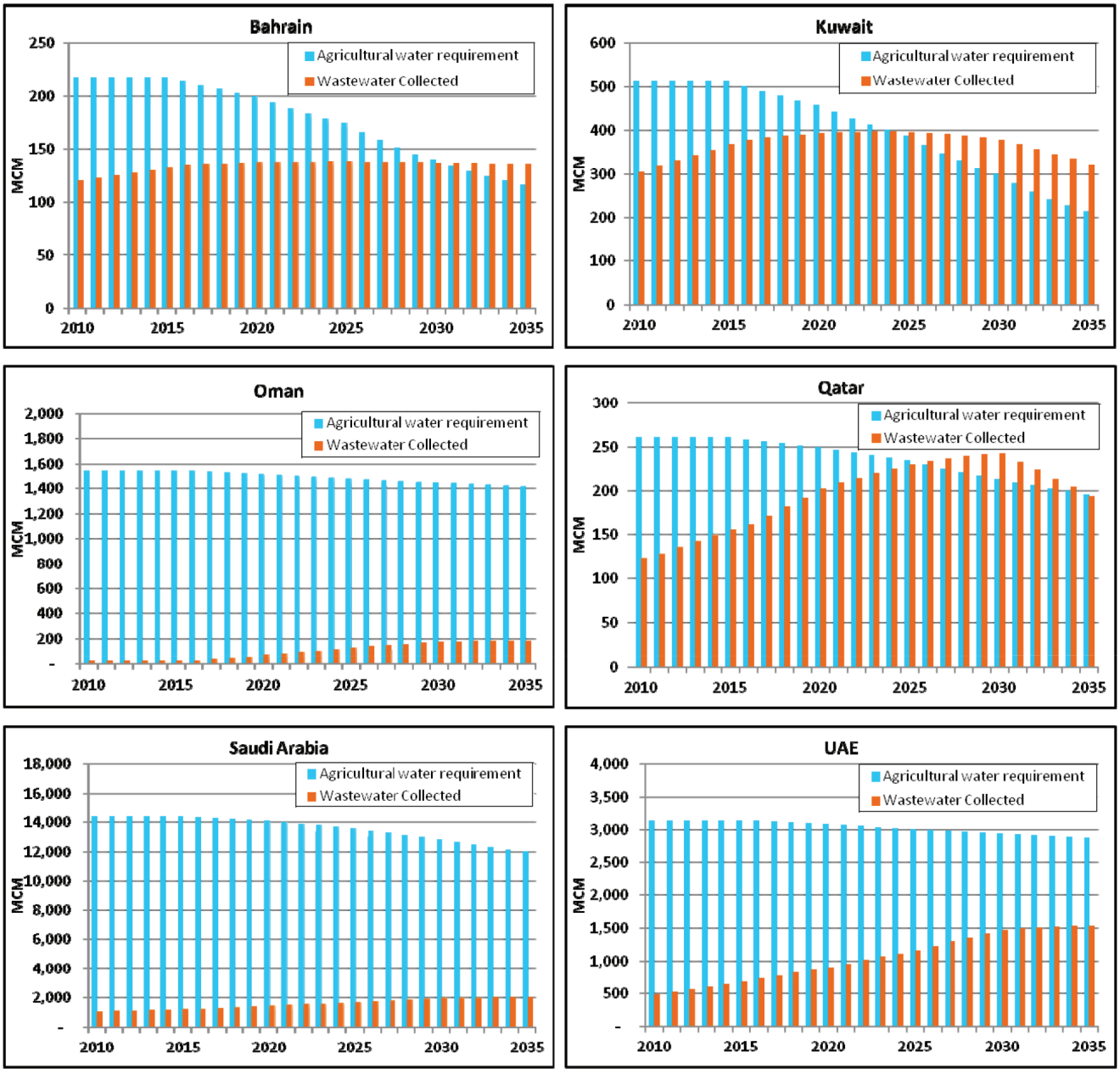

Fig. 6. Potential of wastewater contribution to agricultural water requirements in the GCC countries.

GCC countries implementation of the strategic objectives and policies set in the strategy would result in a multitude of successive benefits and contributes directly to the developmental goals of the GCC countries, would help to ensure reliable water supplies today and for future generation, and enhance the overall level of water security. Such conditions will enable the water sector to continue serving the needs of their socioeconomic development. However, failure to achieve the set targets of the strategy would result in the deterioration of both the quantity and the quality of water supplies and increase the sector's associated financial, economic, and environmental costs, which might eventually impact the GCC countries efforts in achieving their socioeconomic development goals.

Acknowledgements and credits

The development of the GCC Unified Water Strategy and implementation plan 2015–2035 was in response to the directives of their Majesties and Highnesses the leaders of the GCC countries at their 31st session of the Supreme Council in Abu Dhabi in December, 2010. The GCC General Secretariat administered the study (Dr. Mohammed Al-Rashidi, Director, Electricity and Water Department), which was carried out by the King Abdulla Institute for Research and Consulting Studies, King Saud University. The Strategy Development team consisted of the following ten national experts representing the six GCC countries (listed in alphabetical order):

Abdulaziz Al-Turbak, King Saud University, Saudi Arabia.
Ahmed Abdelwahab, Texas A&M University, Qatar.
Ahmed Murad, United Arab Emirates University, UAE.
Ali Al-Tkhais, Shura Council, Saudi Arabia.
Ibrahim Al-Muataz, King Saud University, Saudi Arabia.
Khalid Al-Ruwis, King Saud University, Saudi Arabia.
Meshari Al-Harbi, Kuwait University, Kuwait.
Waleed Al-Zubari, Arabian Gulf University, Bahrain.
Walid Zahid, King Saud University, Saudi Arabia.
Zaher Al-Sulaymani, President, Oman Water Society/ Private Consultant, Oman.

References

[1] United Nations Economic and Social Commission for Western Asia, Updating the Assessment of Water Resources in ESCWA Member Countries, UNESCWA Document E/ESCWA/ ENR/1999/13, UNESCWA, Beirut, 1999.
[2] WB (World Bank) and AGFUND (Arab Gulf Programme for United Nations Development Organizations), A Water Sector Assessment Report on the Countries of the Cooperation Council of the Arab States of the Gulf, Report No. 32539-MNA, 2005.
[3] J. Al-Alawi, M.J. Abdulrazzak, Water in the Arabian Peninsula: Problems and Perspectives, P. Rogers, P. Lydon, Eds., Water in the Arab World, Perspectives and Prognoses, Division of Applied Sciences, Harvard University, 1994.
[4] GWI, Water Market Middle East 2010, Global Water Intelligence, 2010.
[5] W.K. Al-Zubari, Water Security in the GCC Countries, Water and Food Security in the Arabian Gulf, The Emirates Center for Strategic Studies and Research (ECSSR), 2013, pp. 81–101.
[6] Strategy&, Achieving a Sustainable Water Sector in the GCC: Managing Supply and Demand, Building Institutions, Price Waterhouse Cooper, 2014. Available at: www.strategyand.pwc.com
[7] M.A. Darwish, N.M. Al-Najem, N. Lior, Towards sustainable seawater desalting in the Gulf area, Desalination, 235 (2009) 58–87.
[8] A. Al-Hussayen, Inaugural speech by the Minster of Water and Electricity, Saudi Arabia, Water and Power Forum, Jiddah, Saudi Arabia, 2009.

Annexure

Policies of the strategic objectives of the GCC UWS

Strategic objective 1: To acquire technology development and manufacturing of desalination and water treatment plants and diversification of energy resources	
1.1	Establishing joint GCC desalination and water treatment industry
1.2	Establishing an advanced joint GCC R&D base in desalination and water treatment
1.3	Developing professional and technical capacity in desalination and water treatment in the GCC
1.4	Diversifying energy sources in the water sector
1.5	Mitigating the impacts of desalination and water treatment practices on the environment
1.6	Enhancing energy efficiency in desalination sector and the whole water sector
Strategic objective 2: To develop and protect conventional water resources	
2.1	Ensuring longevity of non-renewable groundwater sources
2.2	Restoring renewable groundwater resources and ensure their sustainability
2.3	Maximizing the utilization of surface water
2.4	Ensuring availability of groundwater data and information for planning, management, and decision-making
2.5	Protecting groundwater resources from human activities
2.6	Enhancing institutional and individual capacity for conventional water resources planning and management
Strategic objective 3: To maximize municipal wastewater collection, upgrade treatment and increase economic and safe use of treated wastewater and sludge	
3.1	Increasing wastewater collection rates, treatment capacities, and treatment levels
3.2	Increasing treated wastewater reuse in all appropriate sectors
3.3	Enforcing legislations related to protection of health and environment in all stages of collection, treatment, and reuse of domestic wastewater
3.4	Maximizing the beneficial use of wastewater sludge
Strategic objective 4: To achieve the highest international standards of water and wastewater services	
4.1	Ensuring the highest international standards of water supply and sanitation services to all populated areas in the GCC countries
4.2	Achieving the highest management standards for water supply utilities
4.3	Achieving the highest management standards for sanitation utilities
4.4	Enhancing the capacity and performance of water supply and sanitation personnel
Strategic objective 5: To increase water efficiency and manage demands in the municipal and industrial sector	
5.1	Increasing supply efficiency of the municipal water network
5.2	Managing water demands and enhancing conservation in the municipal water sector
5.3	Increasing water efficiency and manage demands in the industrial sector
Strategic objective 6: To establish a water-efficient and rational agricultural sector compatible with the available water resources	
6.1	Improving water use efficiency and increasing water productivity in the agricultural sector
6.2	Increasing the use of treated wastewater in agriculture in conformity of reuse standards
6.3	Allocating groundwater to the agricultural sector based on groundwater resources management plans
6.4	Adopting low-water consuming landscaping and forestation
Strategic objective 7: To secure water supply during emergencies and disasters	
7.1	Establishing a highly resilient system for potable water supply under emergencies
7.2	Enhancing drinking water supply provision during emergencies in the GCC countries through water gridding
7.3	Establishing an early warning system for seawater contamination
7.4	Protecting the feed water of the GCC desalination plants from pollution
Strategic objective 8: To improve governance in the water sector to achieve effective and integrated water resources management	
8.1	Ensuring integrated planning and coordination among water-related sectors in each GCC country
8.2	Ensuring water sector regulation
8.3	Improving institutional and individual capacity in planning and management decision-making in the water sector
8.4	Improving the legal framework and capacities of the water sector

(*Continued*)

Annexure (*Continued*)

8.5	Providing water data and information for decision-making support
8.6	Customizing water-related standards compatible with the GCC countries conditions
8.7	Regulating the utilization of aquifers in the GCC countries
Strategic objective 9: To achieve water-oriented society in the GCC countries	
9.1	Building water importance and value awareness for the future generation
9.2	Building awareness for water conservation importance and value for all water users
9.3	Building water importance and value awareness for the GCC society at large
Strategic objective 10: To minimize water supply economic costs and increase cost recovery while maintaining quality of service	
10.1	Giving water an economic value in the GCC countries
10.2	Minimizing non-revenue water (NRW) in the GCC countries
10.3	Increasing public private partnership in the water sector
10.4	Adopting and implementing “polluters pay” principle in the water sector