

Water in the Arab region: availability, status and threats

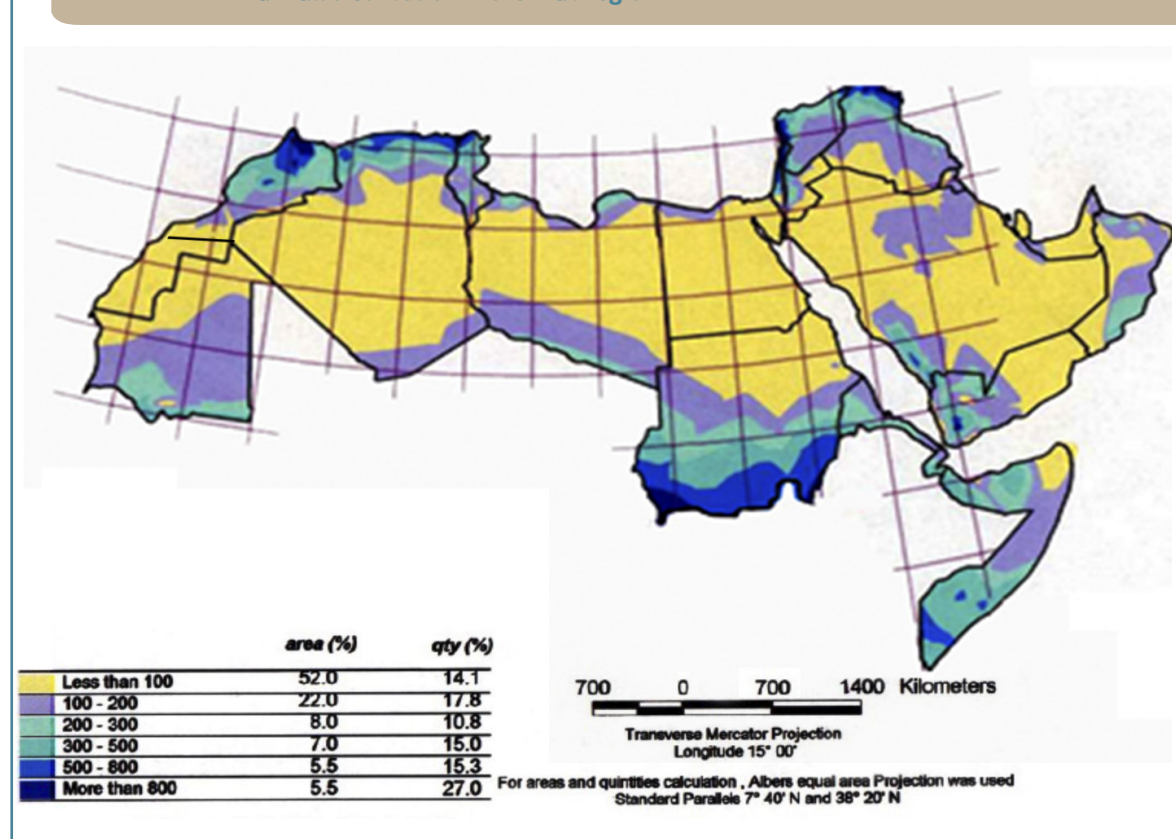
This chapter reviews the state of water resources in the Arab region, the threats to these resources and the impact of diminishing water sustainability.

Water scarcity threatens development in the Arab region. Rainfall is low and variable, evaporation rates are high and droughts are frequent,

all contributing to low water resource reliability and availability.¹ Arab countries cover 10 per cent of the world's area but receive only 2.1

Map 1.1

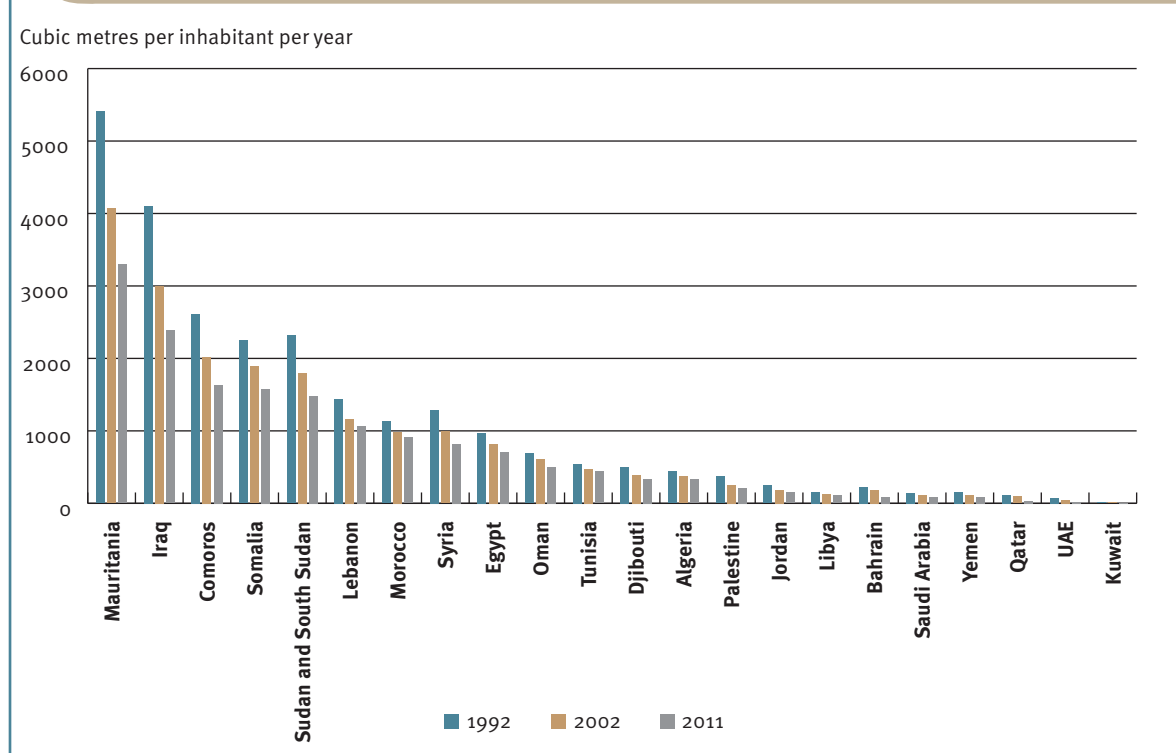
Rainfall distribution in the Arab region



Source: Adapted from Droubi, Inad, and Al Sibaii (2006).

Figure 1.1

Total renewable water resources per capita, 1992, 2002 and 2011



Source: FAO 2013.

per cent of its average annual precipitation. The region's annual internal renewable water resources amount to only 6 per cent of its average annual precipitation, against a world average of 38 per cent.² Most of the region is classified as arid or semi-arid (desert), receiving less than 250 millimetres of rainfall annually.³ Only southern Sudan, the southwestern Arabian Peninsula and the Atlantic and Mediterranean coastlines receive high rainfall (Map 1.1). Coupled with rapid population growth since the mid-1970s, these conditions have caused dramatic shrinkage in per capita renewable water resources, from an average of 2,925 cubic metres a year in 1962 to 1,179.6 in 1992 and to an alarming 743.5 in 2011 below the poverty line level of 1,000 cubic metres a year and far below the world average of 7,240 cubic metres a year (Figure 1.1).⁴ Fifteen Arab countries already face water scarcity, with average water availability per capita below the poverty line of 1,000 cubic metres a year; twelve countries are under the 500 cubic metres a year threshold set by the World Health Organization for severe

scarcity; and seven countries are below 200 cubic metres a year.⁵ By 2025 Iraq, and possibly Sudan could be the only Arab countries with an average above 1,000 cubic metres a year.⁶ And by 2030, the effects of climate change will have reduced renewable water resources by another 20 per cent and increased the frequency of droughts through falling precipitation, rising domestic and agricultural water demand as temperatures rise, and expanding seawater intrusion into coastal aquifers as sea levels rise and groundwater overexploitation continues.⁷

Water resources

To meet escalating demand, Arab countries rely on both conventional water resources (surface water and groundwater) and nonconventional (desalinated water, treated wastewater, irrigation drainage water, water harvesting and cloud seeding). Egypt, Iraq and Sudan depend primarily on surface water, while Jordan, Morocco and Syria depend more heavily on groundwater. All Arab

countries are using more treated wastewater, and desalinated water is a rising share of water budgets in Gulf Cooperation Council countries.

Conventional water resources

The two conventional water resources are surface water and groundwater. Both are under strain.

Surface water resources

The Arab region contains 23 major watersheds with either perennial rivers or ephemeral streams, or wadis (Map 1.2; Table 1.1). The few medium-size rivers mainly in Algeria, Lebanon, Morocco, Sudan, Syria and Tunisia originate and flow within a single country's

national boundaries. Some major rivers, such as the Euphrates, Nile, Senegal and Tigris, originate outside the region, while some others are

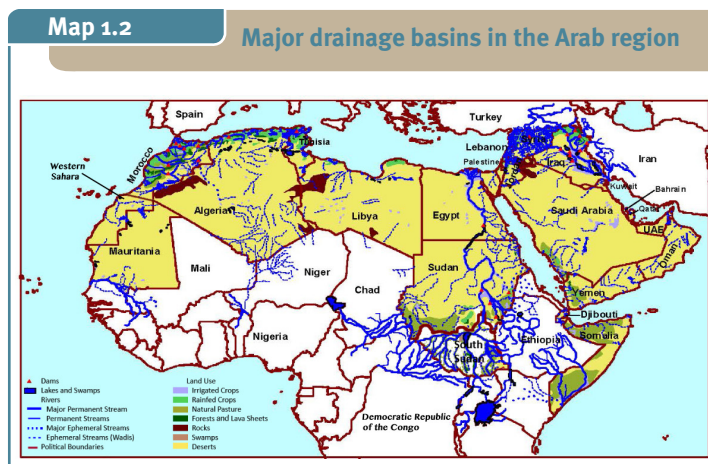
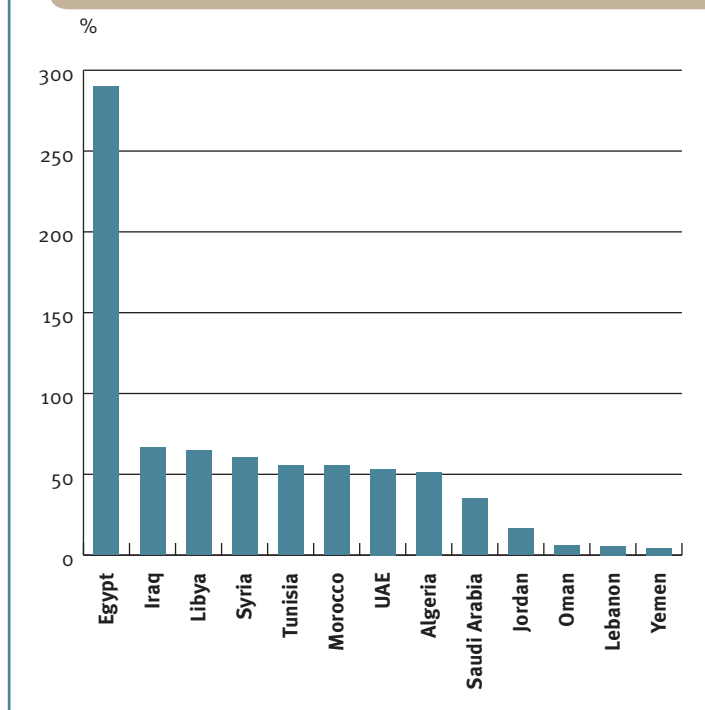


Table 1.1

Size and discharge of major drainage basins in the Arab region

Basin	Tributaries	Basin size	River length	Average discharge	Riparian countries
		1000 km ²	kilometres	million cubic metres per year	
Nile	Victoria Nile/Albert Nile, Bahr El Jabel, Bahr El Ghazal, White Nile, Baro Pibor-Sobat, Atbara, Blue Nile	3,173	6,693	109,500	Egypt, Sudan, South Sudan, Burundi, Democratic Republic of the Congo, Eritrea, Ethiopia, Kenya, Rwanda, Tanzania and Uganda
Euphrates	Sajour, Jallab/Balikh, Khabour	647.075	2,330	32,000	Iraq, Syria, Turkey, Jordan and Saudi Arabia
Tigris	Batman, Khabour, Greater Zab, Lesser Zab, Adhaim, Diyala, Cizre, Wadi Tharthar	146.239	1,718	52,000	Iraq, Syria, Turkey and Iran
Jordan River	Upper Jordan (Dan, Hasbani, Baniyas, Huleh valley, Lake Taberias), Yarmouk, Lower Jordan	19.839	251	1,340	Lebanon, Syria, Israel, Jordan and Palestine
Orontes (Al-Assi)	Afrin and Karasu	37.900	448	2,800	Lebanon, Syria and Turkey
Nahr Al Kebir	Noura el Tahta-Aroussa and Safa-Raweel	0.991	90	330	Lebanon and Syria
Senegal	Falémé, Bafing and Bakoye rivers	300	1,800	22,000	Senegal, Mauritania, Mali and Guinea

Source: Nile Basin Initiative n.d.a, n.d.b; CIA 2003; Kibaroglu 2004; Scheumann, Sagsen, and Tereci 2011; Al-Mooji 2004; OMVS 2003.

Figure 1.2**Share of total freshwater stored in reservoirs in selected Arab countries**

Source: World Bank 2007.

shared among Jordan, Lebanon and Syria. A few wadis are also shared by some Arab countries in the Arabian Peninsula.⁸

Several Arab countries with highly variable rainfall and transboundary waters have invested heavily in water storage and conveyance networks. These networks preserve water sustainability, ensure water availability despite erratic rainfall and reduce the risk of water-related disasters (Figure 1.2).

Other countries, especially in hyper-arid areas, have built dams to recharge groundwater. The Arab region's dam capacity was about 356 cubic kilometres in 2008 (Table 1.2). More than 86 per cent of this capacity is in four countries with large, agriculture-dependent populations: Egypt (168.2 cubic kilometres), Iraq (151.8), Syria (19.7) and Morocco (16.9).⁹ Demand has already outstripped supply, leaving little room to procure additional water economically.¹⁰

These investments have had advantages and disadvantages (Box 1.1). By shielding Egypt from the natural flow variations of the Nile, the Aswan High Dam, completed in 1971, offers many economic and social benefits, including

Table 1.2**Total and per capita dam capacity and share of individual countries in the Arab region**

Country	Estimated total dam capacity (cubic kilometres)	Share of total dam capacity in the Arab region (%)	Per capita dam capacity (cubic metres per inhabitant)
Algeria	5.68	1.56	157.80
Egypt	168.20	46.30	2038.00
Iraq	151.80	41.79	4647.00
Jordan	0.27	0.07	43.43
Lebanon	0.23	0.06	53.53
Libya	0.40	0.11	59.89
Morocco	16.90	4.65	523.70
Oman	0.09	0.02	31.06
Saudi Arabia	1.00	0.28	35.75
Syria	15.90	4.38	893.00
Tunisia	2.50	0.69	237.10
UAE	0.06	0.02	7.74
Yemen	0.20	0.06	10.00
Total dam capacity	363.27	100	672.1541 (average)

Note: Countries not listed have no dams.

Source: FAO 2013; World Bank 2007.

Until the construction of the Aswan High Dam, Egyptian farmers divided the agricultural year into three main seasons: inundation (about 2 metres of water covered arable land for 6–8 weeks during flood time), coming forth and lack of water. Agriculture was abandoned during the river's low-flow periods. In the 20th century the government began to manage the Nile system by building large-scale water structures, including the Aswan High Dam.

The dam quickly became one of the world's most controversial large dams, as political, economic and environmental arguments were arrayed against it.

Most criticized was its reservoir, Lake Nasser, the world's third largest. Building the reservoir required the forced relocation of some 1 million Egyptian peasants and Sudanese Nubians to less fertile areas in Upper Egypt and Eastern Sudan. To the dismay of historians and archaeologists worldwide, flooding Lake Nasser also destroyed many monuments and historic sites of the Nubian civilization, one of Africa's oldest, though some were saved, including the temples of Abu Simbel.

Construction of the dam also caused enormous environmental damage. Water quality has changed, as the dam releases practically silt-free water at a quarter of the previous volume during flood discharge. Siltation in Lake Nasser has led to erosion and land loss in Mediterranean coastal areas and degradation of agricultural soil fertility, necessitating the application of chemical fertilizers. The dam has caused increased salinity and water-logging, the propagation of schistosomiasis and the northward migration of malaria mosquito vectors from Sudan. It has also hurt fisheries in the Nile system and coastal lakes, as the migration of some species

of fish depended on the arrival of turbid floodwater, now impounded upstream.

The dam was caught up in the hydropolitics of the cold war, obscuring its positive agricultural, economic and social impacts. The total cost of the dam was recovered within two years of its construction: its estimated annual return to national income at the time was 255 million Egyptian pounds—140 million from agricultural production, 100 million from hydropower generation, 10 million from flood protection and 5 million from improved navigation. These would be remarkable economic returns for any development project. For farmers, the dam was an irrigation revolution, enabling them to make full use of Nile's water. It guaranteed irrigation water, protected farms from floods, enabled expansion to millions of acres of new agricultural land and conversion from seasonal to perennial agriculture by improving water supply management and generated hydropower for villages.

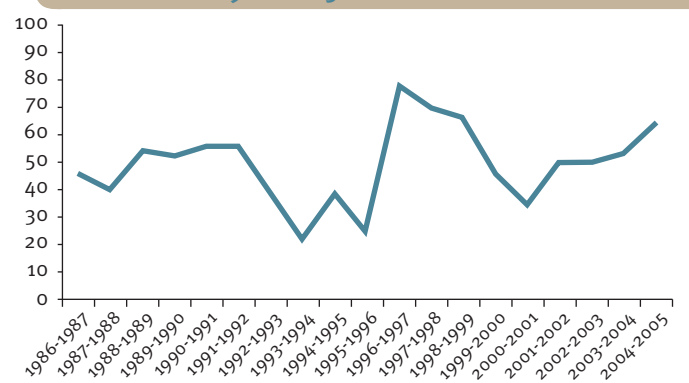
More than thirty years of operational data clearly indicate that the dam's impact has been overwhelmingly positive, contributing greatly to Egypt's overall social and economic development. And the environmental problems have proven to be substantially less severe than expected. As the former executive director of the United Nations Environment Programme noted, "The real question is not whether the Egyptians should have built the [Aswan High Dam] or not for Egypt realistically had no choice but what steps should have been taken to reduce the adverse environmental impacts to a minimum."

Source: Ahmed 1999; Biswas 2002.

land reclamation, energy generation, increased agricultural production, improved navigation and greater tourist capacity. The dam has generated annual net benefits of at least 2 per cent of Egypt's 1997 GDP, according to economic model estimates.¹¹ It has also led adaptive institutions to solve the hydrological and land quality challenges that arose after its construction.¹² It spared Egypt the costs of poor harvests in 1972–1973 and 1979–1987; protected the Nile Valley from major floods in 1964, 1975, 1988 and 1998; and has reduced uncertainty about water supplies for farmers and other

consumers.¹³ But the dam has also reduced soil fertility by preventing the nutrient-rich sediment from replenishing Nile Delta and Valley agricultural lands.¹⁴ In addition, evaporation has reduced water levels in the dam's reservoir (Lake Nasser) by about 5 per cent of the Nile's total flow.¹⁵

Large fluctuations in rainfall can also impede dam functioning. Dams, constructed on the basis of past rainfall patterns, might not have enough water to meet customer demand when rainfall is lower than expected.¹⁶ The fill rate of Jordan's dams, for example, sank from 46 per

Figure 1.3**Annual average fill of dams in Morocco, 1986–2005**

Source: World Bank 2007.

cent in 2010 to 33 per cent in 2011,¹⁷ while that of Morocco's dams fluctuated considerably over 1986–2004 (Figure 1.3).¹⁸

Groundwater resources

The Arab region's second major conventional water resource is groundwater. Shallow and deep groundwater resources, within or across national boundaries, are recharged by precipitation and by rivers. In Bahrain, Jordan, Lebanon, Oman, Tunisia, United Arab Emirates and Yemen, groundwater contributes more than

Table 1.3**Major groundwater systems in the Arab region**

Groundwater system	Localities	Countries sharing the system	Area (1000 km ²)	Remarks
Great desert sandstone aquifer systems in North Africa	Nubian Sandstone Aquifer System	Libya, Egypt, Sudan and Chad	2,200	Sandstone
	Continental Intercalary	Algeria, Libya and Tunisia	600	Sandstone
	Terminal Complex	Algeria, Libya and Tunisia	430	Sandstone
	Bechar	Western Algeria	240	
	Fazzan	Southwestern Libya	450	
Eastern limestone/carbonate Mediterranean aquifer system	Cenomanian-Turonian limestones in Lebanon, Palestine and Syria; and the Wadi as Sir limestone in Jordan	Jordan, Lebanon, Palestine and Syria	48	Contributes to the flow of the Orontes, Litani, other Lebanese rivers and the Jordan River
Hauran and Arab Mountain basaltic aquifer system		Jordan, Saudi Arabia and Syria	15	Contributes to the flow of the Azraq and Yarmouk basins through El-Hamma, Azraq and Mazreeb springs
Eastern Arabia tertiary carbonate aquifer system	Umm er Radhuma dolomite and limestone aquifer in the Arabian Peninsula and Iraq; Dammam limestone and dolomite aquifer in the Arabian Peninsula (except Yemen); and the Neogene aquifer in Bahrain, Kuwait, Oman, Qatar and the UAE	Bahrain, Iraq, Jordan, Kuwait, Oman, Qatar, Saudi Arabia, Syria, UAE and Yemen	1,600	Primarily a limestone and dolomite aquifer; hydraulically interconnected; a recharging-discharging aquifer system

Note: The Continental Intercalary and the Terminal Complex together form the North Western Sahara Aquifer System, which has an area of 1 million square kilometres extending over Algeria, Libya and Tunisia.

Source: Adapted from Ksia (2010); Sokona and Diallo (2008); Khater (2010).

“It was a dream come true, to open the tap and find water all the time at my house” one Libyan man commented to the BBC in a 2006 interview when the Great Man-Made River project finally reached Tripoli. Libya, lacking rivers, lakes and rain, is one of the driest countries on Earth. To meet rising demand accompanying urbanization and population growth, sea water desalination offered the only option—Libya has the longest coast on the Mediterranean (about 1,900 kilometres).

Then in 1953, during oil explorations in the Libyan Desert, large quantities of underground freshwater were discovered in the Nubian aquifer, sparking the idea of installing a huge network of pipes to bring this non-renewable water to the cities. In the past, people moved to water; this new project would move water to the people. Economic analysis indicated that the long-term network costs of the 26-year \$20 billion project would be 10 times lower than for desalination. Critics denied these claims and warned that the project was rife with corruption. Many called for abandoning the project and reinvesting in desalination.

At 2,820 kilometres and with more than 1,300 wells,

most of them deeper than 500 metres, the Great Man-Made River remains the world’s largest pipe and aqueduct network and the largest irrigation project. It supplies some 6.5 million cubic metres of water daily to Benghazi, Sirte and Tripoli, among other Libyan cities. Official sources claim that at 2007 rates, the aquifer would last for some 4,625 years, although independent estimates warn that it might be depleted in a century or less. More recent reviews mention the gradual drying of the aquifer’s nearby oasis. And while former Libyan president Muammar Qaddafi described the project as the eighth wonder of the world, a critic countered that “this is basically a wonder of the world because it’s exactly like the pyramids—it’s huge and massive and probably not cost-effective, as 70 per cent of the water is used in irrigation and none reserved for heavy industry,” adding that “if the farmers had to pay the full cost of pumping and shipping the water to them, they wouldn’t break even on their agriculture.”

Source: UNEP 2010b.

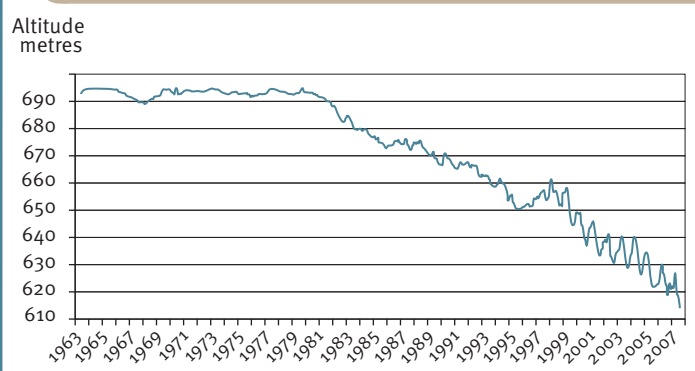
50 per cent of total water withdrawals. In the Arabian Peninsula it accounts for 84 per cent. Even countries fairly rich in surface water are relying more on groundwater to meet steadily rising demand. And in some areas, such as the southern oases of some North African countries, groundwater is the only water resource available. Vast areas, spanning many Arab countries, contain non-renewable groundwater resources, or fossil aquifers. These resources are used mainly for agricultural expansion and development and with few exceptions without integrated planning.¹⁹ As surface water quality deteriorates, groundwater could become the main water resource for domestic use.

Major geological structures and sedimentation processes control groundwater movement, exploitation and quality in both shallow and deep aquifers. Extensive, deep sedimentary formations in northern Africa and the Arabian Peninsula contain major non-renewable fossil aquifers, with very limited recent recharge (most recharge occurred during wet periods 15,000–25,000 years ago). Unconsolidated deposits, mainly sand and gravel from the Neogene and Quaternary periods, form the shallow renewable aquifers under riverbeds,

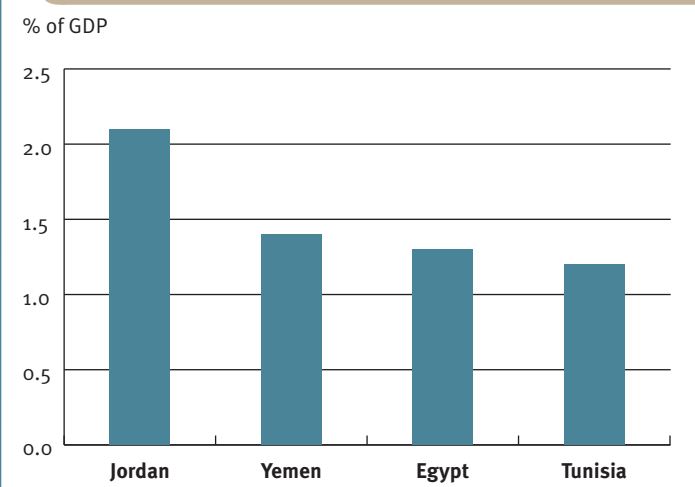
flood plains, deltas, wadi beds, major depressions and the interior coastal plains. Water quality varies widely, with a salinity range of 200–20,000 milligrams per litre. In some aquifers, water requires treatment before use, and in others, temperatures of 40°C–65°C limit the water’s suitability for domestic consumption. However, geothermal water can be used for greenhouses (for warming and some irrigation) before being used for agriculture at more appropriate temperatures. The aquifers of the Tigris-Euphrates and the Nile and its delta, the intermountain valleys in North Africa and the wadis in the Arabian Peninsula store adequate reserves, with good water quality, and are frequently recharged from river flow and floods. These aquifers are used extensively for domestic water consumption and irrigation.²⁰ Iraq, Jordan, the Arabian Peninsula and North Africa share many of the deep aquifers (Table 1.3).²¹

Overexploitation of groundwater resources.

Most Arab countries, especially in the Arabian Peninsula²² and the Maghreb region, draw heavily on groundwater resources (renewable and non-renewable) to meet rising demand

Figure 1.4**Observed declines in the groundwater level of the Saïss basin, Morocco, 1963–2007**

Source: ABHS and others 2007.

Figure 1.5**Value of groundwater depletion in Jordan, Yemen, Egypt and Tunisia, 2005**

Source: Ruta 2005.

for water, particularly for domestic consumption and irrigation (Box 1.2). Non-renewable groundwater resources are used in planned ways (for example, the Sarir basin in Libya and Al-Sharqiyah Sand and Al-Massarar basin in Oman) and unplanned ways (for example, Saq Aquifer, Disi Aquifer, Tawilah Aquifer and Sana'a basin in Yemen and the Palaeogene aquifer in the Arabian Peninsula), with unplanned use far more common.²³ Using groundwater resources beyond their natural replenishment rates has resulted in rapid depletion of aquifer reserves and salinization and deterioration in water quality due to seawater intrusion. In addition to overexploitation and

quality deterioration, groundwater resources in most Arab countries are threatened by pollution from agricultural, industrial and domestic activities.²⁴

In Saïss basin, near the Moroccan cities of Meknes and Fez, overexploitation led to a decline in groundwater levels of about 70 metres over 1981–2006 (Figure 1.4).²⁵ In Gaza, excessive water pumping has resulted in seawater intrusion of about 70–80 per cent of the coastal aquifer.²⁶ In the Amman-Azraq basin in Jordan, excessive abstraction has increased groundwater salinity from less than 400 milligrams per litre in 1994 to 1,800 in 2004 due to encroachment of underlying salt water.²⁷ In the Tunisian oases of Kébili, overexploitation has led to deep groundwater decline and near extinction of shallow aquifers.

Groundwater overexploitation and depletion have also had severe environmental impacts. Water salinization has dried natural springs and degraded or destroyed their surrounding habitats and ecosystems, diminishing these areas' historical and cultural value. For example, most springs in the Syrian Palmyra oasis have dried up, including Afka, former site of the Kingdom of Zanoibia.²⁸ The South Algerian oases, natural springs in Bahrain, most of the oases of the Egyptian Western Desert, the Al Kufrah oasis in Libya, the Al Ahsa oasis in Saudi Arabia and the natural springs used to irrigate Tozeur and Kébili in southern Tunisia have all been lost through excessive pumping and sinking groundwater levels. In the United Arab Emirates, intensive groundwater abstraction in the eastern coastal plains increased water salinity, leading to abandoned irrigation wells and dying date plantations.²⁹ In Yemen, excessive groundwater withdrawal for extensive irrigated agriculture has led to seawater intrusion in several coastal areas, especially Abyan Delta along the Gulf of Aden, the Tihama area and Wadi Mawr.

Overpumping groundwater also depletes national assets. While economic activities based on extracted water boost GDP in the short term, groundwater overexploitation, especially mining fossil water resources erodes a country's natural capital and threatens irrigated areas in the long term. The value of national wealth

consumed by overexploiting groundwater is estimated at as much as 2 per cent of GDP in four Arab countries (Figure 1.5).³⁰

Sustainable management of groundwater resources.

It is vital, therefore, to manage groundwater resources in the Arab countries as public goods by observing their natural recharge rates (Box 1.3). In this way, these resources can continue to support their dependent ecosystems and contribute to sustainable human development. The Tunisian oases of Kébili exemplify efforts to control groundwater overexploitation: satellite images measure the irrigated area and any illegal extensions and help control the number of deep wells.³¹

A regional meeting of water experts in Arab countries in 2005 stressed that achieving sustainability for non-renewable resources is a challenge for water resource managers.³² Participants agreed that sustainability must be clearly defined in socio-economic and physical contexts that fully account for the immediate benefits as well as the longer term negative consequences. They emphasized the need to prepare an exit strategy, one ready to be deployed once an aquifer is depleted and that covers replacement water resources, balanced socio-economic solutions for aquifer reserves and a transition to a less water-dependent economy.

Groundwater reserves must be used with maximum hydraulic efficiency and economic productivity; this implies full re-use of urban, industrial and mining water and careful control of irrigation waters. The management goal would be to use aquifer reserves responsibly, in accordance with expected benefits and predicted impacts over a specified time frame. In Arab countries, investing in desalination and treatment technologies is essential to reduce costs and environmental impact. Investing in modern agricultural technologies is also important if agricultural development is to continue. Establishing the social conditions conducive to aquifer management will require public awareness campaigns on the nature, uniqueness and value non-renewable of groundwater, highlighting full user participation wherever possible.

Box 1.3

Groundwater use rights

Groundwater resources must be treated as public property (or common property) resources. The state, as steward of these resources, must be able to introduce measures to prevent aquifer depletion and pollution.

It is important to create a system of groundwater abstraction rights consistent with hydrogeological realities. That means that well owners become well users who must apply to the state for water abstraction rights. For non-renewable groundwater, it is also important to identify the government level with the highest authority to make decisions on mining aquifer reserves. Monitoring water quality, levels and extraction amounts in an aquifer is the foundation of groundwater resource management. Monitoring should be carried out by the water resource administration, stakeholder associations and individual users. Time-limited permits subject to initial review will normally induce permit holders to provide regular data on wells. The water resource administration must make appropriate institutional arrangements through law enforcement and create an aquifer database for archiving, processing, interpreting and disseminating information.

Source: Foster and others 2005.

Nonconventional water resources

With demand rising and supplies dwindling, Arab countries have drawn heavily on nonconventional water sources, including desalinated water, treated wastewater and other sources such as rainwater harvesting, cloud seeding and use of irrigation drainage water.

Desalination

With more than half the world's desalination capacity, the Arab region leads the world in desalination (Box 1.4).³³ Although desalinated water contributes only a very small share of Arab countries' total water supply (1.8 per cent), it contributes nearly all the water supply for many cities.³⁴ The overall share is expected to grow as a result of industrialization, accelerated urbanization, population growth and depletion of conventional water resources. Some countries, such as Jordan and Tunisia, desalinate brackish water at a low cost and promote it for domestic use.³⁵

Desalination plants in Arab countries have a cumulative capacity of about 24 million cubic

Box 1.4

Desalination processes and the dominant technology used in the Arab countries

The two main types of desalination technology are thermal and mechanical. Thermal, the older technology, separates water from minerals through evaporation-distillation using multi-stage flash technology, a very energy-intensive process. Mechanical processes use reverse osmosis to force pressurized saline water through membranes that exclude most minerals. In the Arab region, the multi-stage flash technology still dominates, particularly in the Gulf Cooperation Council countries, although installed capacity for reverse osmosis is growing. The reverse osmosis technology, easily scalable due to its high modularity, requires no thermal energy and less or equivalent amounts of electric energy than distillation. Most Gulf countries still prefer the thermal technology, however, because they use the disposed heat in cogeneration systems. More recently, hybrid reverse osmosis and multi-stage flash systems are being used in cogeneration systems.

Source: Al-Jamal and Schiffler 2009; World Bank and BNWP 2004; Bushnak 2010; GWI 2010; Jagannathan, Mohamed, and Kremer 2009; World Bank 2005.

cent by 2025. Most of the anticipated increase in capacity will be concentrated in the region's high-income, energy-exporting countries, such as the Gulf countries, where it will be used to supply water to cities and industry. More than 55 per cent of the water supplied to cities in the Gulf countries comes from desalinated water, used directly or blended with groundwater. This share is expected to rise as groundwater resources continue to deteriorate.

High financial and energy costs of desalination

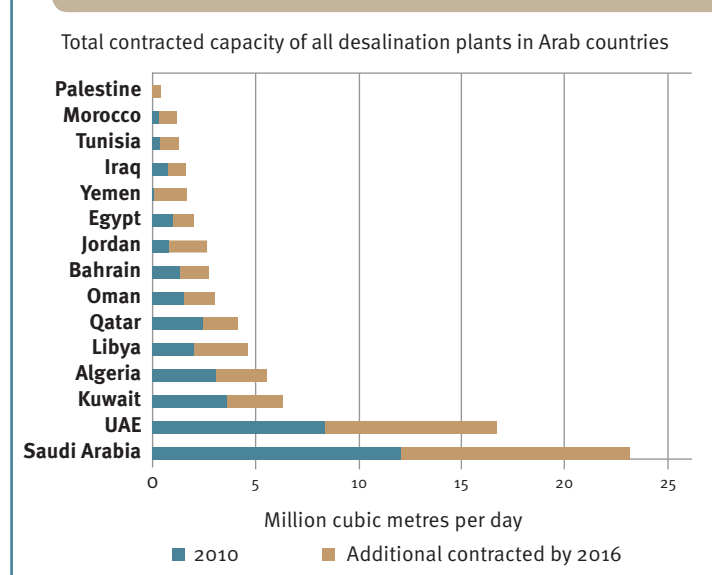
Desalination is an energy- and capital-intensive process, with costs depending on energy requirements, water production costs, technology growth trends and environmental impact. Costs per delivered cubic metre of desalinated water are as high as \$1.50—and even \$4 in extreme cases. The water is subsidized, however, and sold for as little as 4 cents per cubic metre in some Arab countries.

With improvements in desalination technologies, production costs are dropping. New technologies, such as reverse osmosis, electrodialysis and hybrids, are more energy efficient and better suited to different types of water. These advances drove down global prices for multi-stage flash over 1999–2004, from an average of \$1.0 per cubic metre to \$0.50–\$0.80 (Figure 1.7).³⁶ For reverse osmosis, the average cost of desalinated water is estimated at \$0.99 per cubic metre for seawater and \$0.20–\$0.70 for brackish water. Energy requirements vary from 4–8 kilowatt hours per cubic metre for reverse osmosis seawater, as in the Carboneras desalination plant in Spain, to 3.5–5.0 for multi-stage flash technology (Table 1.4). This downward trend in the cost of desalinated water indicates that desalination technology is becoming more viable for poorer countries.

However, a joint World Bank–Arab Gulf Program for Development study found that while the average production cost of desalinated seawater from recently completed large plants in the United States and many other places has fallen to around \$0.70 per cubic metre (excluding distribution costs and varying according to plant size, depreciation duration and energy costs) average costs in the Gulf Cooperation

Figure 1.6

Accumulated desalinated water in selected Arab countries, 2010 and 2016.



Source: AFED 2010.

metres a day. The highest desalination capacity is in the Gulf countries (81 per cent), Algeria (8.3 per cent), Libya (4 per cent) and Egypt (1.8 per cent; Figure 1.6). Growth is expected to remain high for the next decade to meet escalating domestic water demand. Desalinated water will expand from 1.8 per cent of the region's total water supply to an estimated 8.5 per

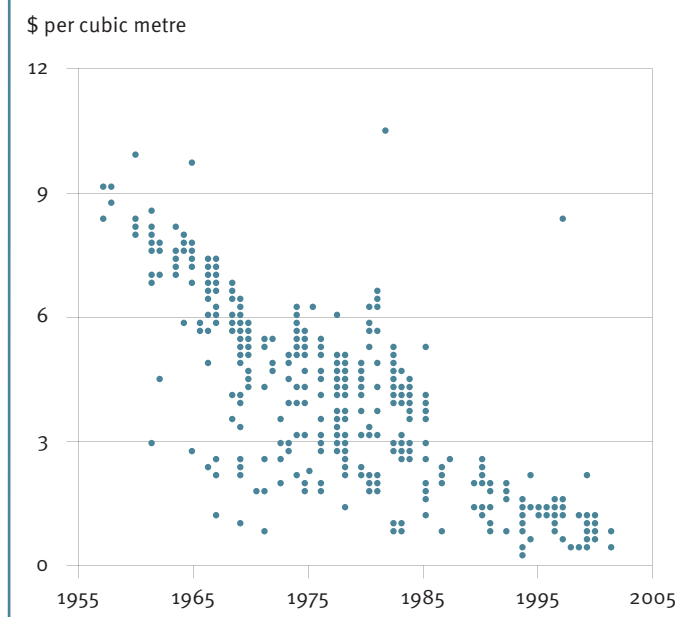
Council countries remain at \$1–\$2 per cubic metre.³⁷ Many factors account for the higher costs, including public sector dominance of the industry and the enormous investment costs for new desalination plants, especially under heavy government subsidies for the water sector. These factors will make it difficult to meet rapidly rising water demand and will place an intolerable burden on national budgets.³⁸

Arab countries plan to increase desalination capacity from 36 million cubic metres a day in 2011 to about 86 by 2025. Most of this investment will be in the Gulf countries, Algeria and Libya. Investment needs to 2025 are estimated at \$38 billion, \$27 billion of it in the Gulf countries (Table 1.5). The energy costs of the anticipated expansion in desalination capacity to 2025 can be estimated using the cost breakdown of a typical reverse-osmosis desalination plant (see Table 1.4), though costs would vary with interest rates and energy prices. At a 10 per cent interest rate, the cost would be \$0.62 per cubic metre.³⁹ Arab countries are expected to desalinate about 19 billion cubic metres in 2016 and about 31.4 billion in 2025, 30 per cent of unmet demand, at an average cost of \$0.525 per cubic metre.⁴⁰ The predicted annual desalination costs are estimated at \$10 billion in 2016 and \$15.8 billion in 2025, of which energy costs will be about \$4 billion in 2016 and \$6.4 billion in 2025. The annualized capital cost is estimated at \$5.4 billion.⁴¹

Desalination is very energy-intensive, so energy efficiency should be a key criterion in commissioning new plants and upgrading old ones.⁴² Saudi Arabia, with 35 per cent of the Arab region's desalination capacity, uses 25 per

Figure 1.7

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



Source: Zhou and Tol 2005.

cent of its oil and gas production to generate electricity and produce water in cogeneration power–desalination plants. If water demand continues to grow at the current rate, this share will top 50 per cent by 2030.⁴³ In Kuwait, cogeneration power–desalination plants account for more than half of total energy consumption; the energy required to meet desalination plant demand is expected to equal the country's current fuel oil production by 2035.

Despite having half the world's desalination capacity, Arab countries devote little R&D to these technologies, which are all imported. In addition, the desalination industry contributes only limited added value in fabricating

Table 1.4

Cost breakdown for typical reverse osmosis desalination plant in the Arab region

Parameter	Cost (\$ per cubic metre)
Capital cost, 800 cubic metres per day capacity	
Energy consumption, 3.5 kilowatt hours per cubic metre	
Annualized capital cost (at 5 % interest rate)	0.180
Energy cost (at \$0.06 a kilowatt hour)	0.210
Membrane replacement cost	0.035
Labour and chemicals	0.100
Total cost	0.525

Source: Al-Jamal and Schiffler 2009.

Table 1.5 Desalination cost in selected Arab countries

\$ million, unless otherwise indicated

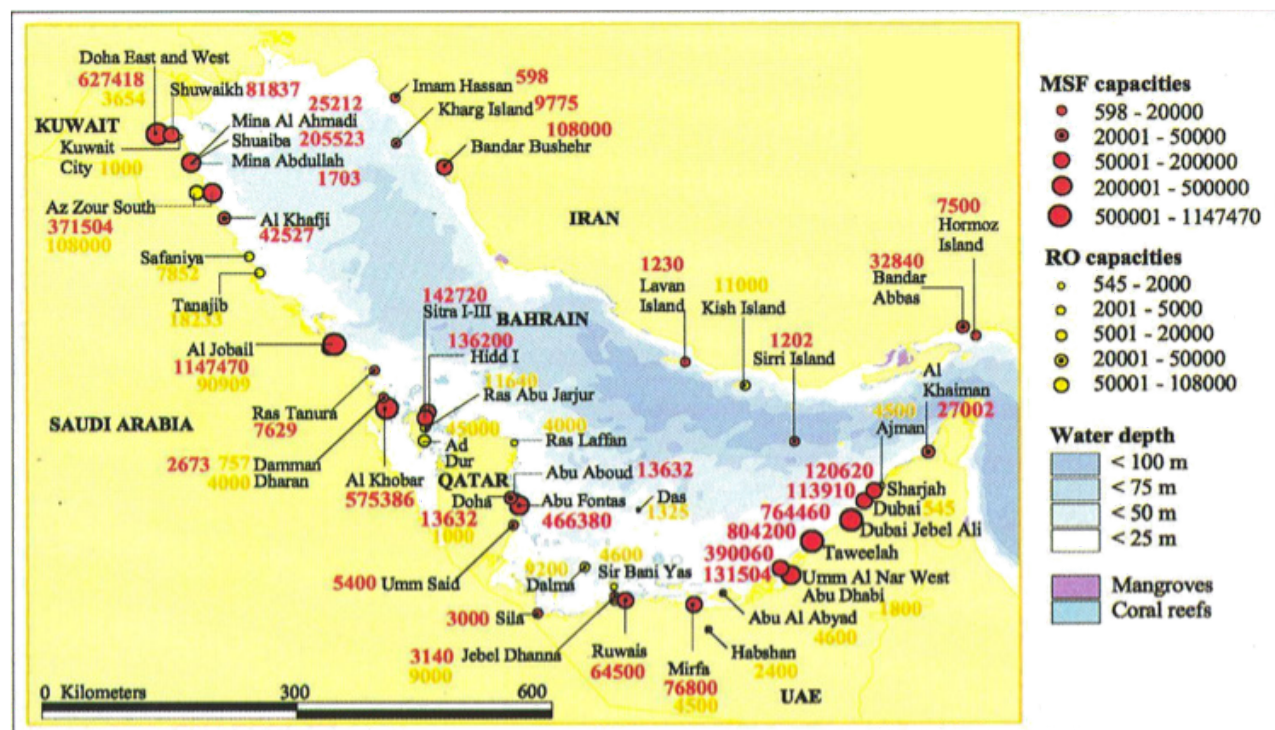
Country	Desalination capacity forecast 2025 (million cubic metres)	Capital cost at \$0.18 per cubic metre at 5% interest rate	Required additional capacity until 2025 (1,000 cubic metres a day)	Investment cost at \$800 a day capacity	Energy cost at \$0.21 per cubic metre and \$0.06 per kilowatt hour	Total cost at \$0.525 per cubic metre
Algeria	8.214 ^a	1.48	5,023	4,018	630	1,574
Egypt	1.536	0.28	1,008	806	118	294
Libya	7.206	1.3	5,337	4,270	552	1,381
Morocco	0.862	0.15	577	462	66	165
Tunisia	0.481	0.09	286	229	37	92
Jordan	1.541	0.28	1,000	800	118	295
Saudi Arabia	26.816	4.83	14,252	11,402	2,055	5,139
Kuwait	6.725	1.21	3,279	2,623	515	1,289
Bahrain	3.406	0.61	2,223	1,778	261	653
Qatar	3.93	0.71	2,254	1,803	301	753
Oman	3.713	0.67	2,573	2,058	285	712
UAE	18.27	3.29	9,240	7,392	1,400	3,501
Total	82.7	14.9	47,052	37,642	6,339	15,847

a. Extrapolated.

Source: Al-Jamal and Schiffler 2009.

Map 1.3

Multi-stage flash (MSF) and reverse osmosis desalination plants in the Gulf, 2008



Source: Lattemann and Höpner 2008.

equipment, refurbishing plants, localizing operations and maintenance, manufacturing key spare parts and training local labour.⁴⁴

Harmful environmental impacts

While desalination plants produce freshwater that augments supply and reduces pressure on conventional water resources, they have harmful environmental effects. New technologies have reduced some of these, but others remain, including air pollution from oxide emissions, seawater and marine life pollution from discharged brine, increased salt concentration from effluents and emission of trace elements and residual treatment chemicals (such as anti-foaming and anti-scaling agents).⁴⁵ The regional impact of the water discharged from thermal desalination plants has not been studied in depth,⁴⁶ but countries surrounding the small, enclosed Arabian Gulf are increasingly concerned about the threat to marine life and damage to the fragile marine ecosystem (Map 1.3).⁴⁷ The growing number of desalination plants along the Gulf coast and the rising temperature of its water warrant close study.

Another major environmental concern is the greenhouse gasses emitted while producing electricity and steam to power desalination plants. In the Arab region, large desalination

plants using multi-stage flash cogeneration technology are typically powered by fossil fuel. They emit 10–20 kilograms of carbon dioxide per cubic metre, depending on the heat cycle rate.⁴⁸ Almost none of the thermal plants built in the Gulf countries uses low heat cycle technology, which would lower their carbon footprint but increase capital costs.⁴⁹ Power generation plants emit 0.5–0.8 kilogram of carbon dioxide per cubic metre, depending on the fuel used and plant efficiency.⁵⁰

Policy implications

The energy requirements for desalination can be met through renewable sources, such as wind, solar and possibly wave power. Until recently, only small desalination plants in remote areas with no access to electricity from the grid used renewable energy, but as R&D has intensified, several pilot desalination plants have operated successfully using solar, wind or geothermal energy.⁵¹ The Arab region has vast solar energy potential. If Arab countries used only 5 per cent of their deserts to build concentrated solar power plants, they could satisfy the world's energy needs.⁵²

Developing solar-powered desalination technologies should be a top priority in Arab countries. R&D investments to identify optimal

Box 1.5

Recommended actions for enhancing water desalination sustainability

The large anticipated expansion in desalination plants requires a review of policies and practices, including ways to increase capacity, knowledge and value added to the local economy. In the Arab region, local capacity and knowledge focus on operations and maintenance, ignoring plant design, manufacturing and construction, even in countries that depend heavily on desalination to meet domestic water demand. The current local talent is not adequate to meet the enormous demand for technicians and engineers. By designing incentives for local businesses, governments can attract local investments in manufacturing key desalination plant components and cultivating local innovations to attain economic sustainability.

Government agencies involved in water policy should consider shifting their role from desalination plant procurers to water purchasers, to enable

the most efficient technology and operation. Such a shift would also contribute to building local skills and capabilities and enlarging the private sector's role in desalination. More critically, the government's role would shift from operator to regulator, to guarantee access and affordability. However, if government enterprises continue to build and operate large desalination plants, steps should be taken to manage these assets in a way that minimizes the life-cycle cost of water. Like private enterprises, government enterprises should value energy at world market prices and provide incentives for in-house R&D departments to promote innovations in technology and operation.

Source: Bushnak 2010.

The term “grey water” refers to domestic wastewater generated from less polluted sources, such as kitchen sinks, washing machines, dishwashers, hand-washing basins and showers. Grey water, at around 50-70 per cent of domestic wastewater, is recognized as a potential water saver and demand management tool. Like harvested rainwater, grey water can be generated on one’s premises, thus circumventing trust issues, one of the major obstacles in wastewater treatment and reuse in the Arab region. Treatment is simple. Grey water kits consist of four connected barrels. The grey water flows from the house gravitationally into the barrels, where treatment occurs in stages; the fourth barrel receives treated water, clean and ready for reuse. Domestic grey water users include not only private homes but also mosques, kindergartens and gardens. More recently, the Lebanese Ministry

of Energy and Water incorporated grey water into its Ten-Year Water Plan for Lebanon.

To explore grey water potential in the region, the Canadian International Development Research Centre has supported grey water treatment in Jordan, Lebanon, State of Palestine and Yemen, equipping more than 2,000 houses with grey water treatment systems over 1998–2008. These projects revealed not only the high regional potential for using such forms of treated wastewater but also the absence of any health risks. Annual economic saving was estimated at more than \$300 per family, but successful implementation will require government incentives, continuous quality monitoring and enforcement of local standards and regulations.

Source: AFED 2010.

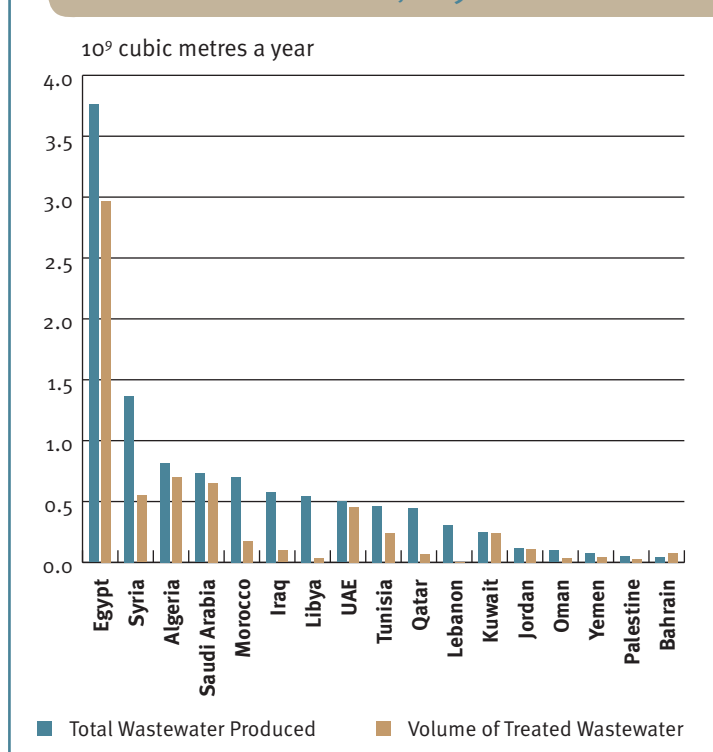
technical solutions and products for solar desalination and cogeneration could improve the region’s social and economic condition. The Arab Forum for Environment and Development strongly recommends that Arab countries

develop joint R&D programmes in desalination and renewable energy and maximize the value of new ideas and research findings emerging from institutional knowledge hubs such as Masdar City in Abu Dhabi, King Abdullah University for Science and Technology, the recently established King Abdullah City for Atomic and Renewable Energy and the Qatar Foundation’s ambitious R&D programmes in solar energy and desalination.⁵³

Unconventional water production plays a large role in preserving groundwater. While desalination is now a necessity rather than an option, large-scale projects, with their high financial and environmental costs, should be considered only after more cost-effective and sustainable supply and demand measures have been implemented (Box 1.5). These measures include effective pricing, reducing nonrevenue water in the distribution network and rationing and conserving water in the domestic sector. Both existing and future desalination plants must also include mitigation measures to reduce their environmental impact, particularly strengthening and enforcing environmental laws for building and operating desalination plants (such as maximum limits on carbon emissions). Also important are reactive measures involving physical changes to plants or processes. Reactive measures include optimizing the

Figure 1.8

Wastewater produced and treated in some Arab countries, 2009–2010



Source: World Bank and others 2011.

siting of plants, using more energy-efficient technologies and employing design and treatment techniques that reduce damage to the marine environment (such as using appropriate sea outfalls and mixing brine with seawater before discharge).

Treated wastewater

Arab countries are using more treated municipal wastewater to meet escalating demand in urban areas. Treated wastewater is estimated at 4.7 billion cubic metres a year and rising.⁵⁴ Water scarcity, financial capacity and agricultural sector importance shape wastewater treatment and reuse.⁵⁵ While most of the region has programmes for reusing treated wastewater in irrigation (fodder crops, cereals, alfalfa, and olive and fruit trees are irrigated mostly with treated water), few countries have institutional

guidelines for regulating treated wastewater (Box 1.6).⁵⁶

Data on generated, treated and reused wastewater in the Arab region are outdated and span so many years (1991–2006) that analysis and comparison across countries are difficult. Arab countries produce about 13.2 billion cubic metres of wastewater a year and treat about 40 per cent of it; they discharge the rest to open water channels, the sea or ground reservoirs, raising concerns for public health and the environment. The Arab region treats a higher share of its wastewater than some other regions (35 per cent in Asia, 14 per cent in Latin America and the Caribbean and 1 per cent in Africa),⁵⁷ but the share ranges widely across countries, from almost none to almost 100 per cent (Figure 1.8). If all wastewater were properly treated and reused, including domestic wastewater, it could support water demand in some sectors, such as agriculture

Box 1.7

Wastewater regulatory management in the Arab countries

Arab countries need to develop guidelines and instructions for treated wastewater reuse—from the plant to the field—to control and ensure visibility and transparency from production to reuse. They also need achievable and enforceable standards and regulations to ensure sustainable wastewater treatment and reuse. Most Arab countries have standards to protect public health and the environment, but the main factor driving strategies for wastewater reuse is the cost of treatment and monitoring. In several cases, treated wastewater does not meet specified quality standards because specified procedures are not followed or enforcement is allowed to slide because of a lack of qualified personnel. In many Arab countries, monitoring and evaluation of wastewater reuse systems are irregular and underdeveloped because of weak institutions, a shortage of trained personnel, lack of monitoring equipment and high monitoring costs.

Arab countries fall into three broad categories of wastewater disposal practices:

Category 1. This group includes Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and the United Arab Emirates. All Gulf Cooperation Council countries follow similar methods in wastewater effluent disposal. A high percentage of treated wastewater is reused in irrigation while the remainder is discharged in the sea after many advanced treatment steps. Strict quality standards are followed before disposal and reuse, but certain parameters could be relaxed to fully use the ever-increasing volume of secondary treated effluent.

Category 2. This group includes Egypt, Iraq, Jordan, Morocco and Syria. These countries have moderately strict regulations for disposal of effluent from wastewater treatment plants, but actual practice does not meet national or international standards. This may be due to the inability of treatment plants to cope with large volumes of raw wastewater. A high percentage of the wastewater effluent is disposed of in surface water bodies for later use in irrigation, following regulations on the types of crops that can be irrigated with this treated water. This water may also be used for landscaping and industrial purposes. The governments do not allow raw wastewater to be disposed of in wadis or through land discharge. Violations may occur in rural areas not connected to the sewer (collection) system.

Category 3. This group includes Lebanon, the West Bank and Yemen, where large amounts of wastewater effluent are disposed of in wadis and subsequently used to irrigate crop lands without treatment. In the West Bank, raw sewage is disposed of in wadis, where it is used to irrigate all kinds of crops and vegetables. No environmental or health controls protect the workers, products or soil or prevent groundwater contamination. In Yemen, raw wastewater is used for irrigation without treatment.

Source: AHT 2009; Fatta and others 2005; Choukr-Allah and Hamdy 2004; Choukr-Allah 2010.

and industry, while avoiding many health and environmental problems.

Treated wastewater deserves particular attention in the Gulf countries, with their large urban populations averaging 87 per cent of the total population and financial strength. In most of these countries, treatment facilities operate with tertiary and advanced treatment capabilities. These countries use about 40 per cent of treated wastewater for fodder, landscaping and irrigation of non-edible crops. About half of municipal wastewater is discharged untreated

into wadis to infiltrate shallow aquifers or into the sea, severely polluting coastal and marine environments.⁵⁸ All the Gulf countries have ambitious plans to reclaim more wastewater to meet the demand for irrigation water and to reduce groundwater abstraction for agricultural use.⁵⁹ Egypt treats and reuses a substantial amount of wastewater outside the Nile Delta for landscaping, desert reforestation schemes and food, industrial, cosmetic and energy crops.⁶⁰ In Jordan, treated wastewater blended with freshwater irrigates food crops on some 10,600 hectares and provides about 20 per cent of the country's irrigation water.⁶¹ In Libya, some 40 million cubic metres (6.6 per cent) of the 600 million cubic metres of wastewater generated annually is treated and reused on fodder crops, ornamental trees and lawns. In Tunisia, around 30 per cent of treated wastewater is reused in agriculture and other areas.

Treated wastewater offers many advantages for the arid Arab countries. It lacks the uncertainties of surface water resources and can meet a proportion share of the rising water demand from urbanization and population growth. Many factors prevent the expansion of water reuse, however, including social barriers, technical obstacles and institutional and political constraints.

Policies are needed for wastewater treatment to protect human health and the environment (Box 1.7). Awareness and government subsidies are not enough to promote the reuse of treated wastewater when another water source is available, even if that source is scarce and insufficient. A cost effectiveness analysis could help decision-makers choose a sustainable course of action. Drainage capacity building is also needed (Box 1.8).

Ensuring social acceptance of treated wastewater is a major issue. Appropriate technologies, proper regulations and participatory management practices can all help. Political will and commitment to expand the use of treated wastewater are essential. Arab governments can help by exercising regulatory and managerial tools, allocating required resources and establishing incentives. Multiple strategies are needed, including monitoring and evaluation, sponsoring public awareness campaigns

Box 1.8

Drainage capacity building in North Africa

The International Programme for Technology and Research in Irrigation and Drainage is a specialized programme for promoting drainage capacity building in Africa. In its workshop on North Africa, the programme presented an overview of the existing systems and key recommendations to develop the drainage sector, including the following:

- All countries need to strengthen their national drainage capacity. Depending on the country, the emphasis may be on surface or subsurface drainage systems. Most countries require a combination of systems: subsurface drainage systems to control water logging and salinity and surface drainage systems to control surface run-off.
- Few drainage engineers are available. All participants prioritized more intensive networking to facilitate information exchange.
- Knowledge enhancement through international courses (involving case studies and site visits in the North African countries to appreciate the different drainage solutions) is essential.
- Collaboration should be international and include R&D institutions from North Africa, Europe and elsewhere.
- Capacity building requires comprehensive attention from beginning to end of a drainage project: identification, design, construction, implementation and socio-economic aspects, such as farmer participation. Greater focus on environmental aspects is necessary. It is important to place the drainage issue in the context of overall water management and to integrate it with water quality control.
- The financial and technical assistance required for capacity building requires medium- to long-term commitment and planning. Participants expressed the need for international collaboration. The details of such collaboration could be discussed with donors and elaborated on and coordinated as appropriate by international agencies and national governments.

Source: IPTRID 2002.

to improve public attitudes towards treated wastewater, setting national standards for reuse and protection of public health, making reclaimed wastewater a more reliable alternative to groundwater or surface water in irrigation and implementing effective plans to increase crop value and conventional water resource conservation.⁶² As social barriers to wastewater reuse (such as farmers' disinterest and religious prohibitions) diminish, the public will begin to accept the need for reuse, especially for non-edible crops, ornamental gardens and the like.⁶³

Other nonconventional water sources

Several Arab countries have investigated alternative water supply strategies. Jordan highlights rainwater harvesting for irrigation and water supply. Water harvesting techniques have been used in the Arab region since ancient times. Water harvesting offered a necessary, low-tech solution to increase water use efficiency, intensify agricultural production during dry seasons and minimize environmental degradation.⁶⁴ In one of the driest regions of the world, sustainable water harvesting should be a priority to ensure optimal use of precipitation, limit water resource depletion and satisfy people's needs.⁶⁵

The main conservation methods in the Arab countries include cisterns (limited quantities of water for short periods), micro-catchments (adjacent to cultivated areas), small dams and underground storage. Spreading systems include terraces (masateh, in Oman, Saudi Arabia and Yemen), irrigation diversion dams, sloped catchment areas next to fields (meskat, in the Maghreb region), artificial recharge and check dams. Shallow dug wells and pit galleries also abstract water from shallow aquifers (for domestic supply as well) and exploit groundwater in the coastal sand dunes. These diverse systems manage rainfall, protect soil moisture and control soil erosion and desertification.⁶⁶

Among the main constraints to greater use of rain harvesting are inadequate data on rainfall and run-off, inefficient catchment conditions and hydrological techniques, and the high cost of installing, monitoring and maintaining water harvesting infrastructure. Socio-economic constraints include farmers' outdated knowledge of water harvesting methods and land tenure

weaknesses that reduce the motivation to invest in new water harvesting structures.

Improving water harvesting techniques requires a long-term government policy to support national research centres and extension services, adequate institutional structures, beneficiary organizations (associations, cooperatives), and training programmes for farmers, pastoralists and extension staff.

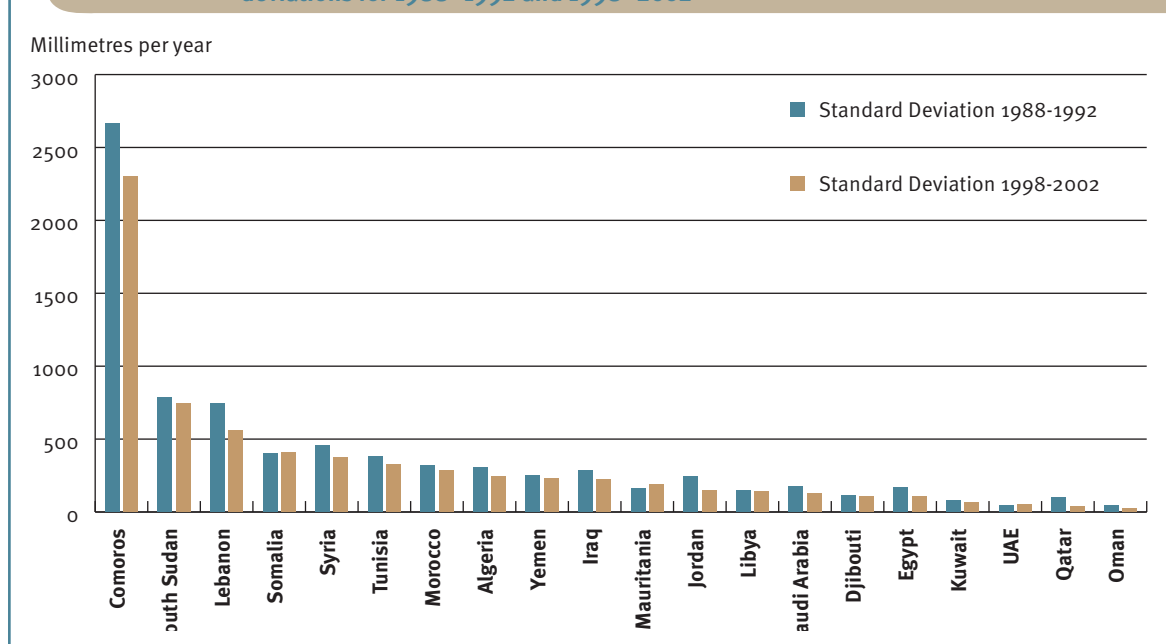
Weather modification through cloud-seeding technologies is also being tested in the region. United Arab Emirates reported positive results with cloud seeding in May 2008.⁶⁷ Jordan reported a 13 per cent average increase in rainfall after 10 rainy seasons following cloud-seeding experiments. Saudi Arabian cloud seeding experiments also registered positive results.⁶⁸ The Saudi National Centre for Meteorology and Environmental Protection is also implementing a weather modification project.⁶⁹ The practice has raised concerns over cloud ownership between countries, however.⁷⁰

The Arab region also draws heavily on reused irrigation drainage waters. Among Arab countries, Egypt and Syria use the most nonconventional irrigation water: Egypt uses about 7.5 billion cubic metres a year of reused agricultural drainage water, and Syria uses 2.3 billion.⁷¹ Egypt adopted a national policy for drainage reuse in 1975 to enhance water use efficiency and increase cultivated area. The amount of drainage water reused for irrigation is expected to reach 8.7 billion cubic metres a year by 2017.⁷²

Despite the benefits, reusing drainage water damages the Nile's water quality; salts, pesticides and industrial and municipal effluents in the water harm human health and the environment. A long-term policy and a comprehensive monitoring programme are needed to improve the efficiency of drainage water reuse and limit its polluting impact. Egypt has operational guidelines for reusing drainage water as part of its horizontal land expansion programme, including evaluating water availability, assessing water quality and examining the socio-economic aspects for landholders.⁷³

Figure 1.9

National Rainfall Index for Arab countries, standard deviations for 1988–1992 and 1998–2002



Note: There are insufficient data for Bahrain and Palestine. The index measures the variation of total annual precipitation from the long-term average for 1986–2000.

Source: FAO 2013.

Vulnerabilities of Arab water systems

Arab water systems have multiple vulnerabilities, from large variability in water resources to shared water resource, water pollution and the impacts of climate change.

Natural variability of water resources

Arab countries face serious challenges in managing their variable water resources. The extremely arid Gulf countries have adapted by relying on desalination. Egypt, Iraq and Syria have hastened to develop renewable, mostly transnational, water resources. Their efforts to secure historical rights to these resources have placed them in competition and potential conflict with upstream countries. Countries with limited renewable water resources and weak financial capability, such as Jordan, have pursued water reuse and demand management initiatives. Several countries now draw heavily on non-renewable fossil aquifers to offset the negative water balance. Most Arab countries have already exhausted their water supply development potential. Consequently,

managing demand, in addition to improving water efficiency across sectors, offers effective and realistic options. Water supplies, exploited to their maximum levels, must be developed and maintained to ensure reliability.

The Arab region's rainfall variability is not only seasonal and geographic but also annual. Natural variability may result in five-year runs with rainfall at 10 per cent above or below average, though in 9 years out of 10, variability is less than 10 per cent. This high rainfall variability is reflected in the National Rainfall Index, which measures the variation of total annual precipitation from the long-term average for 1986–2000. Rainfall variability decreased from 1988–1992 to 1998–2002 (Figure 1.9).⁷⁴ The region's year-to-year rainfall variations have enormous implications for water systems⁷⁵ and require inter-annual water management, storage and conjunctive use between surface water and groundwater.

Shared water resources

More than half of total renewable water resources (surface water and groundwater) in

the Arab region (about 174 billion cubic metres a year of a total of 315 billion) originate from outside the region (water dependency ratio).⁷⁶ These include major rivers such as the Euphrates, Nile, Senegal and Tigris. Many smaller rivers are also shared between Arab countries, including the Yarmouk River in Syria and Jordan and the Orontes (Al-Assi) and El-Kabir Al-Janoubi rivers in Lebanon and Syria. Large regional groundwater systems, both renewable and non-renewable, extend between neighbouring Arab countries and across the region's borders. The region's shared aquifers include the Nubian Sandstone Aquifer (Chad, Egypt, Libya and Sudan); the North Western Sahara Aquifer System (Algeria, Libya and Tunisia); the Mountain Aquifer (Israel and West Bank); Disi Aquifer (Jordan and Saudi Arabia); Rum-Saq Aquifer (Jordan and Saudi Arabia) and the Great Oriental Erq Aquifer (Algeria and Tunisia). Most of these aquifer systems are non-renewable; encompass vast areas, mainly in the Sahara Desert and the Arabian Peninsula; and are shared by many Arab and non-Arab countries. These aquifer systems store substantial water in deep geological formations, but the water has a finite lifespan and quality limitations.⁷⁷

Almost every Arab country depends for its water supply on rivers or aquifers shared

with neighbouring countries. The water dependency ratio (for surface water) of some Arab countries is extremely high (Table 1.6). Egypt, Iraq and Syria rely almost exclusively on transboundary water resources originating from outside their borders, while Jordan and the State of Palestine depend almost entirely on the Jordan River, which is transboundary and essentially controlled by Israel. For some countries the ratio rises when shared groundwater aquifers are included. Algeria, Libya and Tunisia share vast amounts of groundwater, and most of the countries on the Arabian Peninsula share water from the Palaeogene aquifer system, extending from the northern to the southern end of the peninsula.

Water pollution

In addition to overexploitation, pollution from agricultural, industrial and domestic activities threatens the Arab region's groundwater and surface water resources (Box 1.9). As water quality deteriorates, water usability diminishes, reducing water supplies, intensifying water scarcity, increasing health risks and damaging the environment, including fragile ecosystems.⁷⁸

In Gaza, for example, nitrate levels have risen to 600–800 mg per litre due to agricultural and wastewater pollution, much higher than the

Table 1.6 Water dependency ratio in the Arab region (surface water only, 2011)

Country	Water dependency ratio (%)	Country	Water dependency ratio (%)
Kuwait	100.0	Qatar	3.4
Egypt	96.9	Palestine	3.0
Bahrain	96.6	Lebanon	0.8
Mauritania	96.5	Morocco	0.0
Sudan and South Sudan	76.9	Djibouti	0.0
Syria	72.4	Oman	0.0
Iraq	60.8	Yemen	0.0
Somalia	59.2	Saudi Arabia	0.0
Jordan	27.2	Libya	0.0
Tunisia	8.7	UAE	0.0
Algeria	3.6	Comoros	0.0

Note: The water dependency ratio refers to surface water only. Many of the countries with zero water dependency ratio share transboundary groundwater aquifers with other countries.

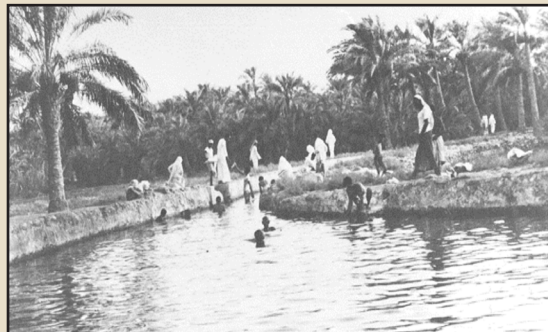
Source: FAO 2013.

Groundwater in the Dammam aquifer is the only natural source of freshwater in Bahrain. The aquifer's safe yield is about 110 million cubic metres per year, estimated as the steady-state under-

considered, along with groundwater's functional value in maintaining ecosystems and providing emergency water.

For Bahrain, the marginal cost is enormous—

Examples of natural springs drying and loss of natural habitat, Ain Al-Ruha region in Bahrain, 1950s and 1990s



flow rate received from the equivalent aquifers upstream in eastern Saudi Arabia. Since the early 1970s, the rapid increase in oil revenues has strengthened the country's economic base and improved standards of living, resulting in rapid population growth, industrialization, urbanization and expansion of irrigated agriculture, substantially boosting water demand. The heavy reliance on groundwater to meet escalating water demand has increased groundwater abstraction rates beyond the aquifer safe yield—rates more than doubled in the late 1990s. This prolonged overexploitation has led to severe deterioration in water quality due to seawater intrusion and salt-water upflow from the underlying strata and the complete loss of naturally flowing springs. Most of Bahrain's original groundwater reservoirs have been lost to salinization.

The social impact of groundwater depletion depends on the level of reliance on groundwater and the marginal cost (the cost of providing replacement supplies). Moreover, the opportunity cost for alternative or competing uses must also be

equal to producing about 110 million cubic metres per year of desalinated seawater or treated wastewater at an estimated cost of \$160 million a year. In addition, the loss of groundwater to salinization affects the country's socio-economic development as well as agriculture and the environment. As groundwater used for irrigation has become more saline, productivity losses and desertification have forced the abandonment of traditional agricultural areas. Cultivated area dropped from about 65 square kilometres to 41 square kilometres in the late 1970s, prompting Bahrain's government to step up its efforts to maintain agricultural lands at their previous level by reclaiming new lands and reusing treated wastewater. Groundwater depletion has also damaged wetlands and biodiversity. The drying of all natural springs and their surrounding environments has destroyed wildlife habitats, eliminated animal species and compromised the ecosystem and its tourism investment potential (see photos).

Source: Zubari 2001; Abdulghafar 2000.

maximum allowable limit of 50 mg per litre for drinking water and posing a serious health risk.⁷⁹ In the Ra's Al Jabal region in Tunisia, nitrate concentrations from agricultural pollution have reached 800 mg per litre.⁸⁰ Nitrate causes methemoglobinemia (blue baby syndrome) in infants, a condition that can result in death or developmental disability.⁸¹ In the Maghreb countries, examples of human-induced pollution include eutrophication (oxygen depletion) of dam reservoirs, nitrate pollution of groundwater by fertilizers, cadmium-rich water releases from phosphate mines and pathogenic pollution of water resources from untreated municipal wastewater effluents.⁸²

The Nile River's northern wetlands are experiencing eutrophication at many locations. In Egypt, excessive application of nitrate and phosphate fertilizers are another source of pollution.⁸³ In addition, domestic sewage, industrial waste and agricultural return flows from Cairo pass mostly untreated through the 70-kilometre Bahr El Baqar channel, discharging into Lake Manzala in the northeast Nile Delta. The discharge from Bahr El Baqar is heavily loaded with contaminants, including bacteria, heavy metals and toxic organics. This contamination has resulted in high fish mortality and malformation and a widespread unwillingness to consuming the lake's fish, formerly a third of Egypt's fish harvest.⁸⁴ In Sudan, the alarming levels of phytoplankton, water hyacinths and sediment carried by surface waters constitute major problems for water management and treatment and result in high reservoir siltation rates (increased concentration of suspended and fine sediments). Insufficient potable water supplies and wastewater collection and treatment facilities can also create health hazards.⁸⁵

In Lebanon, the Upper Litani basin offers another stark example of the negative long-term impact of poor wastewater management. Fed mostly by freshwater springs, it has become a sewage tunnel for most of the year.⁸⁶ Uncontrolled use of fertilizers has further contaminated underlying aquifers.⁸⁷

In Egypt, Jordan, Lebanon, the State of Palestine and Syria (Mashreq), dumping raw and partially treated wastewater from agriculture, industry and municipalities into water courses

Box 1.10

Climate change: impact, vulnerabilities and risks

Climate change will alter the hydrological cycle, affecting water infrastructure and natural ecosystems (see maps below). No country is immune to climate change's effects, but some countries will be affected more than others due to economic and geographic factors. Lack of financial and technological resources will make developing countries more vulnerable to the impacts of climate change. The World Bank estimates that a 2.0°C rise in temperature could put 100–400 million more people at risk of hunger and that 1–2 billion more people might not have enough water to meet their needs. With disproportionate consequences for the developing world, climate change is expected to further widen inequality between rich and poor countries and could seriously affect or reverse development progress.

The risk of climate change depends on the probability of an event and the severity of its impact. The Intergovernmental Panel on Climate Change defines vulnerability as “the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change impacts, including climate variability and extremes.” Vulnerability relates to sensitivity and extent of exposure to a potential hazard. Consider flood hazards. Sensitivity manifests as reduced food security after floods, while exposure increases when floods occur more frequently. Thus, vulnerability to the effects of climate change is a function of sensitivity, adaptive capacity and the character, magnitude and rate of climate change and variation. While efforts to mitigate climate change can reduce exposure, a society's adaptive capacity determines how seriously people will be affected. Strengthening adaptive capacity—a complex function of a society's infrastructure; wealth; economic structure; physical, human and institutional resources; and other factors—is the key to successful adaptation.

Source: World Bank 2010b; IPCC 2001, 2001a

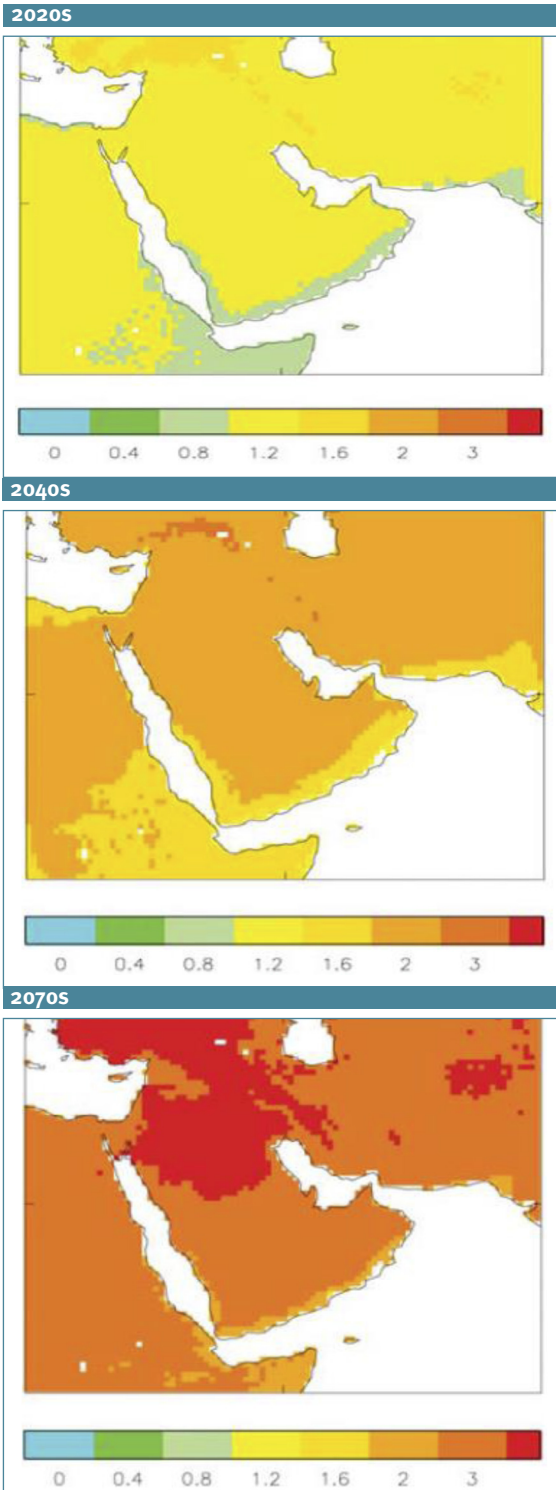
has caused grave health concerns and has severely polluted agricultural lands and water resources, especially during low discharge periods. Contamination of the underlying aquifers is also evident.⁸⁸ River basins show similar symptoms of pollution.⁸⁹ For example, the nitrate concentration in some domestic wells in the State of Palestine may reach 40 milligrams per litre.⁹⁰ Most villages in the Mashreq lack adequate wastewater disposal systems and rely on individual household cesspits, contributing to the contamination of groundwater, often a source of untreated drinking water. Extensive use of manure as fertilizer aggravates the problem, as run-off seeps into aquifers. Once groundwater becomes polluted, it is difficult and usually

cost-prohibitive to rehabilitate, especially in a region with very low groundwater recharge rates.

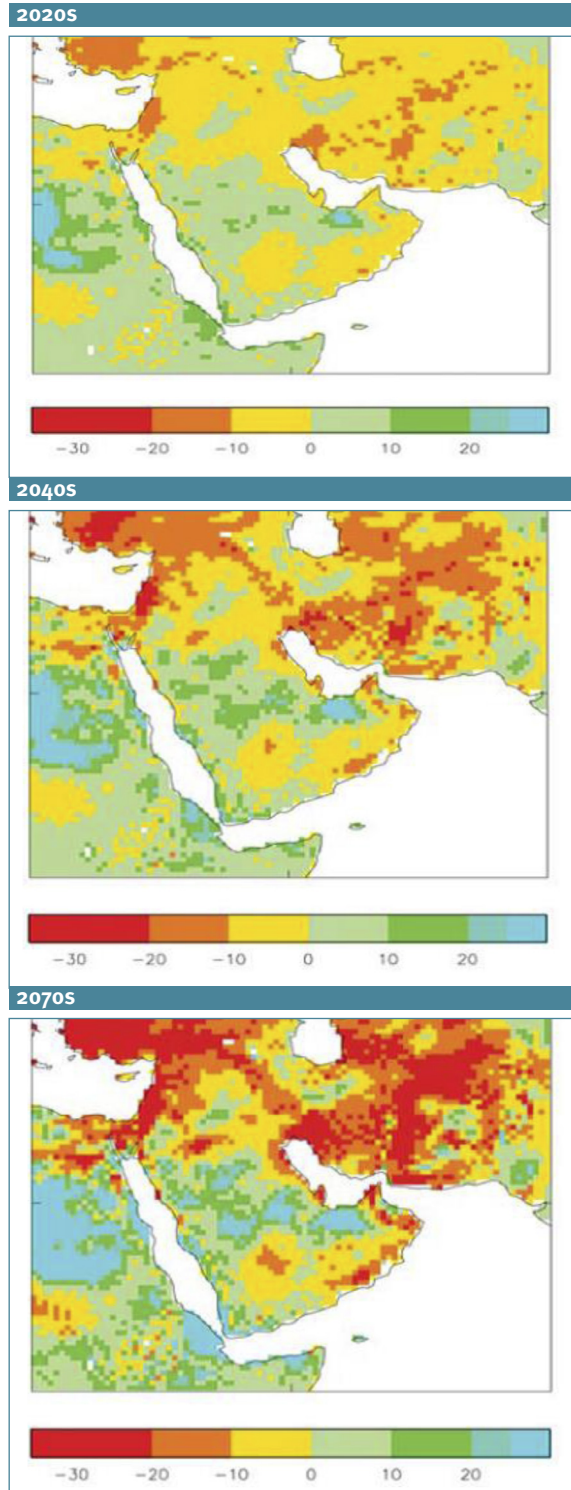
Several Arab countries have acknowledged

the problems associated with polluted groundwater and have taken steps to protect valuable water resources from further degradation.

Map 1.4.a: Regional climate model projections of average temperature changes (°C) for the 2020s, 2040s and 2070s, relative to 1990s



Map 1.4.b: Regional climate model projections of precipitation changes (%) for the 2020s, 2040s and 2070s, relative to 1990s



Source: Adapted from Hemming, Betts, and Ryall (2007).

Wastewater treatment has improved substantially in many countries, particularly Egypt and Jordan. Algeria, Egypt, Morocco and Tunisia began to regularly monitor groundwater quality in the 1990s. Groundwater assigned to domestic water use is now under state control. In Egypt, directly disposing of untreated industrial effluents into the Nile has been banned since 1999.⁹¹ In 2001 the Sultanate of Oman issued a law to protect sources of drinking water from pollution and has since developed drinking water well-field protection zones for all of its groundwater basins.⁹² With the help of the Arab Centre for the Studies of Arid Zones and Dry Lands, the UN Economic and Social Commission for West Asia, Germany's Federal Institute for Geosciences and Natural Resources, and the German Development Cooperation, Jordan, Syria and Yemen have mobilized technical and financial resources to formulate water quality management policies, specify required legal procedures and define responsibilities in institutional frameworks that allow effective coordination between concerned parties, with particular focus on groundwater protection.⁹³

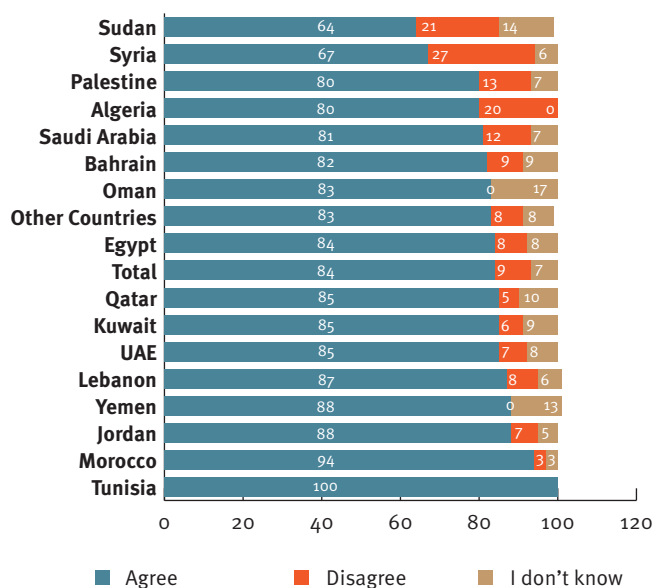
Climate change

The scientific evidence shows that the climate is already changing.⁹⁴ In the Arab region, climate change is manifesting as more severe droughts, storms and flooding (Box 1.10 ; Map 1.4 a & b).⁹⁵ The Arab Forum for Environment and Development report on climate change in the Arab region (2009) states that Arab countries are among the most vulnerable to climate change's effects. For that report, the forum surveyed public attitudes towards climate change: 84 per cent of respondents thought that climate change posed a serious threat to their countries (Figure 1.10). Public opinion in Arab countries recognizes climate change as a reality and accepts that it is caused mainly by human activities. The survey indicates that the Arab public seems ready to accept and participate in concrete national and regional action to deal with climate change.⁹⁶

Simulated ranges of warming indicate that annual average surface air temperature for the Arab region will likely rise a further 2.5°C

Figure 1.10

Survey on recognition of the problem of climate change in the Arab region, February–May 2009



Note: Totals might not sum to 100% due to rounding.

Source: Tolba and Saab 2009.

to 4.0°C by 2100.⁹⁷ The temperature rise is expected to increase evapotranspiration rates, reducing soil moisture, infiltration and aquifer recharge. Projected annual average precipitation ranges for the 21st century will fall 10-20 per cent in the Mediterranean region and the northern parts of the Arabian Peninsula. Simulated ranges also indicate that precipitation will fall 30-40 per cent in Morocco and northern Mauritania. But a 10-30 per cent increase in precipitation is predicted in the southwestern part of Oman, Saudi Arabia, United Arab Emirates and Yemen. Increased rainfall intensity, which usually leads to flash floods, is expected to reduce infiltration and potential aquifer recharge. Simulated impacts of climate change on long-term annual average diffuse groundwater recharge find that the increase in surface temperature and reduction in rainfall will result in a 30-70 per cent reduction in recharge for aquifers in the eastern and southern Mediterranean coast.⁹⁸

A warmer climate brings greater climate variability and higher flood (Box 1.11) and drought risk, exacerbating the already precarious situation created by chronic water scarcity. Drought is one of the most serious

With climate change, extreme flooding events are becoming more probable. A 2000 United Nations Economic Commission for Europe paper on sustainable flood prevention presented guidelines for flood prevention and protection, including preliminary flood risk assessments and flood hazard and risk maps. Effective land planning is vital to ensure some preparedness. Dwellings, critical infrastructure (such as hospitals) and sensitive land uses should be located in areas with lower flood risks or greater capacity to withstand extreme floods. The paper also recommends flood studies, flood prediction and drainage design methodologies, special technical and emergency case studies of river basins, and training and development to meet new demands and expectations.

The Arab region is especially threatened by flash floods, which occur with little warning. They frequently take place in remote mountain catchments where few institutions are equipped to deal with disaster mitigation. In 2009 and 2010 heavy rains led to flash floods in Aswan and Al-Arish in Egypt, Jeddah in Saudi Arabia, Gaza in the

State of Palestine, and many other areas that killed many people, downed power lines and destroyed roads.

Flash flood risk assessment, the core of the disaster risk management process, identifies potential risk reduction measures. Risk assessment must be integrated into development planning to identify actions that meet development needs and reduce risk.

Recommended management and assessment tools to be developed for flood management include environmental assessments, flood loss assessments, basin flood management plans, rapid legal assessment tools, community participation, reservoir operations and managed flows, land planning, adaptation to climate change, flood mapping and prediction, case studies and experiences, flood emergency planning, transboundary aspects, river restoration and wetlands conservation, and flash flood, mud flow and landslide management.

Source: Adapted from UNESCO (2010b) and UNECE (2000a).

water-related disasters threatening the Arab region. Higher temperatures will increase the incidence and impact of drought in the region. Drought frequency has already risen in Algeria, Morocco, Syria and Tunisia. Recent droughts in Jordan and Syria were the worst recorded in many decades. In addition, many countries will experience greater variability in precipitation and reduced water resource availability.⁹⁹

Climate change research identifies the Arab region as home to 5 of the top 10 countries at risk from the impacts of climate change: Djibouti, Egypt, Iraq, Morocco and Somalia. Djibouti, ranked as the most exposed to the impact of climate change, is regularly subjected to tropical storms from the Indian Ocean and will be more vulnerable to inland flooding as sea levels rise. Egypt ranks as the region's second most exposed country. With the vast bulk of its population concentrated in the Nile Valley and Delta, it is at high risk of inland flooding. The Nile's flow will also be uncertain because of unreliable rainfall. Iraq, Morocco and Somalia, the next most vulnerable, are at high risk of coastal flooding and exposure to extreme temperatures. The Gulf countries of Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and the United Arab Emirates are expected to

suffer severe consequences of climate change. Bahrain, with its relatively small land mass, is in danger of inundation as sea levels rise. Qatar is especially susceptible to inland flooding. Bahrain, Qatar, Kuwait and Yemen are considered to be "extremely" vulnerable. Jordan, Lebanon, Libya, Oman, Saudi Arabia, Tunisia and the United Arab Emirate are rated "highly" vulnerable.¹⁰⁰

To reduce vulnerability, Arab countries need to enhance their adaptive capacity and consider the impacts of climate change in their water resource planning. But national plans and regional investment portfolios do not yet reflect a sense of urgency on these vital matters. Key capacities for adaptive governance for climate-induced water scarcity are underdeveloped. Attention needs to focus on good governance, human resources development, institutional structures, public finance and natural resource management. And Arab countries need to foster regional cooperation on adapting to climate change.

Water resources in the Arab region are in an alarming state. Natural water scarcity, rapid population increases, changing lifestyles, the demands of economic development and growth, and inappropriate governance and water

management practices have created a vicious cycle. The effects of climate change and growing competition over water resources are cause for more concern. Effective water governance is the only way out of a rapidly deteriorating situation.

Endnotes

- ¹ Beck Droubi, Jnad, and Al Sibaii 2006.
- ² FAO 2013.
- ³ FAO 2013.
- ⁴ FAO 2013; World Bank 2010a.
- ⁵ FAO 2013.
- ⁶ El-Ashry, Saab, and Zeitoon 2010.
- ⁷ Doumani 2008.
- ⁸ Shahin 1989.
- ⁹ FAO 2013.
- ¹⁰ World Bank 2007.
- ¹¹ Strzepek and others 2004.
- ¹² World Bank 2007.
- ¹³ World Bank 2007; Strzepek and others 2004.
- ¹⁴ Syvitski 2008.
- ¹⁵ Sadek, Shahin, and Stigter 1997.
- ¹⁶ World Bank 2007.
- ¹⁷ Jordan Valley Authority 2011.
- ¹⁸ World Bank 2007.
- ¹⁹ Al-Zubari 2008.
- ²⁰ Al-Zubari 2008.
- ²¹ UN-ESCWA 2009b.
- ²² Tawila Aquifer in Sana'a Basin in Yemen (ACSAD and BGR 2005); Dammam aquifer in Bahrain (Al-Zubari 2001) and Kuwait (Sayid and Al-Ruwaih 1995; Al-Murad 1994); Umm Er Radhuma aquifer in Saudi Arabia (Al-Mahmoud 1987); Al-Dhaid, Hatta, Al-Ain and Liwa areas in the United Arab Emirates (Rizk, Alsharhan, and Shindu 1997); Al-Batinah coastal plain aquifer and Al-Khawd fan in Oman (Macumber and others 1997).
- ²³ LAS, UNEP, and CEDARE 2010.
- ²⁴ UN-ESCWA 1999; FAO 1997.
- ²⁵ ABHS and others 2007.
- ²⁶ PWA 2000.
- ²⁷ Hadidi 2005.
- ²⁸ ACSAD and BGR 2005.
- ²⁹ Al-Asam and Wagner 1997.
- ³⁰ Ruta 2005.
- ³¹ Mecherghi and Van Vuren 1998.
- ³² UN-ESCWA 2005b.
- ³³ Jagannathan, Mohamed, and Kremer 2009.
- ³⁴ Bushnak 2010.
- ³⁵ World Bank and BNWP 2004.
- ³⁶ World Bank and BNWP 2004; World Bank 2007.
- ³⁷ World Bank 2005.
- ³⁸ World Bank 2005.
- ³⁹ Al-Jamal and Schiffler 2009.
- ⁴⁰ Al-Jamal and Schiffler 2009.
- ⁴¹ Al-Jamal and Schiffler 2009.
- ⁴² Bushnak 2010.
- ⁴³ Al-Hussayen 2009.
- ⁴⁴ Bushnak 2002.
- ⁴⁵ Abderrahman and Hussain 2006.
- ⁴⁶ Bushnak 2010.
- ⁴⁷ Al-Jamal and Schiffler 2009.
- ⁴⁸ Sommariva 2010.

- ⁴⁹ Bushnak 2010.
- ⁵⁰ Sommariva 2010.
- ⁵¹ Al-Jamal and Schiffler 2009.
- ⁵² Hmaidan 2007.
- ⁵³ Bushnak 2010.
- ⁵⁴ Qadir and others 2009.
- ⁵⁵ Assaf and Saadeh 2008.
- ⁵⁶ MED WWR WG 2007.
- ⁵⁷ Qadir and others 2009.
- ⁵⁸ World Bank 2007.
- ⁵⁹ Al-Zubari 2008.
- ⁶⁰ AHT 2009; Choukr-Allah 2010.
- ⁶¹ Malkawi 2003; World Bank 2007.
- ⁶² Al-Zubari 2001.
- ⁶³ Al-Zubari 2001.
- ⁶⁴ Zaki, Al-Weshah, and Abdulrazzak 2006.
- ⁶⁵ Zaki, Al-Weshah, and Abdulrazzak 2006.
- ⁶⁶ Nasr 1999.
- ⁶⁷ Gulf News 2008a.
- ⁶⁸ Al-Fenadi 2001.
- ⁶⁹ Gulf News 2008b.
- ⁷⁰ UNESCO 2012.
- ⁷¹ UN-ESCWA 2007.
- ⁷² Rassoul 2006.
- ⁷³ NWRC n.d.
- ⁷⁴ FAO 2012.
- ⁷⁵ Biswas 1994.
- ⁷⁶ FAO 2013.
- ⁷⁷ UNESCO 2012; LAS, UNEP, and CEDARE 2010.
- ⁷⁸ LAS, UNEP, and CEDARE 2010.
- ⁷⁹ PWA 2000.
- ⁸⁰ ACSAD and BGR 2005.
- ⁸¹ UNU 2002.
- ⁸² LAS, UNEP, and CEDARE 2010.
- ⁸³ CEDARE and AWC 2007.
- ⁸⁴ USAID 1997.
- ⁸⁵ LAS, UNEP, and CEDARE 2010.
- ⁸⁶ Assaf and Saadeh 2008.
- ⁸⁷ Assaf 2009.
- ⁸⁸ CEDARE and AWC 2007.
- ⁸⁹ Hamad, Abdelgawad, and Fares 1997.
- ⁹⁰ Zarour, Jad, and Violet 1994.
- ⁹¹ CEDARE and AWC 2007.
- ⁹² Sultanate of Oman 2001.
- ⁹³ LAS, UNEP, and CEDARE 2010.
- ⁹⁴ The International Panel on Climate Change defines climate change to a change in the state of the climate that can be identified (for example, using statistical tests) by changes in the mean or the variability of its properties and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity. This usage differs from that in the United Nations Framework Convention on Climate Change (UNFCCC), which defines climate change as a change in climate attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods. Detection of climate change is the process of demonstrating that the climate has changed in a defined statistical sense, without providing a reason for that change. Attribution of causes of climate change is the process of establishing the most likely causes for the detected change, with some defined level of confidence. Both detection and attribution rely on observational data and model output. Climate change patterns or “fingerprints” are no longer limited to a single variable (temperature) or to the Earth’s surface. More recent detection and attribution work has used precipitation and global pressure patterns, and analysis of vertical profiles of temperature change in the ocean and atmosphere (IPCC 2007).
- ⁹⁵ IPCC 2007.

⁹⁶ Tolba and Saab 2009.

⁹⁷ UNESCO 2010a.

⁹⁸ Khater 2010; Doumani 2008.

⁹⁹ FAO 2002.

¹⁰⁰ Khater 2010.