Bahrain

GEOGRAPHY, CLIMATE AND POPULATION

Geography

The Kingdom of Bahrain is a group of islands located off the central southern shores of the Persian Gulf. The archipelago comprises 40 islands, with a total land area of about 710 km² (Table 1). The largest of these is Bahrain Island where the capital city, Manama, is situated. Bahrain Island accounts for nearly 85 percent of the total area of the country. Next largest is the southern archipelago called Hawar (50 km²), not far from the coast of Qatar, followed by the desert island of Umm Nasan (19 km²), the populous Muharraq Island (18 km²) connected by causeways to Bahrain, and finally Sitra (10 km2), a mainly industrial island also connected to Bahrain by causeways. The remaining small islands, islets and coral reefs make up the rest of the land mass (around 1.5 percent).

Bahrain is low lying. Limestone bedrock slopes rise gently towards the roughly central peak of Jebel Dukhan, with its highest point at 137 meters above sea level. Land use varies greatly, from extensive urban development and diligently cultivated areas in the north, to sandy wastes spreading south, east and west from Jebel Dukhan. Here there are true desert conditions with only sparse tough desert plants growing among the barren limestone rimrock and sands of varying depth.

Climate

Bahrain has an arid to extremely arid environment. According to the aridity criteria used, Bahrain has been regarded as arid or hyperarid as a result of the very great variations in climatic conditions (Elagib and Abdu, 1996). The country is characterized by high temperatures, erratic and often scanty rainfall, high evapotranspiration rates (with peaks of over 10 mm/day in July) and high humidity levels due to the surrounding Gulf waters.

Temperature averages from 17 °C in winter (December–March) to 35 °C in summer (June–September). The rainy season runs from November to April, with an annual average of 83 mm, sufficient only to support the most drought resistant desert vegetation. Mean annual relative humidity is over 67 percent. The annual average potential evaporation is 2 099 mm (Al-Noaimi, 2005).

Population

Total population is 727 000 (2005), of which around 10 percent is rural (Table 1). With a population density of 1 024 inhabitants/km², Bahrain is one of the world's most densely populated countries. It has experienced high rates of population growth and urbanization since the early 1960s following the sudden increase in the country's oil revenues, leading to a fast increase in its economic base and an improvement in the standard of living. The average annual demographic growth rate was 4 percent during

BAHRAIN

FAO - AQUASTAT, 2008

TABLE 1
Basic statistics and population

Physical areas			
Area of the country	2005	71 000	ha
Cultivated area (arable land and area under permanent crops)	2000	4 235	ha
• as % of the total area of the country	2000	6	%
• arable land (annual crops + temp. fallow + temp. meadows)	2000	1 015	ha
• area under permanent crops	2000	3 220	ha
Population			
Total population	2005	727 000	inhabitants
• of which rural	2005	9.8	%
Population density	2005	1 024	inhabitants/km^2
Economically active population	2005	353 000	inhabitants
• as % of total population	2005	48.6	%
• female	2005	23.2	%
• male	2005	76.8	%
Population economically active in agriculture	2005	3 000	inhabitants
• as % of total economically active population	2004	0.85	%
• female	2005	0	%
• male	2005	100	%
Economy and development			
Gross Domestic Product (GDP) (current US$)	2005	16 040	million US$/yr
• value added in agriculture (% of GDP)	2002	0.85	%
• GDP per capita	2005	17763	US$/yr
Human Development Index (highest = 1)	2005	0.866	
Access to improved drinking water sources			
Total population		-	%
Urban population	2006	100	%
Rural population		-	%

the period 1980–1991 but this has dropped to 2.5 percent during the last 10 years. The water supply and sanitation coverage are 100 percent in urban areas. The total economically active population is 353 000 (2005), of which 77 percent are men and 23 percent women. Only 3 000 people work in agriculture.

Urban development at the expense of agricultural land has caused a significant loss of traditionally agricultural areas. Furthermore, soil salinization resulting from deterioration in the quality of the groundwater used in irrigation has led to a general reduction of cultivated land. In 2005, the total cultivated area was estimated at 6 000 ha, or 8 percent of the total area of the country, of which around 95 percent was equipped for irrigation. This area is mainly used for growing date palms, alfalfa and vegetables (FAO, 2002).

ECONOMY, AGRICULTURE AND FOOD SECURITY

The Gross Domestic Product (GDP) is around US$16 billion (current US$), with an annual growth of 7.8 percent (2005). Agriculture is one of the traditional activities in Bahrain but its contribution to national GDP is less than 1 percent (Table 1). Agriculture provided many job opportunities for Bahraini nationals, who accounted for 75 percent of agricultural labour during the 1970s. In 2004, the total economically active population in agriculture was only 3 000, all of whom were men. Agriculture in Bahrain is generally in an unhealthy state with tenancy problems, small farm holdings, labour shortages and lack of financial incentives, all of which restrict investment.

Bahrain is heavily dependent on imports to satisfy its need for animals and animal products, at the cost of home-based production. In an open-market economy, local animal products, especially dairy and eggs, face tough competition from imports. Part of this competition comes from some Gulf States which have the advantage of relatively well-established multifaceted livestock enterprises that started much earlier with more favourable cost structures. Sheep imports in Bahrain are subsidized. Rehabilitation of the national livestock industry would require improvement of the cost structure of locally produced animals and animal products (FAO, 2004).

There are some animal production activities based on local agricultural products, such as milk production or on imported feed, such as poultry and egg production. Nevertheless, livestock productivity is low because of poor management, which is reflected in poor growth rates, high mortality, late sexual maturity, long parturition intervals, inbreeding and poor-quality meat. The availability of feed for the livestock industry is uncertain and most feed ingredients are imported (FAO, 2003).

WATER RESOURCES AND USE

Water resources

Total annual surface runoff is only about 4 million m^3 and there are no rivers, perennial streams or lakes (Table 2). There are also no dams. Bahrain receives groundwater by lateral under-flow from the Damman aquifer, which forms only a part of the extensive regional aquifer system (the Eastern Arabian Aquifer). This aquifer extends from central Saudi Arabia, where its main recharge area is located at about 300 meters above sea level, to eastern Saudi Arabia and Bahrain, which are considered the discharge areas. The rate of groundwater inflow has been estimated at about 112 million m^3/year under steady-state conditions (before 1965) and this figure is considered to be the safe groundwater yield in Bahrain. But groundwater reserves suffer from severe degradation, in terms of both quality and quantity, as a result of over-extraction and seawater intrusion.

Over-utilization of the Dammam aquifer, the principal aquifer in Bahrain, by the agricultural and domestic sectors has led to its salinization through water coming from adjacent brackish and saline water bodies (particularly from the underlying saline aquifer of Umm er Radhuma). A hydrochemical study identified the locations of the sources of aquifer salinization and delineated their areas of influence. The investigation indicates that the quality of aquifer water quality has been significantly modified as groundwater flows from the northwestern parts of Bahrain, where the aquifer receives its water by lateral underflow from eastern Saudi Arabia, to the southern and southeastern parts. Four types of salinization of the aquifer have been identified:

- Brackish water up-flow from the underlying brackish water zones in north-central, western, and eastern regions;
- Seawater intrusion in the eastern region;
- Intrusion of sabkha water (saline water from saline areas) in the southwestern region;
- Irrigation return flow in a local area in the western region.

Four alternatives for the management of groundwater quality are under discussion by the water authorities in Bahrain. Priority areas have been proposed based on the type and extent of each salinization source, in addition to groundwater use in that area. Simulation modelling could be used to evaluate the effectiveness of the proposed management options in controlling the degradation of water quality in the Dammam aquifer (Zubari, 1999).

Since it has become the policy to curb the abstraction of groundwater resources in the Damman aquifer and to improve its quality, further development of water sources will undoubtedly involve desalination, either by a thermal process or reverse osmosis. The choice will depend on site-specific conditions and economy or cost. The first multi-stage flash (MSF) seawater desalination plant was introduced in Bahrain in 1976. The use of reverse-osmosis (RO) desalination for saline groundwater on Bahrain Island began in 1984–1986. One of the world’s largest RO plants for the treatment of saline groundwater, located 25 km south of the capital of Bahrain at Ras Abu-Jarjur, was commissioned in 1984. The plant has an installed capacity of 45 500 m^3/day and its source of raw water is the highly saline brackish groundwater in the Umm er Radhuma formation. The RO plant was designed to meet the domestic water demand of Manama city, taking into account its advantages over an MSF plant, such as short construction time, lower energy cost, ease of operation and maintenance (UNU, 1995). In 2002, the total installed gross desalination capacity (design capacity) in Bahrain was 500 259 m^3/day (Wangnick Consulting, 2002).

The reuse of treated wastewater for agriculture and landscape irrigation started in 1985. The main wastewater treatment plant in Bahrain is the Tubli Water Pollution Control Centre (Tubli WPCC) which is currently (2005) producing about 160 000 m^3/day of secondary treated effluent and around 60 674 m^3/day receives tertiary treatment. There are also eleven minor wastewater treatment plants with a total designed capacity of about 9 720 m^3/day. Treated sewage effluent is expected to reach 200 000 m^3/day or 73 million m^3 per year by 2010 (Al-Noaimi, 2005). The additional amount treated, if properly used for irrigation, could significantly reduce water extraction, reserving the limited freshwater resources for potable supply and other priority uses. In Bahrain the cost of tertiary treated effluent is about US$0.317/$m^3$, while the cost of desalinated water is about US$0.794/$m^3$ (FAO/WHO, 2001).

Water use

Historically, Bahrain has utilized groundwater for both agricultural and municipal requirements. Natural freshwater springs used to flow freely in the northern part of Bahrain and before 1925 the water supply depended on these springs and some hand-dug wells, the total discharge of which was estimated at 93 million m^3/year. With increased water demand after the exploration of offshore reservoirs of crude oil and gas in 1946, spring flow decreased and water started being pumped from boreholes. During the 1980s, most of the springs ceased flowing, and increased demand for water caused deterioration in water quality, including the intrusion of seawater into the aquifer system (UNU, 1995). In 1988, groundwater use in Bahrain was estimated to be 153 million m^3/year, including 138 million m^3 of tube-well abstraction, 8.1 million m^3 of water from land springs, and 6.6 million m^3 of water from marine springs.

In 2003, total water withdrawal in Bahrain was 357.4 million m^3 (Table 2 and Figure 1). The part used for irrigation and livestock watering purposes dropped to 45 percent whereas it was 56 percent in 1991. Total annual water demand was met by three sources: groundwater (238.7 million m^3), desalinated water (102.4 million m^3) and treated sewage effluent (16.3 million m^3) (Table 3 and Figure 2). This means that non-conventional water sources accounted for 34 percent of total water withdrawal in 2003. About 90 percent of the water used in agriculture, including livestock, was groundwater and 10 percent treated wastewater. For municipal and industrial purposes about 48 percent of the water used was groundwater and the remaining part was desalinated water.

The total surface water and groundwater withdrawal represented 206 percent of the total renewable water resources in 2003, meaning that abstraction of fossil water and groundwater mining was taking place.

FIGURE 1
Water withdrawal by sector
Total: 0.357 km^3 in 2003

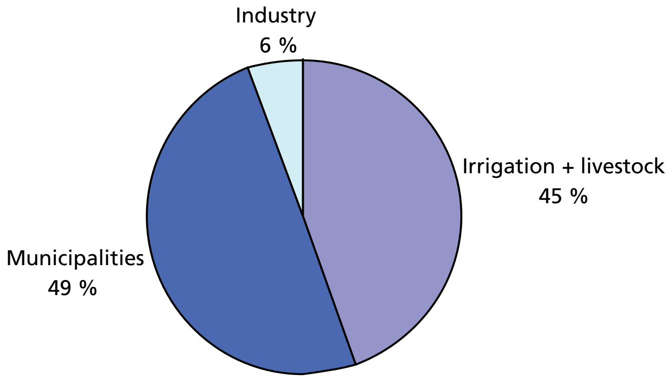


TABLE 2
Water: sources and use

Renewable freshwater resources			
Precipitation (long-term average)	-	83	mm/yr
	-	0.059	10^9 m^3/yr
Internal renewable water resources (long-term average)	-	0.004	10^9 m^3/yr
Total actual renewable water resources	-	0.116	10^9 m^3/yr
Dependency ratio	-	97	%
Total actual renewable water resources per inhabitant	2005	160	m^3/yr
Total dam capacity	1995	0	10^6 m^3
Water withdrawal			
Total water withdrawal	2003	357.4	10^6 m^3/yr
- irrigation + livestock	2003	159.2	10^6 m^3/yr
- municipalities	2003	177.9	10^6 m^3/yr
- industry	2003	20.3	10^6 m^3/yr
• per inhabitant	2003	506	m^3/yr
Surface water and groundwater withdrawal	2003	238.7	10^6 m^3/yr
• as % of total actual renewable water resources	2003	205.8	%
Non-conventional sources of water			
Produced wastewater	1991	44.9	10^6 m^3/yr
Treated wastewater	2005	61.9	10^6 m^3/yr
Reused treated wastewater	2005	16.3	10^6 m^3/yr
Desalinated water produced	2003	102.4	10^6 m^3/yr
Reused agricultural drainage water	2001	3	10^6 m^3/yr

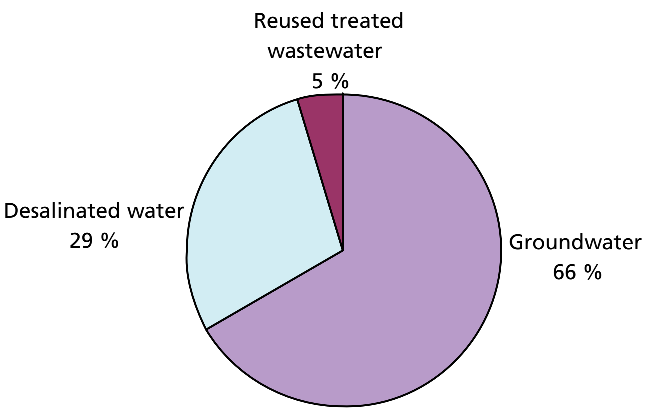
TABLE 3
Water uses in Bahrain by sources and categories of use for the year 2003 (million m^3)

Source	Municipal	Agriculture	Industrial	Total uses
Groundwater	83.3	143.2	12.2	238.7
Desalinated water	94.3	-	8.1	102.4
Treated sewage effluent	-	16.3*	-	16.3*
Total	**177.6**	**159.5**	**20.3**	**357.4**

*Year 2005

The excessive pumping of groundwater caused a sharp decrease in groundwater storage and a reduction in potentiometric levels of about 4 meters between 1965 and 1992. As a result, more than half the original groundwater reservoir has been completely degraded due to seawater intrusion and saline water up-flow from the deeper zones. Table 4 shows that annual extraction is almost twice the annual recharge, leading to an ever-increasing groundwater deficit. While the average annual groundwater depletion over the period 1965-1992 was approximately 40 million m^3, in 1991/92 it was over 96 million m^3.

FIGURE 2
Water withdrawal by source
Total: 0.357 km^3 in 2003



In 2003, the total quantity of desalinated water used was 102.4 million m^3 against 44.1 million m^3 in 1991. In 2005 treated wastewater amounted to about 62 million m^3/year of wastewater (secondary treatment) against about 45 million m^3 in 1991. Despite an increase of 100 percent compared with 1991, only 16.3 million m^3/year received tertiary treatment and part was used for irrigation purposes in

TABLE 4
Groundwater depletion in Bahrain, 1991/92

Component	Average annual rate (million m³)
Inflow:	
Recharge by under-flow (aquifer safe yield)	112.00
Recharge by rainfall on outcrop and irrigation return flows	0.28
Total inflow	112.28
Outflow:	
Wells abstraction for irrigation, livestock, domestic, industrial and other purposes	190.20
Sabkha natural discharge	12.72
Natural springs discharge	5.40
Total outflow	208.32
Total inflow - Total outflow	**- 96.04**

government farms and some private farms, while the rest was discharged to the sea. The chemical and hygienic properties of the tertiary treated water are within international limits and are considered good for agricultural purposes. Although the government has plans for the full utilization of Treated Sewage Effluent (TSE) water through major agricultural projects, delays and lack of funds for these projects have limited the use of these waters.

IRRIGATION AND DRAINAGE DEVELOPMENT

Evolution of irrigation development

The limited availability of good quality soil and water has resulted in the concentration of agricultural development in a relatively narrow strip of land along the northwestern coast of Bahrain Island with isolated pockets in the north central areas and along the east coast. Most soils have a sandy texture, traces of organic matter (0.05–1.5 percent), a deficiency in major nutrients, low water-holding capacity (available moisture 2–6 percent), and high infiltration rates (> 120 mm/hr). In areas along the coastal strip, calcareous impermeable layers are found at depths of 1–3 metres, causing waterlogging and impeding leaching. Electrical conductivity (EC) in irrigated soils lies within a range of 4–12 mmhos/cm, while in the areas of recently abandoned agriculture (1 065 ha) it could reach 60 mmhos/cm.

In the period from 1956 to 1977, agricultural land decreased from about 6 460 ha (with 3 230 ha cultivated) to about 4 100 ha (with 1 750 ha cultivated). This decrease was attributed mainly to urban expansion, waterlogging and soil salinization due to the deterioration of the quality of the groundwater used in irrigation. In an attempt to reverse the situation, the government initiated a major agricultural development programme in the early 1980s consisting of:

- Replacement of surface irrigation with more water efficient localized irrigation by subsidizing more than 50 percent of the implementation cost;
- Construction of major drainage systems to reduce waterlogging and salt accumulation;
- Provision of agricultural extension services in terms of training and advising farmers on types of crops suitable for agriculture under prevailing conditions;
- Introduction of TSE water in irrigation;
- Reclamation of new agricultural lands.

This resulted in a gradual increase and restoration of agricultural lands to about 4 230 ha, with 4 015 ha cultivated and irrigated at present, all power irrigated. Between 1994 and 2000, there was a 4 percent average increase per year of the area equipped for irrigation. It is difficult to estimate the quantity of groundwater available in the future for agriculture since groundwater quality, and hence its availability for irrigation, changes with time. In 2003, groundwater accounted for 90 percent of the total irrigation water (Table 5 and Figure 3).

In 1991, the utilization of 8 million m³/year of tertiary TSE water in reclaimed government lands (280 ha) and on some private farms (150 ha), using sprinkler and localized irrigation techniques, had a palpable effect on the increase of agricultural lands and their productivity. Government subsidy for installation of modern irrigation systems stopped in the 1990s because of lack of funds. Despite efforts to introduce modern irrigation techniques, most farms still use traditional surface irrigation, which

TABLE 5
Irrigation and drainage

Irrigation potential		**-**	**4 230**	**ha**
Irrigation:				
1. Full or partial control irrigation: equipped area		2000	4 015	ha
- surface irrigation		2000	3 390	ha
- sprinkler irrigation		2000	160	ha
- localized irrigation		2000	465	ha
• % of area irrigated from surface water		2003	0	%
• % of area irrigated from groundwater		2003	90.3	%
• % of area irrigated from mixed surface water and groundwater		2003	0	%
• % of area irrigated from non-conventional sources of water		2003	9.7	%
• area equipped for full or partial control irrigation actually irrigated			-	ha
- as % of full/partial control area equipped		1994	100	%
2. Equipped lowlands (wetland, ivb, flood plains, mangroves)		2000	0	ha
3. Spate irrigation		2000	0	ha
Total area equipped for irrigation (1+2+3)		**2000**	**4 015**	**ha**
• as % of cultivated area		2000	94.8	%
• % of total area equipped for irrigation actually irrigated			-	%
• average increase per year over the last 6 years		1994-2000	4	%
• power irrigated area as % of total area equipped		1994	100	%
4. Non-equipped cultivated wetlands and inland valley bottoms		2000	0	ha
5. Non-equipped flood recession cropping area		2000	0	ha
Total water-managed area (1+2+3+4+5)		**2000**	**4 015**	**ha**
• as % of cultivated area		2000	94.8	%
Full or partial control irrigation schemes:	**Criteria:**			
Small-scale schemes	< 50 ha	1994	2 885	ha
Medium-scale schemes		1994	0	ha
large-scale schemes	> 50 ha	1994	280	ha
Total number of households in irrigation		1994	-	
Irrigated crops in full or partial control irrigation schemes:				
Total irrigated grain production		2000	0	metric tons
• as % of total grain production			-	%
Harvested crops:				
Total harvested irrigated cropped area		2000	4 015	ha
• Annual crops: total		2000	1 015	ha
- Vegetables (mainly tomatoes)		2000	1 015	ha
• Permanent crops: total		2000	3 000	ha
- Fodder (mainly alfalfa)		2000	790	ha
- Other perennial crops (dates, fruits)		2000	2 210	ha
Irrigated cropping intensity (on full/partial control area actually irrigated)		2000	100	%
Drainage - Environment:				
Total drained area		1994	1 300	ha
- part of the area equipped for irrigation drained			-	ha
- other drained area (non-irrigated)			-	ha
• drained area as % of cultivated area		1994	41	%
Flood-protected areas		1995	1 300	ha
Area salinized by irrigation		1994	1 065	ha
Population affected by water-related diseases			-	inhabitants

causes higher water losses, estimated at between 24 and 40 percent. Sprinkler irrigation is used only in government projects, while localized irrigation is used in government projects and on a limited number of private farms (Figure 4). Most of the land is cultivated either directly by the owner, often with hired labour, or by tenant farmers under a lease agreement lasting one or two years. Such short and insecure periods do not encourage tenants to invest in the installation of modern irrigation systems, which cost 40 percent and even up to 100 percent more than surface irrigation systems since government subsidies for the installation of modern irrigation systems are no longer available. The small size of agricultural landholdings, ranging between 0.5 and 10 ha, with an average of 2.5 ha, and in particular the fragmentation of the agricultural land of farm holdings, further restrict investment in the more expensive modern irrigation techniques.

FIGURE 3
Source of irrigation water
In 2003

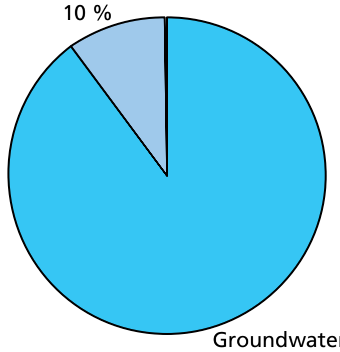
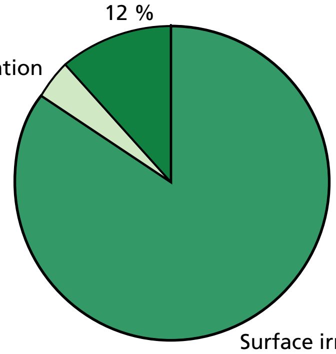


FIGURE 4
Irrigation techniques
Total: 4 015 ha in 2000



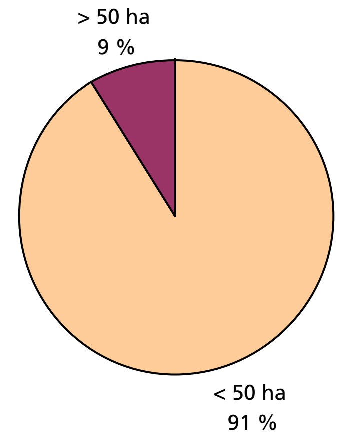
About half of the cultivated area is covered with high water-consuming perennial date palms under traditional surface irrigation practices. Some basic installations with modern irrigation systems (drip irrigation for vegetables and bubbler irrigation for dates) have been established too, but they are rather poorly operated with no irrigation schedules. Unfortunately, many drip and sprinkler systems have been designed on the basis of incorrect criteria, using the outdated irrigation equipment of the 1970s which is poorly installed and inadequately maintained (FAO, 2002). The overall irrigation efficiency is very low, also demonstrated by the huge amount of water used (almost 160 million m^3) on a total irrigated area of just over 4 000 ha.

Role of irrigation in agricultural production, economy and society

In 1991, of the total equipped area of 3 165 ha, 2 885 ha consisted of small schemes (< 50 ha). Most farms in these small-scale schemes were run under the tenancy system and there were about 250 households on these schemes. The remaining 280 ha of large schemes (> 50 ha) were owned and completely run by the government and irrigated by treated wastewater, with a total of 80 government workers of whom 11 were involved in irrigation (Figure 5).

In 1991, the average cost of irrigation development on small schemes varied between US$6 600/ha for surface irrigation, US$9 300/ha for localized irrigation and US$13 200/ha for sprinkler irrigation. For large schemes the cost was US$16 200/ha for

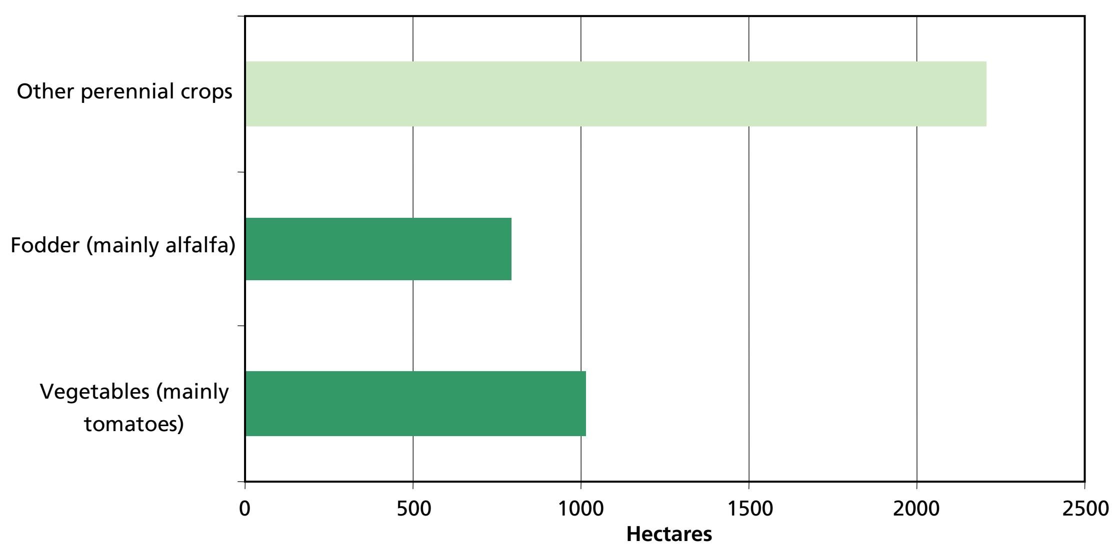
FIGURE 5
Type of irrigation schemes
Total: 3 165 ha in 1994



surface irrigation, US$13 600/ha for localized irrigation and US$19 800/ha for sprinkler (central pivot) irrigation. The high costs for large scheme development were attributed to the fact that the major projects were carried out by the government on reclaimed lands. Operation and maintenance costs varied between 10 and 15 percent of the irrigation development costs on small schemes and between 5 and 15 percent on large schemes.

The major crops grown are: dates and fruit trees with a yield of 7.5 tons/ha; vegetables, mainly tomatoes, with a yield of 11.7 tons/ha; and fodder crops, mainly alfalfa, with a relatively high yield of 74.5 tons/ha. There is no cereal production. In the 1980s, there had been an increasing trend in the cultivation of alfalfa for fodder production rather than the cultivation of the traditional date and vegetable crops. Alfalfa tolerates high salinity and is a cash crop grown all year round with high local demand. However, because of the very high irrigation water requirements of alfalfa, it is expected that this trend will have negative implications for the country's groundwater resources. Horticulture and agriculture flourish in the north, using water from some artesian wells or desalination plants. Gardens grow dates, almonds, pomegranates, figs, citrus fruit, and a wide range of vegetables. In 2000, permanent crops (mainly alfalfa and date palms) covered 75 percent of the irrigated area while vegetables represented the remaining 25 percent (Table 5 and Figure 6). In 2004, Bahrain produced 14 000 tons of fruits and dates and 7 700 tons of vegetables.

FIGURE 6
Irrigated crops
Total harvested area: 4 015 ha in 2000 (cropping intensity on equipped area actually irrigated:100%)



Status and evolution of drainage systems

Drainage works have been carried out on 1 850 ha of the irrigated area. The remaining areas still suffer from shallow water tables resulting in waterlogging in the crop root zones and an increasing salinization of the top soil. Drainage requirements are exacerbated by the inefficient surface irrigation systems used. In 1994, drainage works had been completed on about 1 300 ha (Table 5). The existing drainage network consists of open drains, which are very inefficient and difficult to maintain. The average cost of drainage development was estimated at US$6 600/ha.

The only flood protection works carried out in Bahrain are those against rainfall floods and are developed in one residential, modern town located in the west, over an area of 1 300 ha, where there are no agricultural activities.

WATER MANAGEMENT, POLICIES AND LEGISLATION RELATED TO WATER USE IN AGRICULTURE

Institutions

The Ministry of Municipalities, Affairs and Agriculture is responsible for the country's groundwater resources development, management and utilization. This ministry also manages the utilization of TSE in agriculture. The current organizational structure and staff shortages in the Directorates of the Ministry and the services dealing with water development and use, i.e. the Agricultural Engineering Service and the Water Resources Service, are a major constraint to the efficient performance of these services, both of which lack human resources and updated know-how. One of the constraints in developing optimum irrigation facilities is the lack of engineers and technicians as well as of farmers trained in modern irrigation techniques.

The Ministry of Electricity and Water is responsible for providing adequate electricity and water supplies in a safe and cost effective manner to the different segments of consumers in Bahrain.

Water-related research is carried out by the Arabian Gulf University and the University of Bahrain.

Water management

Given the limited land and water resources, recent development plans for improved agricultural production (FAO, 2003) have the goals of:

- Conservation and rational utilization of the limited water resources through the adoption of modern irrigation and drainage techniques, the promotion of the use of treated wastewater and the implementation of legislation related to water use and management;
- Conservation and rehabilitation of land resources and the implementation of legislation to regulate agricultural and non-agricultural land uses;
- Conservation and rational utilization of marine resources;
- Increased agricultural productivity and profitability through the intensification and utilization of treated wastewater;
- Creation of an enabling environment to promote private sector participation in agricultural investment and enhance the productivity and competitiveness of Bahrain's agricultural products in domestic and regional markets;
- Reduction of natural resource degradation through the promotion of agricultural activities that generate sufficient income and employment to sustain the livelihoods of rural communities.

The authorities intend to take a comprehensive approach to water resources planning, recognizing the close inter-relationship between the country's available water resources and the growing demand for additional quantities from the various sectors of economy, i.e. agriculture, landscape development, industry and domestic supplies. Pressure is also increasing to reallocate water in agriculture from high water consuming to lower water consuming crops, and to higher value uses, such as the expanding the domestic, tourist and services sector.

Policies and legislation

The privately-owned water use rights are the only water rights that exist in Bahrain. The general principle governing these rights is that groundwater is the property of the landowners and, therefore, they have an exclusive right to extract and use as much water as they wish and for any purpose they want without being liable for any damage caused to their neighbours or to the groundwater in general. At present, the agricultural sector's utilization of water is not subjected to any licensing system nor is it controlled by a pricing system. However, from the mid-1980s on, agricultural wells have been metered by the government and the government is in the process of passing a law that would make it compulsory for all well owners to install meters on their wells. The total number of wells metered in 1995 was about 1 670 (86 percent of total). The final objective of this programme is to observe irrigation water requirements, and subsequently to set up a licensing system for groundwater withdrawal and design an appropriate pricing system for excess water utilization.

There is no well-defined national water master plan for sustainable water resources development and management. However, a number of rather fragmented water policies and water conservation measures have been initiated over the last three decades to resolve the escalating water shortage problems in the country (Al-Noaimi, 2005). These include, but are not limited to, the following:

- Increased supply as a result of a major desalination and wastewater treatment programme;
- Demand management measures;
- Water pricing;
- Institutional and legal reforms;
- Enhanced monitoring and information systems.

ENVIRONMENT AND HEALTH

The toxicity level of the groundwater of the semi-arid tract of Bahrain was examined for the fluoride concentration and other chemical constituents such as the sodium absorption ratio (SAR), chloride, sulfate, bicarbonate, and boron. The fluoride concentration varied from 0.50 to 1.46 mg/litre and 38 percent of the water contained concentrations of fluoride deemed harmful for drinking. However, the fluoride concentration in the water is not harmful for most crops. Spring and well water have rather high salinity but could be used for agricultural purposes, particularly for crops that can tolerate high salinity levels (Akther, 1998).

While the standard of living and quality of life of the people has improved in the last 20 years, these improvements have produced negative effects on the terrestrial, coastal and marine environments due to overexploitation of these ecosystems and to unsustainable development practices. Also as a consequence of two Gulf wars and unstructured economic diversification, the country has been subjected to serious environmental and health hazards. However, under its constitution, Bahrain is committed to managing its natural and human resources and has since 1996 implemented a programme to reorganize the country's environmental planning. The government has recognized that sustainable development can only be assured if the full range of potential impacts of development projects is assessed in a timely fashion and that action can only proceed from that assessment. Unfortunately, due to the limitations on the institutional capacity of government authorities and other relevant institutions in this field, there have been no comprehensive environmental health impact assessments.

PROSPECTS FOR AGRICULTURAL WATER MANAGEMENT

A FAO study entitled '*Comparative advantage, competitiveness and policy options for sustainable agricultural development in Bahrain*' was conducted in 2003. The results of the study indicated that most plant production and livestock activities showed a good level of comparative advantage, as measured by the Domestic Resource Cost (DRC) indicator. The activities that appeared to have the best comparative advantage were the production of high-quality date palm varieties, Khalas and Khinezi in particular, and greenhouse production of cucumbers and tomatoes. Most open-field vegetables under drip irrigation also seemed to have a clear comparative advantage, although leafy vegetables generally showed much higher values than other vegetables. However, the production of vegetables under traditional irrigation systems did not show any clear comparative advantage with the possible exception of green onions (FAO, 2003).

Since the 1980s, the government has been taking several steps and courses of action to provide solutions to the water crisis in the country and to stem deterioration in the agricultural sector. These include: water conservation campaigns in all sectors, water pricing in the domestic sector and more reliance on non-conventional water sources (TSE in agriculture and desalinated water for domestic purposes).

Government policy with regard to water use is to reduce groundwater dependency for the domestic water supply, the second main water user, by constructing additional desalination plants. It is planned that groundwater will be exclusively used for irrigation. Additional requirements for future agricultural development should be supplemented by TSE water, which is expected to reach 73 million m^3 by 2010, especially through the expansion and upgrading of the plant production facilities at Tubli under TSE Phase-2 and the construction of transmission and distribution networks. On completion of 150 000 metres of closed pipes distribution network, it will irrigate 588 farms over an area of 2 200 ha. In addition, a drainage network to dispose of highly saline subsoil water will be constructed. However, these plans are still awaiting major government funds for the construction of a TSE conveyance system and farmers' acceptance. Although the intentions exist, an agricultural licensing system and water pricing have still to be put in place.

Although government policy indicates the will to develop a modern farming sector on larger production units using mechanization and up-to-date techniques, these aims have not yet been reflected clearly in the government's capital investment and subsidy programs.

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