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Oman

GEOGRAPHY, CLIMATE AND POPULATION

Geography

The Sultanate of Oman is located in the south-eastern corner of the Arabian Peninsula and has a total area of 309 500 km^2. It is bordered in the northwest by the United Arab Emirates, in the west by Saudi Arabia and in the southwest by Yemen. A detached area of Oman, separated from the rest of the country by the United Arab Emirates, lies at the tip of the Musandam Peninsula on the southern shore of the Strait of Hormuz. The country has a coastline of almost 3 165 km, from the Strait of Hormuz in the north to the borders of the Republic of Yemen in the southwest, overlooking three seas: The Persian Gulf, the Gulf of Oman and the Arabian Sea.

Administratively the country is divided into eleven governorates, which are Ad Dakhilya, Ad Dhahirah, Al Batinah North, Al Batinah South, Al Buraymi, Al Wusta, Ash Sharqiyah North, Ash Sharqiyah South, Dhofar, Muscat and Musandam. It can be divided into the following physiographic regions:

- The coastal plain. The most important parts are the Batinah Plain in the north, which is the principal agricultural area, and the Salalah Plain in the south. The elevation ranges between 0 near the sea to 500 metres further inland.
- The mountain ranges, which occupy 15 percent of the total area of the country. There is the mountain range that runs from Musandam in the north to the Ras Al-Hadd in the southeast. In the north close to the Batinah Plain is the Jebel Al Akhdar with a peak of 3 000 metres. Other mountains are located in the Dhofar province, in the extreme southern part of the country, with peaks from 1 000 to 2 500 metres.
- The internal regions. Between the coastal plain and the mountains in the north and south lie the internal regions, with elevations not exceeding 500 metres. This part covers 82 percent of the country with mainly desert, sand and gravel plains. It includes part of the Rub' al Khali, also known as the Empty Quarter or the Great Sandy Desert.

The most dominant soils are coarse textured (sandy or coarse loamy) with a high infiltration rate. The soil pH is moderately to strong alkaline, and the organic matter is very low.

The cultivated area was 100 900 ha in 2017, of which 69 300 ha consisted of annual crops and 31 600 ha of permanent crops (Table 1). Oman counts five distinct agricultural regions. Going roughly from north to south, they include the Musandam Peninsula, the Batinah coast, the valleys and the high plateau of the eastern region, the interior oases, and the Dhofar region. Over half of the agricultural area is located on the Batinah Plain in the north covering about 4 percent of the area of the country.

Climate

Generally, the climate is arid and semi-arid but differs from one region to another. It is hot and humid during summer in the coastal areas and hot and dry in the interior regions with the exception of some higher lands and the southern Dhofar region, where the climate remains moderate throughout the year. Potential evaporation varies from 1 660 mm/year on the Salalah plain in the south to 2 200 mm/year in the interior. In the north and centre of Oman rainfall occurs during the winter, from November to April, while a seasonal summer monsoon, from June to September, occurs in the southern parts of the country, Dhofar Governorate causing a temperature change.

FIGURE 1

Map of Oman

Map No. 3730 Rev. 4 UNITED NATIONS
January 2004

Department of Peacekeeping Operations
Cartographic Section

Source: UN, 2004.

The long term weighted average annual rainfall of the country is equal to 62 mm (former MRMWR, 2013), varying from less than 10 mm in the Empty Quarter of central Oman to 350 mm in the mountain areas. Meanwhile, on the Al Batinah coastal region it typically reaches between 50 and 100 mm/year, although slightly higher in the North.

TABLE 1
Basic statistics and population

Physical areas			
Area of the country	2018	30 950 000	Ha
Cultivated area (arable land and area under permanent crops)	2018	108 890	Ha
• as % of the total area of the country	2018	0.35	%
• arable land (annual crops + temp. fallow + temp. meadows)	2018	76 660	Ha
• area under permanent crops	2018	32 230	Ha
Population			
Total population	2018	4 829 473	inhabitants
• of which rural	2018	15.5	%
Population density	2018	15.6	inhabitants/km²
Economy and development			
Gross Domestic Product (GDP) (current USD)	2019	76 331.519	(Billion USD/yr)
• value added by agriculture (% of GDP)	2019	2.35	%
• GDP per capita (current USD)	2019	15 343.1	USD/yr
Human Development Index (highest = 1)	2019	0.81	
Access to improved drinking water sources			
Total population	2017	92	%
Urban population	2017	95	%
Rural population	2017	78	%

Sources: WHO-UNICEF JMP, 2000-2017; FAOSTAT, 2021; UNDP, 2020.

Population

The total population was 4.83 million in 2018, of which around 15.5 percent is rural (Table 1). Population density is thus a little more than 15.6 inhabitants/km^2. The annual demographic growth rate was estimated at 2.9 percent between 1990 and 2000, 1 percent between 2000 and 2005, 3.91 percent between 2005 and 2010 and 4.17 in 2017. The high population growth rate is due partly to the increase of immigration to the Sultanate. In fact, the foreign residents in Oman represented 40.8 percent of the total population in June 2020 (NCSI, 2020a).

In 2017, 92 percent of the population had access to improved drinking water sources (95 and 78 percent for urban and rural populations respectively). The sanitation coverage was 100 percent for the urban population in 2017.

ECONOMY, AGRICULTURE AND FOOD SECURITY

Agricultural production played a significant role in the national economy in the period preceding the discovery of oil. The national economy is dominated by its dependence on fossil fuels. In 2019, the Gross Domestic Product (GDP) was USD 76.33 billion, and agriculture and fisheries accounted for almost 2.35 percent of GDP. It increased from 494.8 OMR Million in 2016 to 627 OMR Million in 2017, according to the World Bank collection of development indicators and Trading Economics Website. The economically active population is 3 293 600 (2017) of which 81.6 percent is male and 13.07 percent female. About 3.99 percent of this is economically active in agriculture (World Bank, 2021a).

According to MAFWR (2019) the cultivated land increased from 72 000 ha in 2000 to 108 890 ha in 2018. Fruit trees (dates, bananas, lime, and mango) cover about 29 percent of the total cropped area and date palms occupy 80 percent of the area under fruit trees (Zekri, 2020). Agriculture in Oman totally depends on irrigation. The main crops are dates, fruit crops, alfalfa, vegetables, and other forage crops. All types of crops in the Sultanate of Oman require irrigation. The agriculture production and productivity are significantly affected by groundwater salinity and the depletion of aquifers because of seawater intrusion in the main agricultural area north of the country (Zekri, 2008, 2009; MAF, 2008; MAFWR and ICBA, 2012).

The agricultural sector plays a major role in the food security objective for the Sultanate. The government emphasized the importance of agriculture and food self-sufficiency by increasing domestic production and thereby reducing its reliance on imports. Hence, the Ministry of Agriculture and Fisheries initiated a project oriented towards the food security consisting on substitution of Rhodes grass by vegetables in the Batinah coastal area. Self-sufficiency of vegetables was high and reached 78 percent in 2016 and 42 percent in fruits (Zekri and Al Mamari, 2019).

Oman meets 80 percent of its food demand by imports, with 100 percent of rice and 95 percent of wheat being imported (FAO, 2016). It is important to note that most vegetables are consumed locally and more than 95 percent of the fruit trees are of local varieties. Current cereal production is very limited for a niche market. In 2019 wheat covered around 1 000 ha and production reached 3 615 tons. Barley production reached 1 901 tons on an area of 600 ha (MAFWR, 2019). The Sultanate is expected to depend more on imports in the future as the water resources are getting scarcer and the population is increasing at a high rate (Zekri, 2020).

Agricultural production takes place predominantly on small farm units. More than 59 percent of the total farm holdings occupy less than 2.5 ha and cover 6 percent of the total cropped land (MAFWR, 2013). Production is mainly market-oriented in the farms above 2.5 hectares and uses new farming technologies including hybrid seeds, commercial fertilizers and pesticides, mechanization and water saving irrigation systems.

WATER RESOURCES

The total internal renewable water resources are estimated at 1 318million m^3/year (Table 2) out of which 1 300 million m^3 is in the form of groundwater. Several important aquifers exist in Oman. The main aquifer systems include the alluvial aquifers, the regional quaternary aquifers, the aquifers of the Hadramawt Group and the aquifers of the Fars Group. Some of these aquifer systems are part of large regional aquifers that extend throughout the Middle East. Fresh groundwater is mostly available in the northern and southern extremities of Oman where precipitation and recharge occur. Most of the groundwater in other areas is brackish to saline. There are several hundred springs in Oman and most of them are located in the mountainous areas. These springs vary according to their discharge, temperature, and water quality (former MRMWR, 2005). The springs are predominantly located in the Hajar Mountains in the north of Oman and in the Dhofar Mountains near Salalah. The discharge from springs in this last region feeds the wadis flowing across the Salalah Plain. In many cases, springs have a high alkalinity, especially where they derive from a limestone aquifer. Thermal springs exist on the northern side of the Hajar Mountains and may be used for therapeutic purposes (former MRMWR, 2013).

TABLE 2
Water resources

Renewable freshwater resources			
Precipitation (long-term average)	2018	62	mm/yr
	2018	19 190	million m^3/yr
Internal renewable water resources (long-term average)	2018	1 318	million m^3/yr
Total renewable water resources	2018	1 400	million m^3/yr
Dependency ratio	2018	0	%
Total renewable water resources per inhabitant	2018	345	m^3/yr
Total dam capacity	2020	324	million m^3/yr

The main reliable source of water is groundwater. Apart from some significant wadis like Dayqah and Quriyat that have an average flow of 60 million m^3/year or Halfayn which covers a catchment area of 4 373 km^2 (former MRMWR, 2005), in nearly all wadis surface water runoff only occurs for some hours or up to a few days after a storm, in the form of rapidly rising and falling flood flows. Since the infiltration capacity of coarse alluvium and fissured rock is high, groundwater can be recharged quite easily. Rainfall provided a volume of 19 190 million m^3/year to Oman in 2017 out of which 79 percent is evaporated leaving just 3 288 million m^3/year as effective rainfall (former MRMWR, 2013) generating runoff and direct infiltration to the groundwater reservoirs. The total renewable water resources are estimated at 1 400 million m^3 and the total renewable water resources per inhabitant are estimated at 345 m^3/year in 2018 (Table 2).

Oman has few reserves of fossil water in aquifers that were replenished a long time ago when wet climate conditions prevailed. The present recharge is very low, if any. These non-renewable resources exist in the Dhofar (Nejd), Al Dahra (Al Massarat) and Sharqiyah (Rimal al Sharqia) regions:

- In the Nejd region, the Umm ErRadhuma aquifer is confined in depth over much of the region.
- The Al Masarrat aquifer is located in north-west of Oman, forming part of the Interior Plains' alluvial aquifers. Alluvial fans and wadi beds deposits in the Al Masarrat are thin, generally in the range of a few meters to a few tens of meters. The basin covers an area of 12 560 km^2, with a maximum depth of 400 m and the widest point of 130 km. Two main well fields have been installed in the lower reaches of the two main wadis: Ain and Abu Karbah. Regional groundwater flow is estimated at 17.2 million m^3/year, whereas estimated groundwater storage is 19.5 Million m^3/year (former MRMWR, 2005).
- A'Sharqiyah sands – extending south of the Wadi Batha alluvial area. The primary aquifer is an aeolianite aquifer, which reaches a thickness of 100 m in A'Sharqiyah North. Sharqiya Basin covers an area of 21 546 km^2 and its recharge is estimated at 65 Million m^3/year. The total annual demand in the area is estimated at 80 million m^3/year, which means an annual deficit of 15 million m3/year.

Current mean annual recharge in the Dhofar Mountains, covering an area estimated at 1 570 km^2, has been estimated to 10.7 million m^3 /year distributed over three aquifers (ESI, 2007). Fifty percent of the recharge benefits the Salalah Plain and the other 50 percent goes to the Nejd area. The government decided to use those fossil aquifers essentially to supply water for urban purposes and as a reserve for the future. However, since 2011 some aquifers are used for irrigation purposes in Nejd area to produce mainly fodder crops as well as seasonal vegetables and fruits (Ishag, 2014).

Since 1985, 55 major recharge dams were constructed together with many smaller structures in order to retain a portion of the peak flows, thus giving more scope for groundwater recharge. In addition, 14 flood protection dams and 115 small storage dams were constructed. In total there are 184 recharge, protection, or storage dams across the country. Many of these structures are located in Northern Oman. Several other dams are planned for the future. In 2020, the total dam's capacity reached 324 million m^3, including the largest dam of Wadi Dayqah which was built in 2010 with a storage capacity of 100 million m^3 (former MRMWR, 2013; MAFWR, 2020).

The total available water in Oman is approximately 1 556 Million m^3/year, which comes from 87 percent of conventional (surface and groundwater) and 13 percent of non-conventional water (desalination and treated wastewater). The total water consumption in Oman is approximately 1 873 Million m^3/year (Table 3).

The public Authority for Water, Diam, is responsible for urban water supply. Desalination plants make the highest contribution to water supplies in the large coastal cities and where natural water resources are inadequate. Seawater desalination in Oman started to supply potable water to Muscat city and the coastal area in the early 1970s. The total production was 34 million m^3 in 1995. In 2010, around 190 million m^3 were supplied with 76.7 percent from desalination and 23.3 percent from groundwater. In 2019, the total production of urban water volume more than doubled compared to 2010 and reached 385.9 million m^3. The contribution of groundwater increased in absolute terms to 48.5 million m^3, while in relative terms went down to 12.6 percent. The total number of large desalination plants went from 5 plants in 2010 to 10 plants in 2019 and the small desalination plants increased from 33 to 49 plants respectively (Diam, 2019).

In Oman, all wastewater treatment is undertaken at tertiary level. Haya Water is a semi private wastewater treatment company. It operates 58 sewage treatment plants at 44 different locations, producing around 200 million m^3/year of treated wastewater. The major user of the treated wastewater is Muscat Municipality and use is limited to landscape irrigation using sprinkler, drip and bubbler systems. Some minor uses are for industrial purposes and for cooling (Zekri, 2020). In the Southern part of the country, the Salalah treatment plant produces 16 million m^3/year most of it is used for aquifer recharge to combat seawater intrusion as well as for landscaping irrigation. The use of treated wastewater for landscaping relived the aquifers, which are essentially used for agricultural purposes or as back up storage for emergency urban water supply.

WATER USE

Agriculture is the major user of water in the Sultanate of Oman. In 2018, the total water withdrawal was 1 873 million m³ of which 83 percent was withdrawn for agricultural purposes, 5 percent for municipal and 13% for industrial purposes (Table 3, Figure 2 and Figure 3). The agricultural abstraction represents around 95 percent of the total groundwater uses (former MRMWR, 2013).

TABLE 3
Water use

Water withdrawal			
Total water withdrawal	2018	1 873	million m³/yr
- irrigation + livestock	2018	1 547	million m³/yr
- municipalities	2018	88	million m³/yr
- industry	2018	238	million m³/yr
• per inhabitant	2018	388	m³/yr
Surface water and groundwater withdrawal	2018	1 634	million m³/yr
• as % of total actual renewable water resources		117	%
Non-conventional sources of water			
Produced municipal wastewater	2018	108	million m³/yr
Treated municipal wastewater	2018	94	million m³/yr
Reused treated municipal wastewater	2018	61	million m³/yr
Desalinated water produced	2018	330	million m³/yr
Reused agricultural drainage water		-	million m³/yr

FIGURE 2
Water withdrawal by sector

Total 1 873 million m³ in 2018

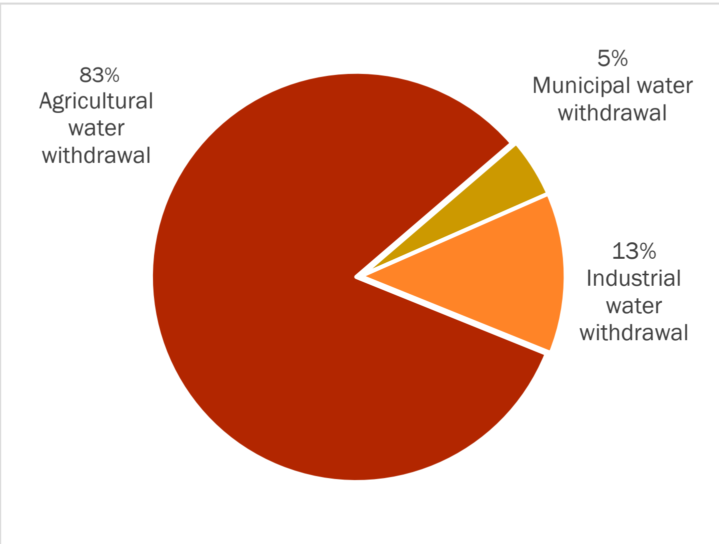
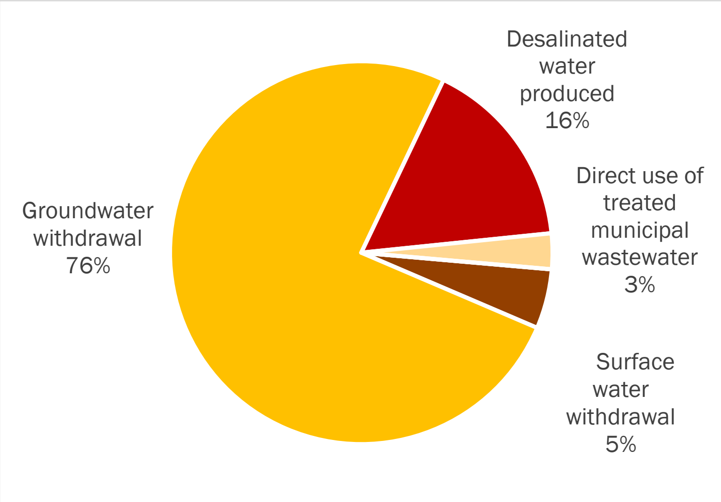


FIGURE 3
Water withdrawal by source

2 025 km³ in 2018



The water balance shows that in many areas water demand exceeds natural replenishment. For instance, in coastal areas, over-abstraction has led to seawater intrusion and deterioration in the water quality. The total agricultural water demand in the Sultanate is increasing and is estimated at 1 546 million m^3 in 2011 while the demand was only 1 131 million m^3 in 2000 (Zekri and Al Mamari, 2019). Out of the 2011 volume of water withdrawn for agriculture, 70 percent or 1 060 million m^3 were extracted from wells (127 000) and 30 percent or 486 million m^3 via Aflaj (3 017) (former MRMWR, 2013).

Agricultural water demand across the Sultanate is not evenly distributed. For instance, the Batinah region uses the major volume of agricultural water with a demand estimated at 687 million m^3 in 2011. The Batinah water demand represents 36 percent of total demand at the Sultanate level.

IRRIGATION AND DRAINAGE

Evolution of irrigation development

Although 2.2 million ha are considered suitable land for agricultural purposes, water is the major constraint to the use of land. Rainfall in Oman is very scarce with an average of 10 rainy days/year making irrigation a must all around the year. The available water resources coupled with existing technology would not allow expanding the cultivated area beyond the current area.

Traditionally agricultural water use in the Sultanate was very efficient and sustainable with the Afalj and custom laws. The change in the agricultural water management occurred at the beginning of the 1970's with the introduction of diesel and electric pumps for the use of individual wells abstracting from common resource pools aquifers. Seventy-two percent of the cultivated area in Oman is allocated to four crops: date palms, Rhodes grass, alfalfa, and banana. The date palms constitute a traditional crop and are a low input activity. On the opposite, high value crops such as vegetables, which require far more water for their production, are input intensive and risky in terms of both yield and price variability. Groundwater in Oman is free and farmers pay only the cost of wells drilling and pumping (Zekri, 2020).

All 108 900 ha equipped for irrigation (MAFWR, 2020) are irrigated from groundwater sources (wells, Aflaj). While the area under sprinkler and localized irrigation has increased considerably to 51 percent in 2018 compared to the traditional surface irrigation system which went down from 80 percent in 2004 to 47 percent in 2018 (Table 4 and Figure 4).

TABLE 4
Irrigation and drainage

Irrigation potential			
Irrigation			
1. Full or partial control irrigation: equipped area	2018	108 900	ha
- surface irrigation	2018	51 400	ha
- sprinkler irrigation	2018	33 400	ha
- localized irrigation	2018	24 100	ha
• % of area irrigated from surface water	2018	0	%
• % of area irrigated from groundwater	2018	100	%
• % of area irrigated from mixed surface water and groundwater	2018	0	%
• % of area irrigated from mixed non-conventional sources of water	2018	0	%
• area equipped for full or partial control irrigation actually irrigated	2018	-	ha
- as % of full/partial control area equipped	2018	50.84	%
2. Equipped lowlands (wetland, ivb, flood plains, mangroves)		-	ha
3. Spate irrigation		-	ha
Total area equipped for irrigation (1+2+3)	**2018**	**108 900**	**ha**
• as % of cultivated area	2018	100	%
• % of total area equipped for irrigation actually irrigated	2018	100	%
• average increase per year over the last 13 years	2004-2018	4.5	%
• power irrigated area as % of total area equipped	2018	84.11	%
4. Non-equipped cultivated wetlands and inland valley bottoms		-	ha
5. Non-equipped flood recession cropping area		-	ha
Total water-managed area (1+2+3+4+5)	**2018**	**108 900**	**ha**
- as % of cultivated area	2018	100	%
Total number of households in irrigation	2013	98 718	
Irrigated crops in full or partial control irrigation schemes			
Total irrigated area (wheat and barley)	2013	1 261.6	ha
• Area under modern irrigation	2013	17.8	%
Harvested crops:			
Total harvested irrigated cropped area	2013	68 463	ha
○ Annual crops: total	2013	17 194	ha
- Wheat	2013	298	ha
- Barley	2013	964	ha
- Sorghum	2013	283	ha
- Sugar cane	2013	165	ha
- Vegetables	2013	11 581	ha
- Other field crops	2013	3 903	ha
○ Permanent crops: total	2013	51 269	ha
- Date palms	2013	24 120	ha
- Bananas	2013	1 421	ha
- Alfalfa	2013	5 535	ha
- Rhodes grass	2013	1 184	ha
- Elephant grass	2013	1 866	ha
- Citrus fruits	2013	75	ha
- Coconuts	2013	637	ha
- Other fruits	2013	4 541	ha
- Other forages crops	2013	11 890	ha
Drainage – Environment			
Total drained area	2013	0	ha
- part of the area equipped for irrigation drained	2013	0	ha
- other drained area (non-irrigated)	2013	0	ha
• drained area as % of cultivated area	2013	0	%
Flood-protected areas	-	1 900	ha
Area salinized by irrigation	-	-	ha
Area waterlogged by irrigation	-	-	ha

Source: NCSI, 2020b.

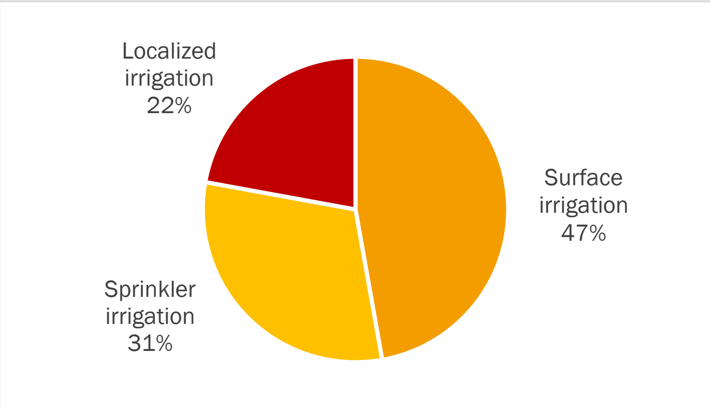
Sprinkler and localized irrigation systems, also called modern irrigation systems as opposed to traditional surface or flood irrigation systems, are mainly found on new farms. The introduction of modern irrigation systems is subsidized by the government: The Ministry of Agriculture and Fisheries (MAFWR) is continuing its efforts to introduce modern irrigation techniques. To encourage farmers to adopt the new techniques, the MAFWR has a financial assistance program to small farmers. The feasibility of modern irrigation systems has been proven as well as their impact on water use efficiency at farm level. However, the introduction of these modern technologies did not result in a reduction of groundwater pumping or water saving due to the open access to the groundwater resource (Zekri *et al.*, 2009).

In most parts of Oman irrigation systems have been improved gradually which is reflected by the increase in agricultural production: first with the cemented lined channels and then with pressurized modern irrigation systems.

FIGURE 4

Irrigation techniques

Total 108 900 ha in 2018



The falaj system ('aflaj' in plural) is the traditional method developed centuries ago for supplying water for irrigation and domestic purposes. Many of the systems currently in use are estimated to be over a thousand years old. The falaj comprises the entire system: (i) the source, which might be the upper reaches of wadis from which water is diverted, a qanat, or a spring; (ii) the conveyance system, which is usually an open earth or cement-lined ditch; (iii) the delivery system. The falaj has assumed a social significance and has well established water property rights and rules of usage allowing proper maintenance and administration. Based on the source, three types of falaj can be distinguished:

1. the Ghaily falaj, which is a simple diversion and canalization of surface wadi flow; it normally uses open channels to collect and transfer the water; it dries out after long periods of drought with low rainfall since it depends on a shallow groundwater table;
2. the Dawoodi falaj, also known as Qanat, which is a very ancient system for extracting water from the water table by gravity, through a nearly horizontal gallery; this type of falaj has a system of deep and long channels, the lengths of which sometimes extend to 16 km, while the whole falaj network may reach up to 45 km;
3. the Aini falaj, which is a simple canalization of springs.

The flow of water in a falaj system is continuous and the distribution of water is divided among falaj owners into periodic units, or time share units: Al Athar is a 30 minutes time share and most used unit for water distribution. According to MRMWR, the total number of Aflaj was 4 000 falaj (Zekri *et al.*, 2012). Around 1 000 Aflaj were lost due to drought and over-abstraction of groundwater from wells. Currently 3 017 Aflaj are operating in the Sultanate, with almost 46 percent depending only on surface wadi water and shallow water tables and they are active only in wet periods (Table 5).

TABLE 5
Types and numbers of Aflaj in Oman

Type of aflaj	Operating	Dry	Total	Percentage of operating aflaj
Dawoodi	627	340	967	65%
Aini	989	163	1 152	85%
Ghaily	1 401	592	1 993	70%
Total	3 017	1 095	4 112	74%

Source: former MRMWR, 2013.

According to Agricultural Census 2012-13, wells and Aflaj are the main sources of irrigation. The area irrigated by dug wells represents 51 percent, 30 percent by bore wells, while only 11 percent is irrigated by falaj. The remaining area (8 percent) was irrigated by other sources like springs, treated water and other unknown sources.

Role of irrigation in agricultural production, the economy and society

In 2019, agricultural production reached 3 million tons compared to 2.361 million tons at the end of the 5th Five-Year plan (2015), achieving an annual growth rate of 6.3 percent during this period and an increase of 28 percent. The annual growth rate during the period from 2011 until 2019 was 10.2 percent. The production of vegetables registered the highest increase rate during this period (308 percent). This rise was due to the increase of productivity and the use of modern technology by agricultural companies and farmers of the Omani Agricultural Association. During the agricultural season 2018-2019, almost 3 615 tons of wheat was produced on 938.7 ha of cultivated area.

Total date production in 2018 was estimated at 368 808 tones (25 126 ha) which represents 80 percent of total fruits production (NCSI, 2019). Among all cultivated crops in Oman, date palms are the major water consuming plants. In 2014, they consumed 558 million m^3 that is 38 percent of total irrigation water and 31 percent of groundwater (Al-Mulla *et al.*, 2017).

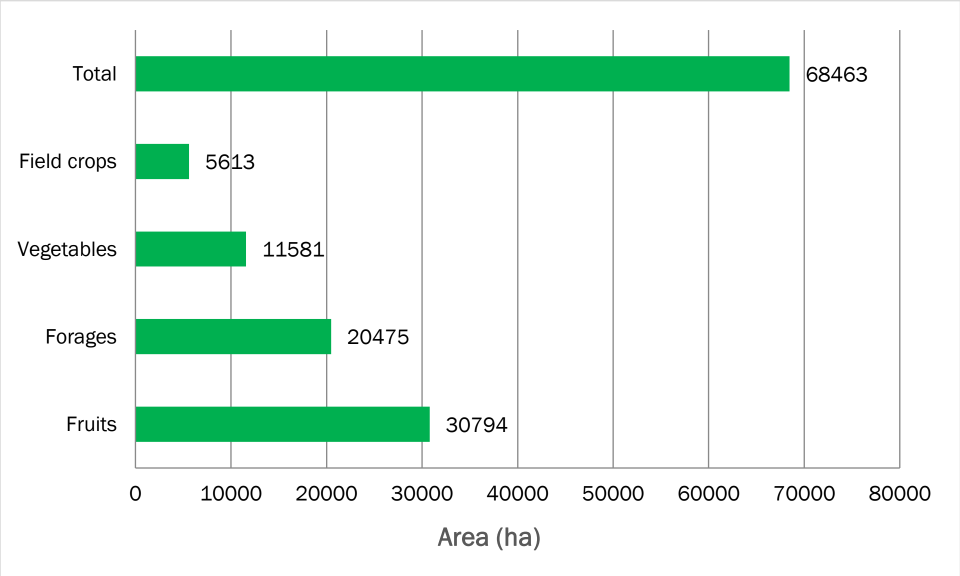
The average cost of installing sprinkler and localized irrigation systems varies between USD7 500 /ha for large and medium schemes and USD 8 000/ha for small schemes. The combined capital, maintenance and energy cost of pumping groundwater from a typical dug well of 40 meters depth is estimated at about USD 0.021/m^3. Pumping costs from a tube well for a modem irrigation system, requiring a larger pumping head, are between USD 0.07 for a 100 deep well and 0.25/m^3 considering a depth of 500 meters. These last figures apply essentially for fossil water located in Nejd area.

The amount of water used for irrigation depends on the type of crop and the cropping system adopted, as well as on the climate of the regions. It varies from 16 700 to 20 800 m^3/ha per year depending on the regions and from 4 000 to 27 400 m^3/ha per year according to the type of crops. The net return on water from agriculture depends on the type of crops. It is the highest for vegetables given the low demand of water for this type of crops. In Salalah returns on water are much better because crop water requirements are lower than in the other parts of the country and higher value crops are grown, such as bananas and coconuts.

Employment in agriculture in Oman was reported at 4.32, 4.14, and 3.99 percent of total employment in 2017, 2018, and 2019, respectively (modelled ILO estimate) (World Bank, 2021b). Only men are involved in agricultural water management. Women are involved in product harvesting and processing as well as taking care of the animals. In 2018, the number of females working in the agriculture sector was 513 compared to 85 902 males. The total number of expatriate employees represents the major labor force with 85 293 in 2018 distributed as 163 females and 85 130 males (Statistical Yearbook, 2019).

FIGURE 6
Major crops

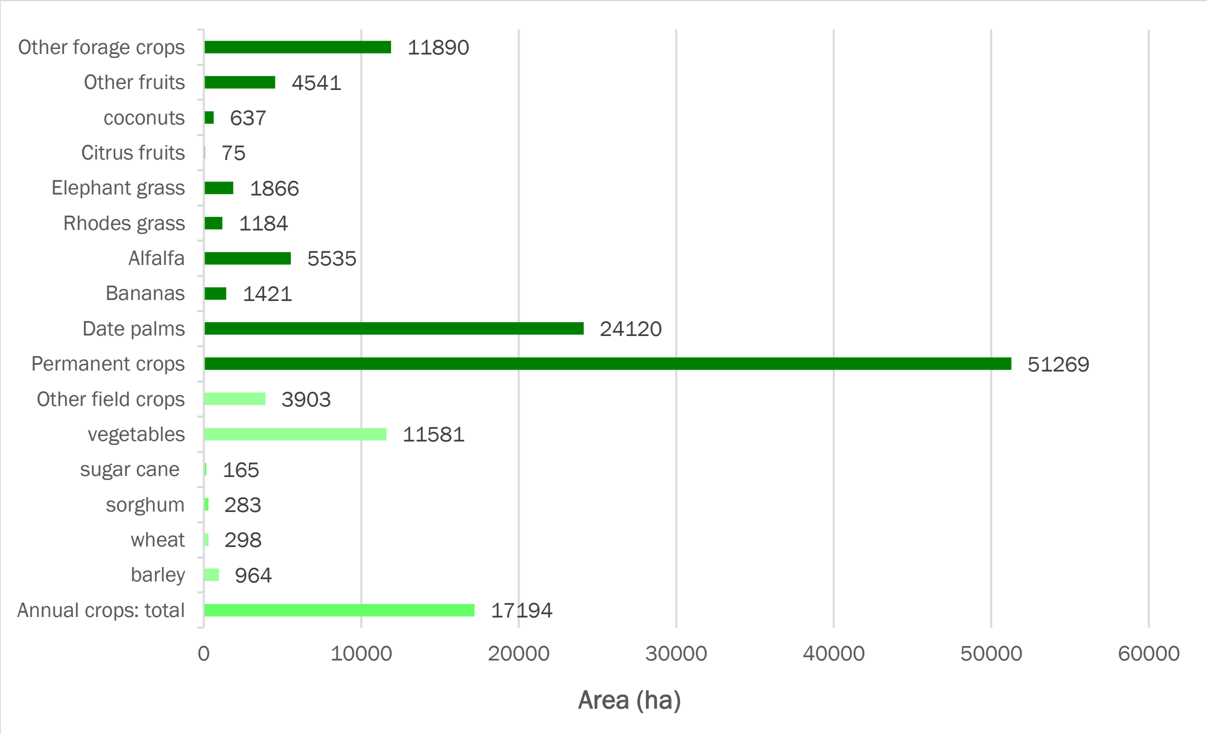
Total harvest area 68 463 ha in 2013



Source: MAFWR, 2013.

FIGURE 7
Irrigated crops

Total harvest area 68 463 ha in 2013



Source: MAFWR, 2013.

Figure 7 shows the major crops produced in Oman. Date palms occupies the first rank with 24 120 ha, followed by Rhodes grass with 11 844 ha and tomatoes with 1 358 ha (MAFWR, 2013).

Status and evolution of drainage systems

According to the Oman Salinity Strategy (OSS), there are two quite different salinity problems in Oman. The first is soil salinity in areas supplied by fresh water caused by poor irrigation management. The second salinity problem is the result of using brackish water due to seawater intrusion and secondary salinization. The major cause of water salinity in Oman is due to the decline in the aquifers' water level caused by the deficit between the total recharge and abstraction resulting in seawater intrusion. This is evidenced by the increase in groundwater salinity in the monitoring wells. The OSS proposed several initiatives aiming at controlling salinity such as the reduction of the abstraction rate to mitigate the current unsustainable environmental impacts, the reuse of tertiary treated wastewater, building recharge dams and improving irrigation efficiency at farm level by encouraging higher rates of adoption of drip and sprinkler irrigation systems (MAFWR and ICBA, 2012).

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

Institutions

At the national level, environmental agriculture and water management responsibilities fall under two central administrations, which are the Ministry of Agriculture, Fisheries Wealth, and Water Resources (MAFWR) and the Environment Agency (Zekri, 2020). Urban water is under the responsibility of the Public Water Authority (Diam) and the Oman Power and Water Procurement Company (OPWP). Both of these authorities are under the direct control of Ministry of Finance. The wastewater collection, treatment and reuse are in the hands of two major semi private companies Haya water and Salalah Wastewater Company. More than 3 000 water user associations exist and each managing a falaj. Finally, the Oman Water Society completes the government's efforts of awareness provision to water conservation.

TABLE 6
Oman's water administration

Organization	Subsector	Responsibilities
Ministry of Agriculture, Fisheries Wealth and Water Resources (MAFWR)	Water resources	Regulation
		Water resources management
		Water resources assessment
		Water resources development
	Irrigation water	Irrigation water management
Environmental Authority	Water quality and discharge	Legal and regulatory standards
Public Authority of water (Diam) (under Ministry of Finance)	Urban fresh water	Regulator for the urban water sector
		Direct water service provider
		Urban water supply and management to users
Oman Power and Water Procurement Company (OPWP) (under Ministry of Finance)	Desalinated water	Ensures bulk supply of desalinated water to the Diam
		Planning and contracting new capacity from the private sector companies
Falaj organizations (water users Associations)	Community	Falaj water allocation
		Falaj protection
		Falaj maintenance
		Falaj water distribution
Oman Wastewater Company (Haya)	Wastewater	Collection, treatment, and reuse of treated water
Salalah Wastewater Company	Wastewater	Collection, treatment, and reuse of treated water
Oman Water Society	Community water use	Water conservation and awareness

Water management

A National Water Resources Master Plan was prepared in 2000 and established a strategy and plan for the period 2001-2020 for the sustainable development, management and conservation of water resources in the Sultanate of Oman. The latest Water Master Plan of 2013 updated the previous plan with improved data availability and an improved methodology. Large datasets were used for the study. These included rainfall, evaporation, wadi flows, groundwater levels and population census figures. Agricultural and urban demands were calculated separately as part of the water balance. The former MRMWR has undertaken a series of investigations and studies to improve the water resource database making it appropriate to undertake an updating of water balances to provide a foundation for future planning decisions. Water balance results showed that total deficit for Oman is estimated at 316 million m^3/year. Distributions of both demand and recharge components are highly variable across the country. The highest agricultural demand is on the northern coastal plain of Al Batinah. Similarly, recharge from wadis and reservoirs are controlled by the location of these features. Wadi recharge is most important on the alluvial plains of the Al Batinah and Al Massarat regions and in the Nejd area (former MRMWR, 2013).

According to the 2013 Master Plan, the highest deficit is observed in the Al Batinah plain where 53 percent of the agricultural activity is located. The deficit in the coastal plain resulted in seawater intrusion and groundwater salinization. In order to monitor groundwater, the government has censed all the wells in the country which have been licensed. Drilling of new wells is subject to approval. Furthermore, proper legislation exists and allows the former MRMWR to control the volumes of water extracted from each well. Because groundwater is an open access resource and given that agriculture depends 100 percent on irrigation, the adoption of modern irrigation systems does not allow saving water. Farmers often own more land than what they can irrigate with the traditional flood system. Hence the adoption of modern irrigation technologies results in expanding the portion of the irrigated part of the farm and does not lead to groundwater saving at an aquifer level. Data from the last agricultural census 2013 showed that the cropped land represents only 48% of the farm land. The government has funded research to introduce smart metering to control groundwater pumping from well at a small scale (Zekri *et al*., 2017). The SARDS 2040 has recommended the use of smart meters at an aquifer level and to generalize progressively this system according to success (FAO and MAFWR, 2016). Efforts at research level are being deployed to develop and test smart irrigation systems that fit small scale farms in Oman. Irrigation based on sensors will reduce the excess on the volumes of irrigation required by crops (Zaier *et al*., 2015).

Haya Water Company prepared a master plan for the reuse of treated wastewater which aims to increase the reuse of treated water up to 67 percent by year 2026. In Oman, the wastewater is treated to the tertiary or the quaternary level, which makes it suitable for irrigation of all sorts of crops. However, the major obstacle related to irrigation with treated wastewater is the cost. The cost of delivering treated wastewater up to the farm gate requires investments in pipes and pumps as well as the expenditures in operational and maintenance costs energy. Thus, without a proper program of subsidy to the water conveyance infrastructure farmers are not willing to pay the price of USD 0.52 per m^3. Kotagama *et al*. (2016) estimated the farmers' willingness to pay for tertiary treated wastewater at USD 0.23 per m^3which is less than half of the current price requested by Haya. Replenishing the aquifers with treated wastewater and creating new agricultural land to use tertiary treated wastewater are proposals being considered by the Ministry of Agriculture and Fisheries and Water Resources

In the urban water sector, several water conservation initiatives have been developed, such as leakage control in municipal water supply schemes. The Public Authority of Water (Diam) has brought the total physical losses in the public urban network to 22 percent in 2019 compared to 43 percent in 2010 (Diam, 2019). Public awareness of water resource issues has created a general and focused understanding of the overall situation and of the specific contribution each citizen can make and the improvement of irrigation methods through subsidy programmes.

The top four national priorities and strategies related to water resources development are the following:

1. monitor and control aquifer depletion;
2. conserve and protect water resources from pollution;
3. optimise, collect, and use of all water resources; and
4. delineate and manage high-risk flood plain and coastal areas.

Policies and legislation

With Oman having entered the arena of recent developments in 1970 and with the increasing demand for water, legislation was prepared to safeguard interests with regard to the rights established by customs and traditions. Many plans and programmes were set up to increase the efficiency of water use.

In 1988, Royal Decree No. 82/88 declared the water resources of Oman to be a national resource. This is the most far-reaching and important piece of legislation on water resources. Oman has several laws on water resources and the main measures taken for water management and conservation are:

- No wells may be constructed within 3.5 km of the mother well/source of the falaj.
- Permits are required for the construction of new wells, for deepening existing wells, for changes in use and for installing a pump.
- All drilling and well digging contractors are required to register with the Ministry of Regional Municipalities, Environment and Water Resources (MAFWR) on a yearly basis.
- The MAFWR has the cooperation of other government agencies such as the Ministry of the Interior and the Royal Oman Police in dealing with offenders.
- No extension of existing agriculture lands and no cultivation of new lands are allowed.

Royal Decree No 72/89 was issued for the application of modern irrigation systems in the Batinah region with the intention of rationalizing water use, increasing agricultural production and improving its quality. As an incentive to the farmers to introduce the systems the Government provided a financial subsidy to alleviate the cost burden.

In 2000, a new Royal Decree, No. 29/2000, defined water as a national asset to be protected and regulated activities related to wells and Aflaj and the use of wells for desalination. The Ministerial Decision 264/2000 allows the MRMWR to determine the quantity of water to be taken from each well (former MRMWR, 2000).

In 2001, Royal Decree No 114/2001 on conservation of the environment and prevention of pollution regulated the disposal of solid and hazardous waste, pollution control and the issuing of permits for discharging untreated wastewater (former MRMWR, 2005). Royal Decree 115/2001 refers to the disposal of liquid and solid waste products. The Ministerial Decision 159/2005 regulates the discharge of reject brine from coastal desalination plants into the sea. The Ministerial Decision 4/2009 regulates the use of small desalination units on individual wells and discharge of reject brine.

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The quality of the water in the wells differs according to the geographic location and to the native groundwater. In locations close to the sea the Electric Conductivity (EC) may reach more than 16000 mg/l, owing to the abstraction of groundwater at rates higher than the natural recharge leading to seawater intrusion inland affecting the salinity of the groundwater and hence the agricultural productivity.

Seawater intrusion has a distinct pattern of occurrence. In fresh water areas groundwater salinity typically increases quite slowly until salt concentration reaches 4 000 to 6 000 mg/l. Thereafter it tends to rise quite quickly, although this is not always the case. In 2010, Barka was the region most affected by seawater intrusion (1 680 hectares) followed by Saham and Shinas. Over the same period, the cultivated area affected by seawater intrusion grew from 98 hectares to 798 hectares (OSS, 2012).

The use of agrochemicals, both fertilizers and pesticides, is a widespread practice and a potential hazard to groundwater quality where, as in most of the Sultanate, groundwater is unconfined and most soils are sandy loam with low organic content implying a low water-holding capacity and a high deep-percolation. The government is strict about the use of all types of agrochemicals.

The former Ministry of Environment and Climate Affairs (MECA) applied several measures to protect water quality and the rare endangered and exposed to extinction flora and fauna species. The main measures are summarized in the following points below (former MECA, 2010):

- improving the efficiency and management of irrigation water;
- assessment of soil contamination and vegetation resulting from use of agricultural land;
- reclamation of agricultural land and rational use of irrigation water;
- assisting farmers to increase productivity and conserve water resources;
- encourage the use of organic fertilizers instead of chemicals;
- the introduction of mixed farming to incorporate elements of flora and fauna;
- the production and use of herbs and the remaining portions of crops and organic manure as fertilizer;
- the agricultural and pastoral rotations should be included in the implementation for breeding;
- the extensive use of improved seeds should be included in the implantation for breeding; and
- implementation of an integrated development to the Nejd in Dhofar Governorate.

PROSPECTS FOR AGRICULTURAL WATER MANAGEMENT

The Sustainable Agriculture and Rural Development Strategy (SARDS) 2040 has been developed by the government in collaboration with FAO (FAO-MAFWR, 2016). SARDS 2040 proposed a set of interventions to carry out the envisioned changes over a period of 25 years. One of the top priority pillars is sustainable management of natural resources in agriculture which includes water management in focus regions including Al Batinah, the country's mainstay for agriculture. The strategy recommends maximizing the income per unit of irrigation water and increasing the capture, re-use and storage capacity of water. This will be done through establishing a groundwater governance framework that will allow the progressive reduction of abstractions and promoting high value, water efficient cropping systems at farm level. A collaborative institutional approach is deemed possible as smart meters have been tested and farmers are prepared to collaborate in a program of groundwater quotas and regulations. This will ensure correcting the groundwater over abstraction and increase farmers returns. Monitoring groundwater will be implemented in collaboration with farmers. In new irrigation areas, water quotas will be allocated to farmers and agreements on pumping to be metered and regulated from the outset. In existing irrigation areas collaborative regulation will be introduced step by step following the Ministerial Decree 264/2000. On the other hand, there are volumes of water including flood flows and storm waters lost to the sea and sinks, as well as tertiary treated wastewater that may be harnessed through recharge dams or injection to aquifers. The strategy proposes to assess these supplementary resources and to develop those that can be used economically and sustainably while protecting the quality and quantity of existing resources and to get the absolute maximum value out of every drop. Last not least the strategy encourages farmers to get organized around existing water user associations and enlarge the cooperation to marketing of agricultural products.

With the aim of increasing irrigation efficiency, the government committed itself to encouraging the introduction of localized irrigation systems. The introduction of these systems is considered to be one of the most important projects implemented by the Ministry of Agriculture and Fisheries (MAFWR) to conserve water and achieve agricultural development. The MAFWR has set the standard specifications and the technical terms for the implementation of modern irrigation systems, as well as for the calculation of crop water requirement for different areas. In fact, during the period 2005 and 2013, the percentage of the total harvested area under modern irrigation has substantially increased from 19 to 46 percent. According to the 2013 agricultural census, 81 percent of the vegetables area was under modern irrigation as well as 54 percent of perennial forage. However, only 21 percent of field crops and 16 percent of dates and other fruits are under modern irrigation systems.

Agricultural water in Oman faces a couple of challenges. The major obstacle is water scarcity making Oman one of the most water-stressed countries in the world. Salinity of water and soil is another challenge in many localities and the limited cultivated land has been subject to degradation, risk of desertification as well as loss of biodiversity.

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