Chapter 6
Oman Water Policy

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Abstract Oman is a country under severe water stress. Currently Oman produces around 1 Mm^3/day of desalinated seawater for urban purposes to expand supply. This policy was partially imposed by the irregularity of rain and the concentration of the population on the coastal areas. Most of the conventional water resources are in the form of groundwater and are used in the agricultural sector. Abstractions from wells are subject to licenses. But licenses so far do not carry any limits. The result is a race for water with overabstractions in the coastal areas causing seawater intrusion and damage to the aquifers. The government is planning to introduce progressively water quotas to farmers and monitoring through smart meters and online system. Large volumes of tertiary treated wastewater are produced daily and are only partially reused for landscaping. There is a mismatch between the willingness of farmers to pay for treated wastewater and the price set by the public authority leading to a limited demand. The actual context of free and unlimited access to groundwater does not encourage to shift the demand toward high-quality treated wastewater. Plans are being considered for recharging some of the aquifers with the treated wastewater. Irrigation efficiency improvements have been observed mainly for vegetable producers where the adoption of irrigation technology resulted in higher revenues and lower labor costs. Urban water prices are at 1/3 of their costs discouraging water saving and adoption of water saving/recycling devices at homes or industries. Urban water security is being addressed by aquifer storage and recovery techniques using excess winter desalinated water.

Keywords Groundwater · Desalination · Climate change · Pricing

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6.1 Introduction

The rapid population increase and the extremely harsh climate conditions characterized by an erratic precipitation, high temperatures, and high evaporation rates are among the major factors that affect the water sector in Oman. The population reached 4.4 million in 2016 with expatriates representing 45% of the total population. On average, the population grew at 5.6% in 2016. The growth rate of expatriates reached 9.1% the same year. The local population growth rate is still on the high side with 3.5% (NCSI 2017). Furthermore, rural migration, concentration of the population in the coastal cities, and the economic growth exacerbate the pressure on urban water systems.

The annual average precipitation in the coastal areas of Oman is around 100 mm/year. Evapotranspiration is estimated at 2000 mm a year, exceeding average rainfall by 20 times. In the mountain areas, where most of the recharge of aquifers comes from, rainfall reaches 250 mm/year. The mountains are rocky with fractures allowing rainfall to penetrate in the aquifers while the surface flows and run-off recharge the coastal aquifers directly through the Wadis' beds and through recharge dams. The conventional water resources represent 87% of the nation's water resources whereas nonconventional water resources including desalinated water and treated wastewater represent nearly 13%. Groundwater represents 94% of the conventional water sources (MRMWR 2013). Given the rainfall irregularity and the mismatch of the locations of aquifers and cities, most of the urban water is thus supplied by desalination plants. This has been facilitated so far by the availability of gas and oil resources for desalination purposes. While the urban water falls under the responsibility of the Public Authority for Electricity and Water, the agricultural water falls under the responsibility of the Ministry of Regional Municipalities and Water Resources (MRMWR) and the Ministry of Agriculture and Fisheries Wealth (MAF). Agriculture is the highest user of the conventional water in the country to produce mainly dates, forage crops, and vegetables. The country depends heavily on imports for food and will remain so in the future given the small annually renewed water resource, estimated at an average 1300 Mm^3/year. Water policy in Oman is predominantly under the command and control approach. Historically, however, water governance was initially decentralized and community based with Aflaj as a millenarian successful example of community water management. The current trends of water policy show a trend of swinging back to the allocation of water rights, learning from the Aflaj long lived experience.

6.2 Administrative, Legal, and Institutional Aspects of the Water Sector

Several administrations are involved in the regulation and management of water resources in Oman. These entities have evolved over time and the current picture is as follows. For the conventional water resources, the two main bodies are the

MRMWR and the MAF. The MRMWR is in charge of: development of policies plans and programs necessary for the water sector; mMonitoring, evaluation, and development of water resources to achieve a balance between water uses and renewable resources; conservation of water resources from depletion and the rationalization of water consumption in coordination with the concerned authorities.

The MAF is responsible for the use of water for irrigation purposes only. MAF provides farmers with extension services, advice on crop mix, and subsidies to adopt modern irrigation systems at farm level. The MAF plans for innovation in the traditional Aflaj irrigation systems and undertakes pilot studies for reforms. Irrigation water user associations are numerous and quite spread in the whole country. These associations are called Aflaj. They have their own water regulations and management rules. The Ministry of Environment and Climate Affairs is the third ministry with responsibilities on water. It has the responsibilities of developing and delivering policies and plans for protecting the environment, controlling pollution and nature conservation, and climatic affairs. The majority of its activities focus on developing legal and regulatory standards and permitting and controlling procedures for protecting the environment from different activities, including discharges into and abstractions from water and air emissions from water production processes. Both the Ministry of Environment and Climate Affairs and the MRMWR are responsible for protecting the water resources from pollution, and it is not always clear where the role of one ministry ends and the other begins.

Most of the water for urban uses is nonconventional water. The urban fresh water sector is governed mainly by the Public Authority of Electricity and Water (PAEW) and the Oman Power and Water Procurement Company (OPWP). These two public agencies are responsible for the planning, finance, procurement, and supply of desalinated water in the whole country. Both public and private desalination plants are under the umbrella of the PAEW. The PAEW is responsible for the pricing of urban water. The Oman Power and Water Procurement Company (OPWP) is a government-owned holding company under the umbrella of the Ministry of Finance. The OPWP is in charge of ensuring supply of bulk desalinated water to the PAEW. The OPWP is in command of planning and contracting the private sector companies producing desalinated water.

The treated wastewater is taken care of by two semipublic companies. Oman Wastewater Company (Haya) is the Sultanate's largest state-owned company in charge of building and operating the wastewater network and sewage treatment plants in ten Governorates of the country. The Salalah Wastewater Company has the same role as Haya but limited to the southern part of the country and in the Governorate of Salalah only. Both companies are in charge of extending the collection network, treatment, and distribution of the treated wastewater.

Oman Water Society (OWS) is a nonprofitable nongovernmental organization. It gathers professionals with interest in the water sector as a whole with an integrated perspective. OWS organizes workshops and seminars to raise awareness about the challenges facing the water sector and is a platform for the exchange of ideas and technology advances among experts and the public in general.

The water sector regulations in Oman are in the form of Royal Decrees and Ministerial Decisions. A number of Royal Decrees and Ministerial Decisions were issued to protect, conserve, and improve the management of the water resources. The most salient laws are reported below. The Royal Decree 82/1988 is considered the most important piece of legislation on water resources. The Royal Decree 82/1988 considered for the first time water as a national resource. It is a sort of nationalization of the resource giving full right and power to the government to make decisions and choices on the water sector. It states that "…the water of the Sultanate of Oman is a national resource to be used according to the restrictions made by the government and organizing its optimum utilization in the interest of the state based on comprehensive development plans." In 1989, the government issued the Royal Decree 72/89 encouraging the adoption of modern irrigation systems to rationalize water use, stressing the need to increase crop yields, and enhancing the quality of the products. The decree allowed the government to provide a fund to subsidize the cost of modern irrigation systems as an incentive for farmers to speed up the adoption process. The same decree is still in use for the incentives.

Given that 94% of the natural water resources are in aquifers, the Royal Decree 29/2000 is a Water Resources Protection Act that emphasizes the regulations of wells and Aflaj, permits, and maintenance and regulates desalination units on wells. The Royal Decree 114/2001 on environment conservation and prevention of pollution regulates the disposal of solid and hazardous waste, pollution control, and the release of permits for dumping untreated wastewater. Royal Decree 115/2001 refers to organizing the disposal of liquid and solid waste products. In 2001, a series of Ministerial Decisions established water supply well field protection zones in several regions of the Sultanate.

6.3 Agricultural Water

All agricultural activities depend totally on irrigation, except the range lands that partially feed some of the animals. Currently 83% of the conventional water resources are used for agricultural purposes (MRMWR 2013). Most of the water is used to produce dates and fodder crops. Seventy nine percent of the cropped area is allocated to four crops: date palms, Rhodes grass, alfalfa, and banana (see Fig. 6.1). Not only these crops have the highest water requirement per hectare, they have also the lowest net return per cubic meter (FAO 2008). The reasons why farmers are producing these crops are that water is free and farmers pay the cost of pumping only. The only limitation for pumping is the well's yield. As for forages, the crops are easy to produce with automatic irrigation, are risk free in terms of yield variability, and market is secured both locally and export for neighbor country. 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 less water for their production, are risky in terms of both yield and price variability and are input intensive. Joseph (2017) estimated the virtual water export from dates and alfalfa to be 40 and

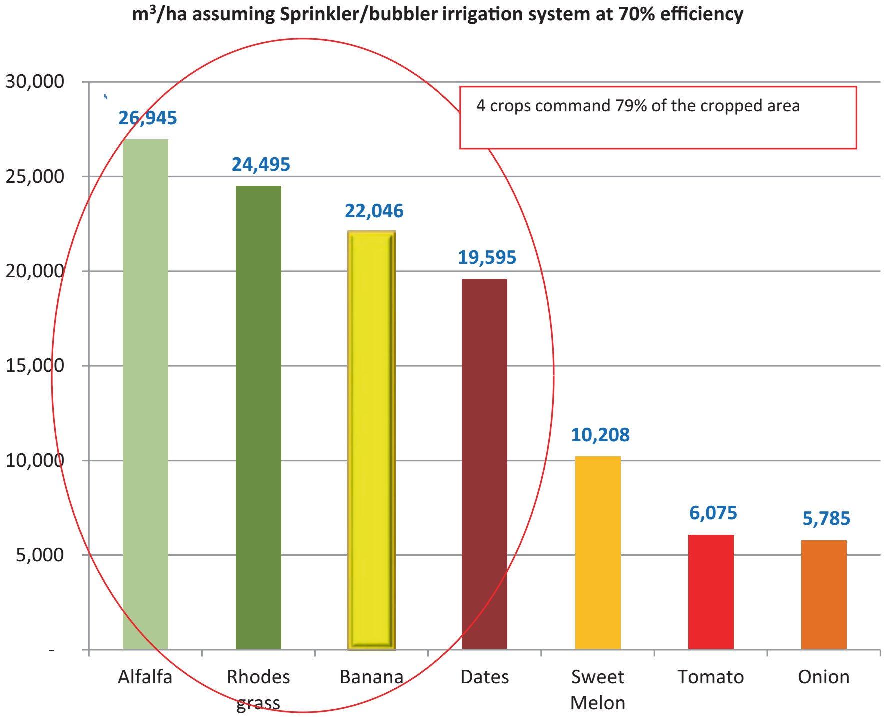

Fig. 6.1 Water consumption in m^3/ha assuming Sprinkler/bubbler irrigation system at 70% efficiency. (Source: Self elaboration)

19 Mm^3/year, respectively. The net sale for dates was 0.107 OR/m^3 for the whole chain and for alfalfa it was 0.185 OR/m^3. Changes to farm management and export policies are required to contribute to the reduction of the water deficit.

The agricultural water is supplied through two main systems in which traditional Aflaj account for 32% of total groundwater while the remaining amount is pumped from private wells (MRMWR 2008). The total demand for agricultural water has increased annually at a rate of 3.3% during the period 2000–2011. As a consequence, groundwater deficit increased from 285 million m^3 in 1990 to 316 million m^3 in 2011 with alarming levels of seawater intrusion in the coastal aquifers (MRMWR 2013). Master water plans since 2005 recommended the management of groundwater resources to control saline water intrusion as an absolute priority for the country. Agricultural water demand is not evenly distributed. The largest volumes of agriculture water are abstracted from the Batinah coastal aquifers with an estimated demand of 730 million m^3 in 2011 representing 36% of the total demand in the country. The agricultural area in the Batinah region is the largest and estimated at 73,626 Feddan (acres) covering 53% of the total cropped area in the Sultanate (MAF 2013). Al Dakhlia region is the second highest region in water demand with an estimated volume of 267 million m^3.

Table 6.1 Oman's water administration

Organization	Subsector	Responsibilities
Ministry of Regional Municipalities and Water Resource (MRMWR)	Water resources	Regulation
		Water resources management
		Water resources assessment
		Water resources development
Ministry of Agriculture and Fisheries (MAF)	Irrigation water	Irrigation water management
The Ministry of Environment and Climate Affairs	Water quality and discharge	Legal and regulatory standards
Public Authority of Electricity and Water (PAEW) (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 PAEW
		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

The total balance and distribution of water among Oman's regions are shown in Table 6.1, which shows the available conventional water resources supply and the total demand. The average available amount of groundwater in Oman is estimated at 1465 million m^3 annually, while the total demand is estimated at 1781 million m^3. The net water balance is consequently a deficit of 316 million m^3 that comes in the form of seawater intrusion. In general, 50% of Oman's regions have a positive water balance. The other six governorates have a negative balance. The last row shows that less than 10% of the rainwater is captured into aquifers, despite the government's efforts of building recharge dams (Table 6.2).

The excessive abstraction of groundwater causes quality degradation, financial losses, and threatens sustainability of the aquifer usage in the future. Groundwater deficit or aquifer depletion has been triggered by the land distribution program, the introduction of diesel pumps, and provision of rural areas with electricity since the late 1980s.

The Oman National Water Resources Master Plan in 1991 (NWRMP) called for the reduction of 215 million m^3 in the abstraction of groundwater. The NWRMP

Table 6.2 Water balance per governorate in million m³

Region	The volume of rainfall	Groundwater recharge	Groundwater uses	Excess/deficit
Musandum	333	57	31	26
Al Batinah North	1243	280	535	−256
Al Batinah South	329	104	195	−91
Muscat	518	56	80	−24
Al Burymi	569	92	67	25
Al Dhahirah	1423	108	250	−142
Al Dakhliyah	4627	219	267	−57
Sharqiah North	1136	122	177	−55
Sharqiah south	296	75	27	48
Masira	43	10.9	5.7	5.2
Al Wusta	1894	97.1	2.5	93.6
Dhofar	2390	244	133	111
Total	15,841	1465	1781	−316

Source: The Ministry of Regional Municipalities and Water Resources (2013)

recommended the adoption of modern irrigation systems, cropping of winter vegetables instead of date palm trees, implementation of suitable tariff system for all other purposes excluding the agricultural sector, and the reuse of treated wastewater for municipal irrigation and landscaping. The recommendations have been only partially implemented. For example, the modern irrigation system is currently covering around only 39% of all cropped areas given the limited funds for subsidies. Most landscape irrigation is undertaken using treated wastewater. Date palm and forage crops, requiring high volumes of water, are still the dominant crops. Finally, the most important recommendation regarding the monitoring of groundwater abstraction has not yet been implemented due to technical problems and reluctance to face the farmers with abstraction quotas. The MRMWR preference was to act on the supply side with the construction of 43 recharge and flood protection dams. Most of these dams are located along the Batinah coastal area and were designed to control floods and reduce seawater intrusion. The average captured volume that recharged the aquifers, during the period 1990–2010, was 50 million m³.

6.3.1 Aquifer Depletion

Farmers are extracting much more water than is renewed each year. As a consequence, some 144 Mm³ of seawater are flowing into Oman's aquifers each year. Up to now, 23,000 feddan of farmland have become too salty and have been abandoned (MAF 2012). If the current groundwater overabstraction continues, the aquifers will become increasingly salinized and the groundwater will be impaired.

One important step toward groundwater monitoring was undertaken in 1992 through the national well inventory project. The inventory allowed locating all the wells with their respective GPS coordinates, the installed pumps' type and horse power and abstraction purpose. The data base was used to estimate the total groundwater abstraction. The second step was the issuing of the Ministerial Decree that for the first time introduced the possibility of groundwater monitoring through individual quotas. The MD 264/2000 article (21.A) states that "The Ministry shall determine the quantity of water to be taken from each well". Even though the well inventory did not lead to measures to control abstraction, it had the merit to bring under strict monitoring the wells' deepening, the creation of new wells, or the replacement of existing wells. No new wells are allowed for agricultural uses unless to protect and preserve existing plantations or as a support for dried up Aflaj. However, new wells are allowed for municipal uses, petroleum, industrial, and touristic uses. This is an indicator that the new wells and water are allocated implicitly to high value uses. The sustained demand on new licenses is an indicator of the increased scarcity of groundwater as well as a proof of the negative impact of drought periods on the users. The licenses issued reached a peak during 2004 with 7129 licenses issued. This peak coincided with the low runoff in 2003 and 2004 (see Fig. 6.2). Thus, the demand for licenses depends on the drought periods and their duration. Every drought period is accompanied by new demands for wells' licenses.

The increase of abstraction affected the traditional Aflaj irrigation systems. Since 1990, the MRMWR counted some 1000 dried-up Falaj, out of a total of 4000. To mitigate the degradation of Aflaj the MRMWR supported 669 projects allowing farmer communities to dig new wells in order to maintain life in the rural areas. A study of a sample of 33 dried-up Falaj shows that the resulting impact was the loss of agriculture income, deterioration of lifestyle, and changes in land value. Around 16% of the families living around Falaj were obliged to relocate as result of the dry-up. The total losses at the national level related to Aflaj dry-up were estimated to 59 million Omani Rials per year (Zekri et al. 2012). The lack of implementation of

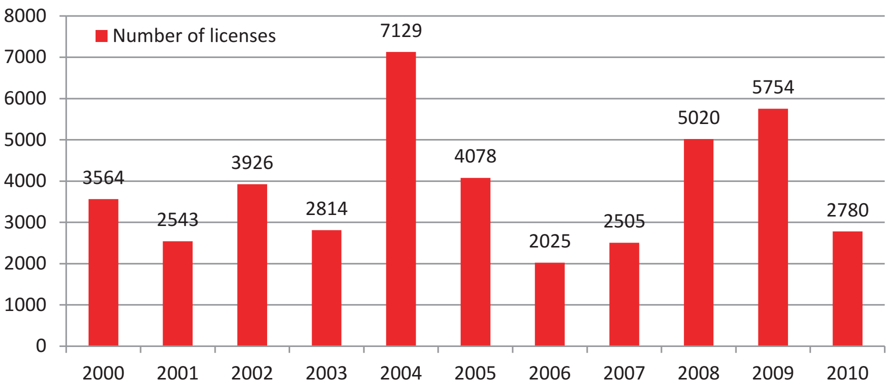

Fig. 6.2 Wells licenses issued by the MRMWR during the period 2000–2010 all over the Sultanate. (Source: The Ministry of Regional Municipalities and Water Resource 2013)

the law protecting the Aflaj (3.5 km exclusive protection zone around the mother well), which prohibits digging wells in the vicinity of Aflaj, is one of the main causes for the drawdown of the water table and hence the dry up of Aflaj.

Zekri et al. (2017) tested smart water meters on a pilot study that included 40 farmers and estimated the potential benefits of monitoring groundwater. The advantage of the smart water meters is that they have no moving parts and are monitored online. Optimization of abstraction over the next 70 years showed that a proper management of the groundwater requires a reduction of abstraction by 20% and changes in the crop mix that will improve the salinity of the aquifer in the long run compared to the current status and farmers' maximize profit. The recent sustainable agricultural and rural development strategy 2040 proposed to start the introduction of water metering in a large-scale area of 8000 farmers for a bigger test before generalization (FAO-MAF 2016).

6.3.2 Water Rights

Even though the Royal Decree 82/1988 considered water as a national resource, it excluded the Aflaj systems, which are still governed by the traditional water laws and rights. In Aflaj, users have access to irrigation water only if they own/rent a water right, while all community members have open access to Falaj water for domestic purposes. The traditional law protects the water rights for production purposes and protects the basic human needs for water. In small villages, domestic demand is often relatively negligible compared to agricultural water demand. The community members are allowed water for domestic purposes from the main channels but without connecting the houses by a network of pipes to avoid excessive use of water. This is a way of making access to domestic water costly to encourage water saving. The traditional laws reflect a vision of water rights based on both equitability and efficiency. Furthermore, public baths built on the Falaj sides are available for free for all users. The graywater flows from these baths are returned to the irrigation channel. This shows an advanced water management system totally adapted to the dry conditions of the country devised several hundred years ago.

The water rights in Aflaj are private, common, or quasi-public. Most of the water rights are private (88%), licensed, and can be traded. The common water rights are owned by the Falaj community. They are rented through lease auctions and the rent insures a sustainable management through the provision of continuous monetary flows for maintenance and operation. The last category is the quasi-public water rights that are owned by charity entities. This category of water rights is leased in short-period markets and the revenue is used to support social organizations. The common and quasi-public water rights represent 6% each (Zekri and Al-Marshudi 2008).

Water rights in Aflaj are millenarian and are characterized by separation from land, privacy, proportionality, seniority, and transferability. These characteristics fluidize the exchange of the rights freely among farmers. Water rights privacy has similar legal sides to any other private asset and it is recognized at the national level. The water rights are in the form of timeshare of the resource flow reflecting the principle of sharing existing supplies and shortages according to the water flow rate, allowing handling the uncertainty of water flow. The structural design of the Falaj's main channels grants the priority to use water for domestic purposes. The total dependence of domestic users on Falaj flow boosts the volunteering of community members to restore the water flow if interrupted in case of collapse of the channels. This contributes to the sustainability of the system by speeding up the repair and cuts labor costs in cases of big repairs since it is a win-win option. Users get the domestic water for free but they need to give hand to restore the system whenever needed.

The law maintained the existing seniority right through an exclusive zone surrounding the mother well to protect the Falaj ownership, since the aquifer source of groundwater is the same for both the Falaj and the wells. The system's sustainability depends extremely on the implementation of the seniority principle and groundwater abstraction regulation.

6.3.3 Reuse of Treated Wastewater

Haya Water is a semiprivate wastewater treatment company established in 2002. In 2014, the Omani Government assigned to Haya Water the responsibility of the development, execution, and management of wastewater facilities in the country, except the Governorate of Dhofar. Haya Water currently operates 57 sewage treatment plants at 44 different locations. Previously, Haya was responsible only for wastewater in Muscat and the MRMWR was in charge of the plants outside Muscat. Currently, the plants operated by Haya produce around 550,000 m^3/day of treated wastewater, and this volume is expected to increase to 660,000 m^3/day by 2020 as the number of connected houses to sewage network increases (Haya 2018).

In Muscat city, the amount of tertiary treated wastewater produced in 2017 reached 60 Mm^3, out of which 31 Mm^3 were recycled. Muscat Municipality buys 68% of the volume at a price of 0.100 OR/m^3 and uses it to irrigate public landscapes. So far citizens do not pay any municipal tax and Muscat Municipality is funded from the central government budget. This hinders the sustainable use of treated wastewater in the future given that the governmental funds depend heavily on nonrenewable oil income. The remaining uses are for industrial purposes or golf courses with varying prices. The agricultural uses of treated wastewater are negligible given the high price asked by Haya, far higher than the farmers' willingness to pay. The result is that 30 Mm^3 of high-quality tertiary treated wastewater end up in the sea while the country is under absolute water scarcity and a huge water deficit.

Zekri et al. (2016) estimated at 0.111 OR/m^3 the average farmers' willingness to pay for treated wastewater for irrigation. The study included both hobby and commercial farmers. Commercial farmers are willing to pay less than the average with 0.087 OR/m^3. Haya Water Company is demanding a price of 0.220 OR/m^3, which most of the farmers cannot afford as it is higher than their marginal benefit. Besides, treated wastewater is currently far more expensive than the groundwater open access resource, the cost of abstraction of which ranges between 0.005 and 0.023 OR/m^3. Under such conditions, the treated wastewater demand for agricultural purposes will be restricted only to hobby farmers who have seen their groundwater badly salinized.

On the other hand, households are charged an average price of 0.154 OR/m^3 far below the cost of treatment estimated at around 0.800 OR/m^3 for the city of Muscat. Haya owns the treated wastewater and sells part of it to cover partially the costs (19%). The difference between cost and revenue is covered by public subsidy estimated at 60% of the cost (Zekri et al. 2016).

Several policy changes are required to avoid the wasteful disposal of tertiary treated wastewater into the sea: (1) households and users should pay the full cost of the treatment, (2) groundwater quotas should be allocated to each user, (3) treated wastewater price should take into account the farmers' willingness to pay, and (4) considering artificial aquifers' recharge, using treated wastewater, similarly to the public investments in recharge dams. During the period 1990–2010 all the recharge dams allowed to capture variable quantities ranging from 122 Mm^3 in 2007 to 3.2 Mm^3 in 2008 with an average of 50 Mm^3/year. Aquifer storage and recovery of treated wastewater is independent from rainfall variability and produces reliable volumes annually (Al-Maktoumi et al. 2016). Recharge using treated wastewater might be less costly than the recharge via dams estimated at 0.300 OR/m^3, depending on the distance between the source and the aquifer. This will entail allocating certain aquifers to agricultural uses exclusively given the quality of injection water. El-Rawy et al. (2018) evaluated the impact of managed aquifer recharge using treated wastewater in a coastal aquifer. They found that Net Benefit Investment Ratio can reach up to 3.18 if the injection takes place within a limit of 1 km from the water source.

6.3.4 Pricing

Groundwater is mainly extracted through Aflaj and wells. Groundwater is a free access resource in Oman. Farmers based on individual wells pay only the cost of the wells, pumps, and electricity for abstraction. In Aflaj, water markets among farmers prevail. Marginal prices of water in Aflaj vary from year to year, between seasons, and among Aflaj. Zekri et al. (2006) reported marginal prices in the range of 0.005–0.025 OR/m^3.

Domestic water prices are in the form of two block tariff (0.440 OR/m^3 for consumption of less than 23 m^3/month and 0.550 OR/m^3 above). These prices have not changed since the year 1980, even though the second block was instituted in year 2000. Prices are uniform through all the country. Most urban water is desalinated seawater. According to the Public Authority for Electricity and Water (2016), the subsidy covers 2/3 of the water cost and is estimated at OR 186 million/year. Prices for commercial and governmental uses have been revised in 2016 and established at 0.780 OR/m^3 as one block tariff. The prices of water are still far below the average cost of production plus distribution estimated at 1.550 OR/m^3. The low prices to domestic and industrial users do not encourage users to save water or adopt water saving/recycling technologies. In fact, domestic water consumption in Oman is on the high side with 200 L/cap/day. Kotagama et al. (2016) found that the price elasticity of water for residents in villas is high and is −2.10 due to the outdoor uses. The authors highlighted the possibility of managing water demand in Muscat through modifying the price of water and reforming subsidies for domestic users. The protection of vulnerable sectors in the community is the main argument of keeping the domestic water and electricity prices at a low level (PAEW 2016). There are several international experiences where prices have been increased without hurting the low income households. Even the Omani experience of fuel price increases is a successful one that could be mimicked for the water sector. Since 2018, users are paying the full cost of fuel with a protection of the low income households, earning less than 600 OR/month. The subsidy is allocated using an electronic card to access fuel up to 200 L/month at a subsidized price. The fuel subsidy is now targeted exclusively to the low income households. Furthermore, Oman has also started a price policy reform in the electricity sector for large users. The new price scheme is Cost-Reflective Tariff intended to reduce the high-cost peak generation and additional investment for network. On the same line, there has been an increase in the price of water sold to both governmental and commercial sectors in 2016 as an initial step of performing the full cost recovery from both sectors. Introducing new pricing methods such as the uniform price with rebate or the more detailed method of the allocation-based pricing that takes into account the family size and the outdoor uses (Baerenklau et al. 2014) can help avoid the reform rejection by low income users.

6.3.5 Irrigation Efficiency

Wichelns (2014) affirms that "*In cases in which water is limiting, relative to land, the profit-maximizing solution will be the same as that which maximizes the average productivity of water*." Surface or flood irrigation is the dominant irrigation system in Oman. The adoption of modern irrigation systems (sprinkler, drip, bubbler) increased from 6% in 1993 to 39.2% in 2013 as shown in Table 6.3. Despite the increased use of modern irrigation system, the abstraction from the aquifers has not been reduced. The main reason for this is the fact that groundwater is an open access resource and farmers pay only the cost of abstraction. The last column of Table 6.3 shows that the cropped area observed an increase of 16% during the period 2005–2013. In general, farmers who introduce modern irrigation systems tend to extend their cropped areas and/or further intensify the existing activities. The result is an improvement of water use efficiency without any water saving at the aquifer level. Farmers abstract water until the marginal cost of abstraction is equal to the

Table 6.3 Evolution of the area covered by MIS during the period 1992–2013 in Feddan

	Plantations	Vegetables	Field crops	Forage crops	Total crops under MIS	% cropped area using MIS	Total cropped area
Agr. Census 1992/1993	2440	1776	291	4326	8833	6.00	146,515
Agr. Census 2004/2005	5368	6384	1179	16,098	29,030	20.70	140,118
Agr. Census 2012/2013	11,913	22,286	2823	26,902	63,925	39.20	163,045
Rate of change 1992/2005	120%	259%	305%	272%	229%		−4%
Rate of change 2006/2013	122%	249%	139%	67%	120%		16%

Source: Agricultural Census 1992–93, MAF 2004, and 2012–2013

marginal benefit subject to the well daily yield. This is further aggravated by the fact that the abstraction cost is also artificially low given the 2/3 subsidy of electricity prices. Since aquifers are an open access resource, farmers have no incentives to save water. They are rather interested in increasing production to maximize profit. There is no warranty that the saved volume of water will remain available to them given the absence of ownership, the absence of a pricing scheme, and low abstraction cost. Farmers equipped with modern irrigation systems tend to crop the area irrigated even in summer, which is only possible, under a hot climate, with a modern irrigation system given the very high summer temperatures. The data shown here is evidence that the investment in modern irrigation systems alone is not sufficient to stop the over-abstraction of groundwater. A proper monitoring of groundwater abstraction via the allocation of water quotas should be put in place to ensure the sustainability of agriculture in the future. Only after allocation of quotas can the modern irrigation systems lead to tangible water saving. The attribution of subsidy for the adoption of modern irrigation systems, thus, should be linked to real water saving if monitoring of the aquifers is implemented.

6.3.6 Research

The main research in the water sector is undertaken in Sultan Qaboos University and the research center under MAF with either internal funding or national funding from The Research Center, MAF, and MRMWR. Very limited and sporadic international funding through the Network of Water Research Centers was obtained. The main areas of research are on groundwater hydrogeology, groundwater management and governance, treated wastewater technology and reuse, irrigation technology, and efficiency. Some intents of research on smart irrigation have been observed but still not in the phase of transfer to the farm level. More applied research to the needs of the sector should be funded to help devise optimal solutions to the challenges faced by the water sector. Continuity of funding is a major requirement to bring both institutional and technological innovations.

6.3.7 Food Security Versus Virtual Water/Food Imports

The increase of groundwater salinity and depletion of aquifers are the major threats to the agricultural production (Zekri 2008, 2009; MAF 2012). The cropping pattern in Oman is shown in Fig. 6.3. Fruit trees such as dates, banana, lime, and mango cover about 53% of the total cropped area. Date palms occupy 80% of the area under fruit trees. More than 95% of the fruit trees are of local varieties with poor quality and low yield. Current cereal production is very limited for a niche market. Most vegetables are consumed locally. Export of vegetables is limited to the United Arab Emirates or to a niche market in Japan by a few large vegetable producing companies. Oman meets 80% of its food demand by import, with 100% of rice and 95% of wheat imported (FAO 2016) and achieved 78% self-sufficiency in vegetables and 42% in fruits. Figure 6.4 shows the rate of self-sufficiency for 2016. 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.

6.3.8 Water Salinity/Other Pollution Problems

Groundwater pollutants can be classified as chemical and biological pollutants. The most known biological pollutant is the Coliform bacteria, which is attributed to animal and human waste. Several aquifers used for domestic purposes in remote rural areas are affected by biological pollutants due to the unsafe use of sceptic

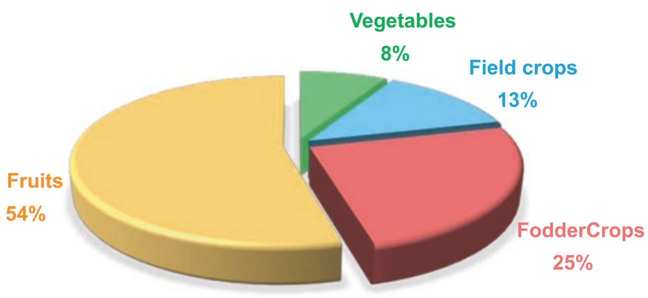

Fig. 6.3 Cropping Pattern. (Source: MAF 2013)

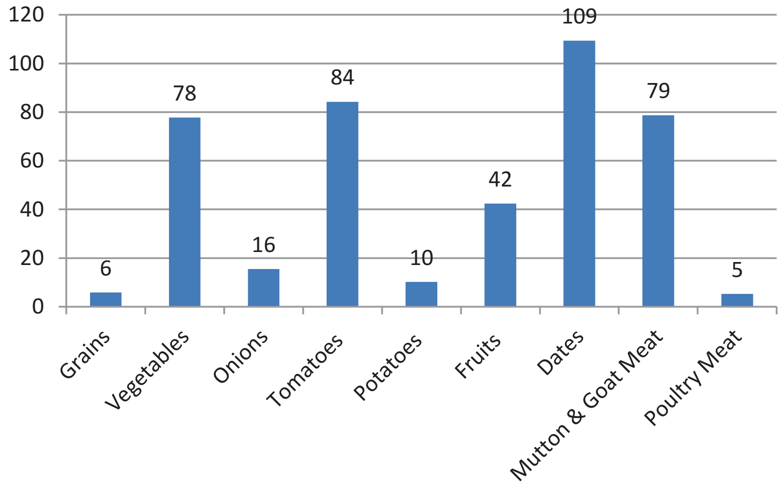

Fig. 6.4 Self-sufficiency ratio of major agricultural products. (Source: FAO 2016)

tanks. Organic pollutants are those related to hydrocarbon chemicals. Oil companies are required to treat all the oil-produced water before injecting it to the ground again or disposing on the surface. The use of fertilizers and pesticides by farmers percolates and reaches groundwater. However, the main source of pollution of coastal aquifers in Oman is the seawater intrusion.

6.4 Urban Water

The two main sources of urban water in Oman are the desalination water provided by large desalination plants and covers 80% of total needs of potable water and public wells, which are connected to the main transmission system network and cover 15%. Other wells such as single or small groups of wells supply water for the scattered houses particularly in rural areas. The remaining 5% of total potable water is covered by small desalination plants and small local distribution network system (PAEW 2016). Currently Oman produces around 1 Mm^3/day of desalinated seawater.

To cover the increased demand of water the government relies on a supply policy based on increasing the number of the large desalination plants or expanding the capacity of existing ones. Earlier the small desalination plants were owned by the Public Authority for Electricity and Water and the electricity was produced at the same site. Recently the Public Authority for Electricity and Water adopted a new policy of "Build Own Operate" in which the desalinated water is purchased from the private sector, which resulted in substantial savings (PAEW 2016). The groundwater extracted from wells is used during peak demand periods and covers 15% of the total water in the large transmission networks (PAEW 2016).

The fundamental element to improve the efficiency of the distribution system is the control of the 30% unaccounted for water or nonrevenue water. Water enters the system from several sources, wells and desalination plants, and is then transferred and distributed through pipe network. Recently, the PAEW installed pressure mitigation valves to regulate the pressure in the network expecting substantial reduction in the leakages.

One major problem related to urban water in countries heavily dependent on desalination is water security. Desalination plants are exposed to risks when seawater intake is polluted by harmful algae bloom, oil spills, or by mechanical failures. One of the options to improve water security is to inject desalinated water in excess of supply during winter low demand periods in close by aquifers. Zekri et al. (2019) estimated that up to 8.4 Mm^3/year of excess winter water can be stored and would serve for emergency as well as pick demand period. The expected potential net benefit of storage and recovery is around $ 17.80 million/year.

6.5 Water and the Environment

The availability of fresh water relies on the function of healthy ecosystems while water balance through water cycle is essential to achieving sustainable water management. Oman produces 4% of the global seawater desalination capacity (Lattemann and Hooepner 2008). The desalination of seawater provides socioeconomic and environmental benefits by supplying unlimited and sustained high-quality potable water, but at the same time, multiple concerns arise as a result of the disposal of the concentrate and chemicals. The discharge of these chemicals and reject brine can lead to water quality degradation, affect the marine system, and increase air pollution through greenhouse gas emissions. Therefore, an integrated management on a regional scale is a necessity to regulate the use of water resources and the various desalination technologies in a sustainable way.

The Ministerial Decision 159/2005 regulates the discharges of reject brine from coastal desalination plants (MRMEWR 2005). Oman has adopted different types of brine discharge, including nonenvironmentally friendly methods such as discharge to infiltration manhole units and surface discharge or lined and unlined evaporation ponds. Desalination plants, which are mainly located in coastal areas, rely on discharging brine to the ocean. The maximum capacity of marine outfall system is estimated at 122,000 m^3/h in order to mix discharge brine with the cooling water from the power generation plants. The brine is usually disposed of with outfall pipes in the sea of a length ranging between 650 and 1200 m. In some of the plants, multiport diffusers are installed as an engineering solution to rapidly dilute the discharged brine (Al-Barwani and Purnama 2011; Purnama 2011). In general, the temperature and concentration of brine are within the Omani regulations and regulatory mixing zone of 150 m radius from the outfall, which is below the maximum permissible limits set (above the surroundings by 1 °C and 2 ppt) (Bleninger and Jirka 2010). However, some damage to large coral reef areas at the bottom of the sea, which was close to the outflow, is observed in Sur where brine disposal is undertaken through an open sea pipe near to the shoreline (Bashitialshaaer 2016).

6.6 Energy–Water Nexus

Water and energy are intimately linked. So far, fossil fuels (natural gas and oil) are the unique source of energy for desalination and water operations in Oman as well as groundwater abstraction and irrigation. While depending on fossil fuel to operate the desalination plants, a loss of opportunity for revenue from exporting hydrocarbon fuel is observed. The analysis of natural gas used between 2000 and 2011 shows that power and water production uses almost 1/5 of the total uses as shown in Fig. 6.5.

The Ministry of Oil and Gas provides natural gas for power generation and associated water production. The introduction of new efficient power plants enhanced the efficiency of natural gas use for water and power production. As a result, the annual amount of gas utilized has decreased at a rate of 4.8% during the period 2010–2016 (OPWP 2016) while the volumes of desalinated water kept increasing, as shown in Figs. 6.6 and 6.7. This is a good indicator of a better management of the

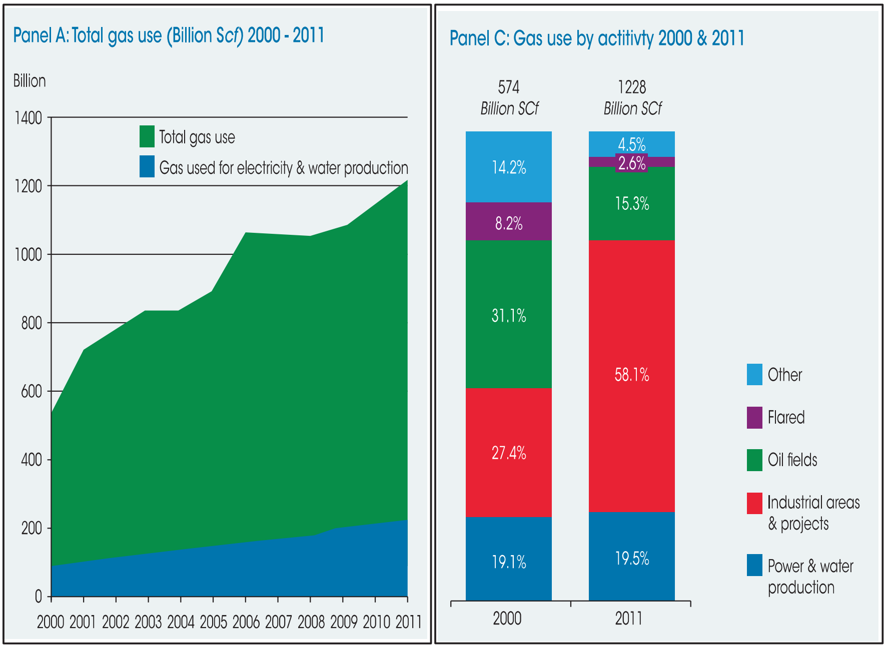

Fig. 6.5 Analysis of natural gas use in Oman 2000–2011. (Source: IRENA 2014)

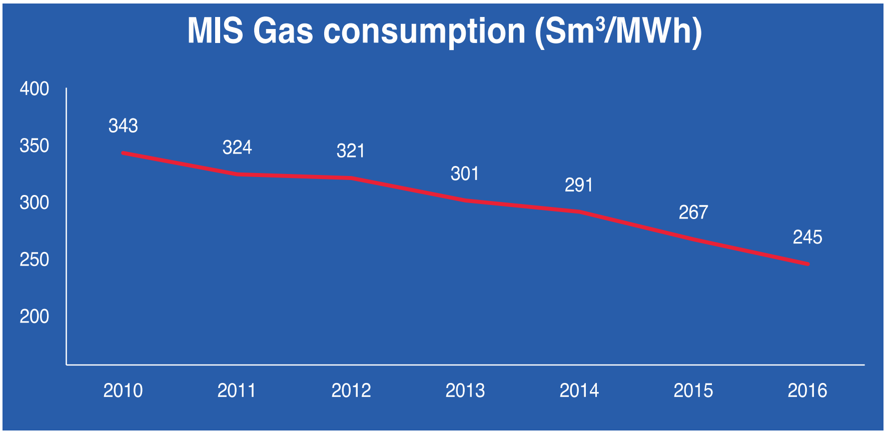

Fig. 6.6 Gas consumption for energy production decrease from 2010 to 2016. (Source: OPWP annual report 2016)

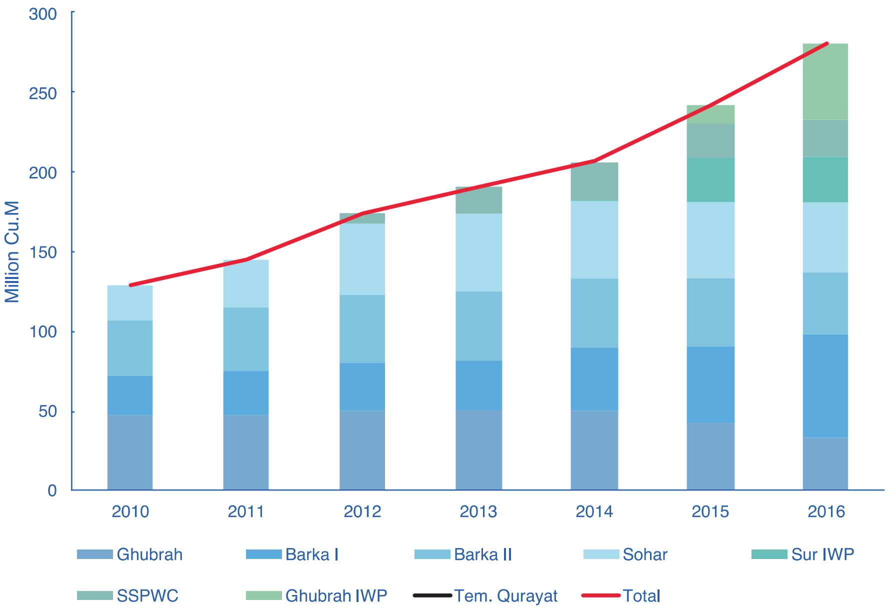

Fig. 6.7 Freshwater purchased by the PAEW from 2010 to 2016. (Source: OPWP annual report 2016)

nonrenewable resources. Oman's natural gas recoverable reserves are estimated at 20 years according to the World Energy Council. Oman is currently a net exporter of natural gas. However, given the increased domestic demand, the country decided to divert gas exports back toward domestic consumption by 2024 (https://www.worldenergy.org/data/resources/country/oman/gas/, 2018).

The move toward the use of renewable energy for water and energy production is on the agenda. Even though Oman meets substantial challenges related to water and energy security it can still use the current wealth of fossil fuels to move forward the essential transitions to assure long-term security of water, energy, and food. Oman plans to reach 10% of its energy from renewable energy by 2020 (IRENA 2015). OPWP expects solar energy projects to supplement hydrocarbon fuel generation in the near future. In the short run, nonrenewable energy is the only source to develop new capacity of power and desalination to meet the peak demand (International Water Summit 2018). It is expected that the introduction of renewable sources of energy will allow a potential reduction of 8% in water use for power generation in Oman by 2030 (IRENA 2015).

6.7 Conclusions

A collective of governmental and nongovernmental administrations are responsible for regulating the water sector in Oman, with each organization being liable for specific tasks. Although the responsibilities are scattered among these entities, often the concerned organizations are consulted and their members are called to sit in committees and participate in the decision-making process. The expected further development of E-government will provide better access and exchange of information among ministries and organizations, which will likely result in improved coordination and sounder decisions. However, given the "private" type of management of some of the water utilities (PAEW, Haya) involved in the sector, often each organization is looking for its own interest that does not necessarily coincide with the national interest and the economic benefit rather than the financial benefit.

Oman as an arid country faces real water challenges given that already the current demand exceeds the supply. The agricultural sector depends totally on groundwater, while natural groundwater recharge rate is very low. The excessive uncontrolled abstraction of groundwater threatens the future generations and causes groundwater salinization through the intrusion of seawater. Around 83% of groundwater is used for crop irrigation. Salinity and water scarcity are the major threats for the agricultural sector. Oman has achieved 78% self-sufficiency in vegetables and 42% in fruits and meets 80% of its food demands by import. The Sultanate's dependence on food imports is expected to increase considerably in the future, given the high population growth (due partly to immigration) and the very limited water resources that do not allow any expansion in irrigation. However, irrigation efficiency and better farmers' organization can increase the rates of self-sufficiency in vegetables and food balance.

The traditional Aflaj systems play a significant role in irrigation efficiency. The water turn depends on timeshare formal water rights. The active millenarian water markets in Aflaj organize the transfer of water to the users who are willing to pay higher prices than others and thus efficiency is guaranteed. In times of drought the markets allow the plantations to be given priority while producers of other annual crops get compensated partially through the market if they sell their water shares. With the presence of the traditional water markets, drought periods are managed smoothly and without conflicts. Besides, the horizontal channels of Aflaj do not put any stress on the aquifers and thus farmers accommodate with the renewable part of the groundwater.

Treated wastewater can become an alternative source for irrigation if the required policy changes of groundwater quota allocation, cost recovery of the treatment, and establishment are implemented.

Desalination plants provide most of the water for urban purposes. The main concern related to desalination is the high cost of freshwater production and the disposal of brine by an environmentally friendly method. Desalinated water supply is expected to increase to cover the rapid increase in urban demand. All desalination plants in Oman are operated using natural gas. Currently, water desalination and power generation use around 20% of total natural gas. In the long run, the authorities are planning for solar energy projects to supplement hydrocarbon fuel generation.

To face the challenges, several reforms are needed and are multifaceted. The top 10 required reforms are (1) to allocate groundwater quotas by user capitalizing from the traditional Falaj knowledge; (2) to professionalize the agricultural sector by requiring qualifications for the expatriate workers in line with what is applied in the health sector; (3) to open up international markets for Omani vegetables that are produced during the winter season; (4) to improve the irrigation efficiency at farm level and explore the introduction of smart irrigation; (5) to encourage the production of vegetables instead of the high water demanding crops such as forage and dates, which can be achieved by banning the production of forages at least in the coastal areas; (6) to stop export of forages and dates from Oman, which will allow saving 60 Mm^3/year; (7) to improve urban water security by storing excess desalinated water for emergency and peak demand periods; (8) to increase domestic water prices to reduce waste and encourage water saving technologies and reuse of graywater for outdoor purposes; (9) to achieve cost recovery of treated wastewater; and (10) to recharge some of the aquifers with treated wastewater instead of losing to the sea.

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