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Comparative analysis of economic and institutional aspects of desalination for agriculture in the Sultanate of Oman and Spain

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ABSTRACT

Water availability is the most critical component for sustaining agriculture in the Sultanate of Oman. Farmers along the coastal strip of AlBatinah region started using small desalination units to supply of good-quality irrigation water from brackish groundwater aquifers. We conducted a research project aiming to explore different aspects of the use of desalination technology for agriculture in the country. Economic and institutional constraints of desalination for agriculture in Oman were explored and compared with the leading experience of Spain. The study revealed that desalinated water in Oman is exclusively used to irrigate low-income field crops. Despite the energy subsidy in Oman, current agricultural practices and economic returns make the desalination technology an expensive option for providing irrigation water. Moreover, none of the farmers are following the regulations that outline the nature of use of small desalination units set by the Omani governmental agencies. On the contrary, there is no exclusive use of desalinated water for irrigation in Spain. Spanish farmers mix it with low-quality surface and ground water in efforts to reduce the cost of desalination. Farmers own the desalination plants and their agriculture is practiced within their organized societies to compete with local and international markets. The Spanish government has clear institutional framework that defines the use of desalination for agriculture. Given the current situation of agricultural desalination in Oman, we are suggesting considering alternative sources of water for irrigation. However, such sources will not be feasible unless agricultural practices are managed through more efficient practices of irrigation schemes.

Keywords: Oman; Spain; AlBatinah; Almeria; Desalination; Irrigation; Soil; Salinity; Seawater intrusion

1. Introduction

The Sultanate of Oman is an arid country with an average rainfall rate of 100 mm/y [1], and a population of 4.6 million [2]. Population growth, rapid development in services and infrastructure and improvements of life quality resulted in substantial increase of water demand by all sectors. Despite its low contribution towards the national GDP (less than 1.2%), the agricultural sector in the Sultanate consumes about 90% of all groundwater resources [3].

The coastal strip of AlBatinah hosts the major agricultural activities in Oman. The cultivated area and production in AlBatinah have reached their peaks in the late 1990s, but started to decline subsequently [3]. About 5040 ha in AlBatinah were abandoned between 1997 and 2010 due to high levels of salinity of irrigation water and consequent salinization of soils [3]. Salinization of irrigation water is attributed to gradual contamination of coastal aquifers from seawater due to over pumping. Al Barwani and Helmi [4] reported that groundwater salinity along the strip ranges between 10,000 and 30,000 ppm. This significantly ruined the quality of irrigation water and, hence, agricultural soils. The

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salinity of soil and water resources resulted in limiting the variety of crops to be grown. Affected farmers have given up growing high-value vegetables and fruits and replaced them with less productive date palms and forages, which consume more water and have low economic returns.

The above discussion clearly indicates that the availability of water, in terms of quantity and quality, is the limiting factor for development and sustainability of agriculture in AlBatinah coastal strip. In efforts of sustain their agricultural practices, many farmers are currently using small, reverse-osmosis (RO) based, desalination units for irrigation water [5]. Despite the associated constraints, many countries around the world are using the desalination technology for producing irrigation water; such as Spain, Australia, Chile, USA, Italy, and several countries in the Arabia Peninsula [6]. Vietnam, despite being a tropical country, is desalinating brackish river water for rice production [7]. Spain is the leading country for adopting desalination for agriculture, where 22% of its desalination capacity is utilized for irrigation purposes [8]. At the global level, only 2% of desalinated water is used for agricultural purposes [9]. The main advantage of desalination for agriculture is the assured supply of water of desired quality all around the year. However, many economic and environmental challenges hinder the adoption of the technology for agriculture. Given the current economic circumstances in the Sultanate of Oman, there is a need to evaluate the suitability of desalination technology for agricultural sustainability in the country. The objective of this study is to evaluate the suitability of desalination technology for agriculture in Oman within the context of economic and institutional constraints. The current situation of Oman is compared with the world-leading experience of Spain.

2. Aspects of desalination technology for agriculture

Assessment of the appropriateness of a desalination technology for agriculture is based on the net economic returns of agricultural products as well as environmental costs. Therefore, the feasibility of the technology for agriculture in Oman should be explored on such concerns. Burn et al. [6] provided a detailed analysis of desalination technologies available for agriculture, including reverse osmosis (RO), nanofiltration (NF), electrodialysis (ED), electrodialysis reversal (EDR), and multistage distillation (MSD). Other technologies, such as membrane distillation (MD), are either at advanced stages of development or are about to be commercialized. The choice of technology depends on the quality of feed water and desired quality of product water, capital costs, operation and maintenance (O&M) costs, energy costs, and expected net returns of agricultural produce. Given energy-saving efficiency and amounts of water produced, Burn et al. [6] identified the RO technology as the most suitable technology for agriculture. The RO desalination of brackish water requires approximately one third of energy used for seawater desalination [10]. Compared to 4 kWh/m^3 energy requirements for seawater desalination, inland RO desalination plant for agriculture in Cuevas de Almanzora (Almeria, Spain) uses about 0.9 kWh/m^3 for brackish water [11]. Moreover, renewable solar energy, can be utilized to operate the RO desalination process. Farmers in the Sultanate of Oman, and in neighboring countries, will not consider the use of renewable energy due to the current energy subsidy rates [12]. Burn et al. [6] indicated that even the use of RO technology with energy-recovery turbochargers, desalination technology can be an expensive option for agriculture. Farmers, however, can still make a profit by adopting intensive horticulture of high-value fruits, vegetables, and ornamentals.

Currently, hundreds of farmers in AlBatinah are using small, RO based, desalination units to produce irrigation water (personal communications with unit vendors). The waste product, i.e. brine, from their RO membranes is about 55% of feed water. Inland RO desalination requires disposal of brine through an environmentally sound procedure. Therefore, brine disposal is a challenge for inland RO desalination and adds an extra cost to the overall O&M costs. Another challenge is the increase of salinity of brackish water with time, which implies that cost of desalination increases as the salinity level increases [11]. Other issues related to the RO technology are the fouling of membranes and presence of boron (B) in brackish water. Boron is toxic to most fruits and vegetables at concentrations above 0.5 ppm. Removal of B ions requires special procedures (second pass RO, ionic exchange, etc.) at an extra cost. Molina et al. [11] cited that the RO plant in Cuevas de Almanzora did not require replacement of its RO membranes for the last eleven years and boron levels are below the toxicity level; i.e. < 0.5 ppm.

3. Desalination costs of brackish water

Desalination costs around the world vary considerably and depend on the plant size, energy costs, quality of feed and product waters, and proximity of the plant from intake sources. Obviously, cost of desalination is lower for large desalination plant (i.e., economy of scale) and may reach as low as US$ 0.5/m^3 [13]. Burn et al. [6] indicated that the cost of energy for the RO technology represents 30–50% of the total cost of desalination process. Most of the energy is used to generate the RO pressure to remove dissolved salts through the membranes. Despite that energy requirements have been reduced by a factor of five (or more) in the last 40 years, the technology is currently close to the thermodynamic limit and it is becoming increasingly difficult to further reduce energy consumption below current values [14].

4. Desalination for agriculture in Spain

The cost of desalination of brackish water for agriculture in Spain is optimized through the utilization of pricing schemes for energy. Spain has six pricing schemes depending on time of the day, week, and year. The desalination plants for agriculture are operated during the low-demand periods that correspond to the lowest price scheme. Furthermore, desalination costs in Spain are reduced further by mixing desalinated water with other sources of water, such as low-quality surface and groundwaters. Energy-pricing schemes do not exist in the Arabian Gulf countries. Furthermore, energy is subsidized in Oman and farmers pay only 30% of the actual cost [15].

Desalination for agriculture in Spain is mainly practiced in the provinces of Almeria, Murcia, and south of Alicante, where the agricultural industry is one of the main economic pillars. In Almeria, for example, agriculture represents nearly 20% of the local economy and 5% of Spain [8]. The Canary Islands use the RO and EDR desalination technologies. The EDR plants are more efficient in removing silica that is present in brackish water from dissolution of volcanic rocks. Groundwater in such areas is brackish with an electrical conductivity (EC) ranging from 3.5 to 8 dS/m (2,300 to 5,400 ppm). Farmers of these regions in early 1990s started installing small RO desalination units for producing irrigation water [8]. They used to dispose reject water (i.e., brines) from the RO units into aquifers through old wells or surface water pathways. The Spanish government built in 1997 a network of pipelines to collect brines from almost all farms in the Campo de Cartagena area (Murcia). This was an effort to protect the environment, especially the national reserve lagoon of Mar Menor, from eutrophication. Due to difficulty of brine disposal, small RO units were abandoned, and efforts were made towards building centralized medium RO desalination plants to serve the growing community of farmers.

4.1. Nijar Brackish Water RO (BRWO) desalination plant, Almeria

The farmers' association of Nijar in Almeria was the first community in Spain to build a desalination plant for irrigation purposes. The drop of water table to critical levels and the increase of salinity of groundwater forced the farmers to consider this option to sustain their agricultural activities. The project started in 1999 and completed in 2003 with a capacity of 25,000 m^3/d. The cost of the project is € 12.2 million (about US$ 14 million) with 50% subsidy provided by the local government of Andalusia. In addition to the BRWO plant, the project included construction of seven emergency and regulation storage reservoirs and 700 km of pipelines with a SCADA system up to the farms. The plant operates at one-third capacity and serves 2,400 farmers in the Nijar area for a total irrigtated area of 8,400 hectares (ha). On average, a hectare requires 5,600 m^3 of water a year. The delivered desalinated water has an EC of 0.6–0.8 dS/m. Roofs of green and net houses at most of farms are designed to harvest rainwater so that collected water is mixed with the desalinated water. Farmers also mix desalinated water with surface and ground water in efforts to minimize the overall costs of irrigation water. Therefore, there is no exclusive use of desalinated water for irrigation; with only 30–40% of water demand is desalinated water. The main crops grown in the area are tomato, lettuce, cucumber, capsicum and melons. Farmers sell their produce via auction markets or to the corporative.

The project capital cost is financed over a period of fifty years with a government collateral. Therefore, the project is still owned by the government and will be reverted to the farmers' association after all payments are made. Each farmer pays a fixed price for water rights and delivery to his/her farm's gate. The water right and delivery costs are paid once a year and start at € 60/ha in 2006 and currently is about € 1500/ha for a steady pumping rate of about 1 m^3/h. The current overall cost of desalination is at € 0.525/m^3, which covers costs of tax, desalination, pumping, and O&M. Depending on depth of water table, the cost of groundwater pumping is estimated at € 0.25/m^3 in this region. Because of water mixing, the farmers have full control of the quality of their irrigation water. Ratios of water mixing is done according to the type of crop, the variety, cropping cycle and season. The average cost to farmers of the mixed conjunctive water is around € 0.39/m^3 and with an estimated EC of 1.5–3 dS/m.

The farmers' association in 2000 signed an agreement with the Ministry of Agriculture that regulates the price of water for the farmers. The agreement sets the price of water based on the full capacity of the desalination plant with no clause for reconsideration. Therefore, the farmers are paying a price that is less than the actual cost of desalination because the plant is running at one third of its capacity. This indirect subsidy is estimated at € 0.10/m^3. The subsidy is justified by the fact that the water level and quality of the aquifer at the farming sites are improving. This is considered an investment for the future generations in the region. Therefore, the subsidy benefits current and future generations of the community and sustains agriculture as well as job opportunities. This model of water distribution and administration allows water billing on monthly basis, which is practiced by the association. Late payments are negotiated pending farmers' commitment towards payment schemes. Moreover, the SCADA system allows monitoring the whole network for possible meter defects, leakages, and fraudulent farmers.

4.2. Cuevas de Almanzora brackish water RO (BWRO) desalination plant, Almeria

The second case study is the BWRO plant in the Cuevas de Almanzora, Almeria. Similar to the first case study, the farmers' society of Cuevas de Almanzora owns the project that commenced operation in 2002. The plant's capacity is 30,000 m^3/d with an expansion option to double the capacity. The plant is currently in partial execution with options under study to include new seawater trains. The plant is equipped with RO membranes to accommodate varying salinity levels up to seawater (i.e., up to 35,000 ppm). The plant serves 1,800 farmers with a total cultivated area of about 5,800 ha. Desalinated water is mixed with brackish groundwater, and low quality surface water that is delivered from nearby river basins of Guadalquivir and Tajo-Segura. Irrigation water that is delivered to the farmers is a mixed one, with about 30% desalinated water. Therefore, there is no exclusive use of desalinated water for irrigation in these areas. The salinity of delivered water varies during the growing season, and water mixing procedure takes into account the available volumes of water from the different sources and desired quality set by the farmers' association according to the type of crop and growing stage.

The plant is operated at variable rates between 40–60% of its capacity. The association buys the mixed water for a price of € 0.33/m^3 and pays the monthly electricity bill of the plant that is estimated at € 23,000 on average. The total volume of water distributed to the farmers is around 19 million cubic meter per year (Mm^3/y). The costs of water from the Guadalquivir River and the low-quality water from Tajo-Segura are about € 0.30 and € 0.10/m^3, respectively. Moreover, the pumping cost of brackish groundwater, which is used for mixing with desalinated water, is about € 0.08/m^3. In addition to this, farmers pay a fixed cost of € 20/ha/y. The total investment cost of the desalination plant plus piping and reservoirs is € 12.2 million. The cost includes the desalination plant, pumping wells for the plant, brine discharge, pumping station and in situ storage pond. Other reservoirs and pipe networks were undertaken prior to construction of this project. The Andalusia Regional Government provides 50% of the investment cost as a subsidy.

Farmers in this area have good farming experience in greenhouse and open-field environments. Main products are citrus, watermelons, and high-value tomato varieties. Most farmers sell their produce to the same corporative, which collects the produce at the farm gate. The cooperative pays the farmers the average of wholesale price on weekly basis. Farmers usually make high yields that cover the relatively high cost of delivered water. For instance, tomato yields are between 130 and 140 ton/ha; and watermelons' yield are between 80 and 90 ton/ha. On average, the production of vegetables in greenhouses reaches 15 kg/m^2. The water cost per hectare is estimated at € 2,500/y, which farmers believe that it constitute 4% of the total production costs. Although the farms are small in size, farmers are fully engaged in the agricultural production that constitutes their main and unique activity. Farmers hire labor on part-time basis at the peaks of the seasons. Labor cost, according to the framers, accounts for 50% of the total production cost per hectare.

Corporates that own with hydroponic greenhouses is another experience in the region that use "mixed" desalinated water for irrigation. High-value leafy vegetables and strawberries are grown in such fully automated hydroponic systems. Irrigation water is more efficiently used in this closed systems. Solar panels provide required energy for running the hydroponic system and greenhouses. Despite all the constraints for the installation of desalination plants and associated costs, some groups of large industrial farmers and end users are currently beginning the formalities for the construction of one to two large desalination plants in Murcia/Almeria regions.

5. Desalination for agriculture in the Sultanate of Oman

We conducted a survey to assess the extent of the adoption of desalination technology for agricultural purposes along AlBatinah coast in Oman. Fifty farms were visited in coordination with some vendors of desalination units in the country. The survey explore many aspects related to the subject, among which are the economic indicators. We are presenting part of economic and institutional findings of the research work. Farm visits revealed that farmers have introduced small RO units in their farms to sustain their current agricultural practices. Table 1 presents the major crops that are irrigated with desalinated water as a percent from all surveyed farms. Table 1 indicates that most farmers are utilizing desalinated water for irrigating field crops. Only 20% of participated farms had greenhouses where "classical" crops, such as cucumber and tomatoes, are grown. With such low-income field crops, results clearly indicate that farmers are not business oriented and most farms are meant to sustain existing agricultural practices among other purposes. Upon securing a new source of fresh water, farmers moved forward to add more facilities to their farms; mainly residential buildings (small resorts and/or swimming pools) or animal-raising facilities.

Table 1
Major field crops grown with desalinated water and cost comparison of irrigation of water in Oman

Major crops (% of surveyed farms)		Cost of irrigation water in Oman (US $/m^3)	
Crop	%	Source	Cost
Date palm	80	Desalination without subsidy	0.65
Lemon	60	Desalination with subsidy	0.55
Forages	60	Well water	0.03
Mango	20	Falaj water	0.13

The survey included economic indicators to estimate the cost of desalination using small size RO units. Indicators are capital costs, costs of operation and maintenance (O&M), energy requirements, life span of unit and membranes, spare parts; among others. Some of information are collected from the vendors of the units as well. The economic analysis assumed that the life span of the unit is five years with an interest rate of 5%. The RO membranes are changed every 2.5 y, and the O&M costs include the cost of chemicals, filters and energy as well as the cost of groundwater pumping. The price of electricity is subsidized in the Sultanate and our analysis here is based on energy requirements and average operating hours of units [15]. All farms have permanent employees who do the routine maintenance of the desalination unit among other agricultural activities. Therefore, labor cost is not accounted for here. Moreover, the cost of brine disposal is not included in the analysis. Economic analysis shows that, depending on unit size, the cost of desalination ranges between US$ 0.46–1.32/m^3 with an average of US$ 0.55/m^3. The analysis is based on the average irrigated area of visited farms, which is about 0.7 hectares (ha), and irrigation water requirements that is based on annual potential evapotranspiration (ET) of the region (about 22,700 m^3/ha; [3]). Therefore, the cost of desalination for agriculture is estimated at US$ 8,700/ha in AlBatinah. The survey showed that the capital cost accounts for 77% of total costs of desalination for agriculture in Oman. The O&M cost is 8% only. Energy cost is 16%; which is, due to subsidy, very low when compared with the international standards that is about 30–50% [6].

Table 1 also compares the cost of desalination using small-size units with the conventional water sources for irrigation in the Sultanate of Oman. Groundwater is the main source for irrigation in Oman. It is extracted from private wells or through the Falaj collective gravity system. The Falaj water system is an ancient system composed of a horizontal well, where water is drawn from aquifers by gravity. Water is conveyed to the irrigated lands via open channels [16]. The Falaj irrigation system has water markets and its average price is about US$ 0.13/m^3 [17]. Water pumped from private wells is the cheapest with an average price of US$ 0.03/m^3 [17]. The annual desalinated volumes per farm vary between 2,000 and 41,500 m^3/farm with an average of 13,000 m^3/farm. Compared with these two sources of irrigation water, desalinated water from small units costs twenty times high and is used for the almost the same crop mix. Such disparity in price of irrigation water is justified with current water quality along AlBatinah coast and spatial distribution of other sources of water.

6. Comparison of the Spanish and Omani experiences

6.1. Economic aspects

Desalination for agriculture is relatively a "new" option for sustaining the sector in the Sultanate of Oman. Therefore, economic and institutional/administrative indicators can be used to benchmark it against the leading world-user of the technology for agriculture; i.e., Spain. The cost of desalination from small units in Oman (without electricity subsidy = US$ 0.65/m^3) is 63% more expensive than what farmers are paying in Spain (US$ 0.40/m^3). Moreover, farmers in the Sultanate pay more for the water "bill" due to the fact that crop water requirements are higher than that of Spain for the surveyed crops (22,000 vs. 5,600 m^3/ha·y). While all farmers in Spain mix the desalinated water with other sources of low quality water, 78% of surveyed farmers in Oman exclusively use desalinated water to irrigate low-value crops. All these factors contribute to make farming with desalinated water much less profitable than in Spain. Moreover, Spain uses central desalination plants with high recovery rates compared to low rates from small units that are used in Oman. The "economy of scale" and high recovery rates greatly reduce the cost of desalination.

Water management and water-use efficiency are the other factors that make desalination option more attractive for agriculture in Almeria (Spain) compared to Oman. Highly skilled, full-time farmers are members of strong cooperatives that control most of the marketing chain for their agricultural products. The farmers use desalinated water to produce crops of high economic returns, such as ornamental and horticultural plants, fruits, and vegetables. Such crops are mainly exported to the European market with more than 400 million consumers with an estimated added value of water between US$ 1.25 to 6.70. On the contrary, most of farmers in Oman are low-skilled expatriates or locals where agriculture is their second activity. They are fragmented and non-organized farmers who are producing low-value crops such as low-quality dates and forages. They are selling their products to the narrow local market with difficulty to access the international market due to the absence of cooperatives, and facing competition for the same products from farmers pumping free available groundwater. The combination of size of the desalination plants in Spain (i.e., central, medium size), type of crop grown (high cash crops), and efficient water management schemes make the option of desalination for agriculture more attractive and competitive for farmers in Spain when compared with the situation in Oman.

6.2. Institutional aspects

The Ministry of Regional Municipalities and Water Resources of Oman (MRMWR) issued an order (numbered 4/2009) [18] that regulates the use of small desalination units for domestic (individual) use. The document outlines the conditions for the installation of the units, extent of use, extraction scheme of water, and means of disposal of brine. It points out that no individual can install a unit without a permit form MRMWR and the criteria for brine disposal is met. However, and according to our survey results, all farmers who own desalination units did not seek any installation permits nor constructed environmentally sound brine-disposal ponds.

The main Spanish legislation regulating the activity is the Royal Decree 1327/1995 (about seawater or brackish water desalination installations), which establishes the requirements for their authorization. The main regulatory challenges for the Spanish farmers using desalination are: the authorization for the construction of the desalination plant, declaration of environmental impact, permits for seawater intake or well authorization (for groundwater), and management of brines. The latter is the main constraint for installation and use of desalination units for agriculture. Desalination is also affected by the coastal law, the regional environmental regulations, uses of brackish water and wells and hydrological plans (Hydrological Basin responsibility), discharge limits, etc. Authorizations depend on different criteria (seawater/groundwater, size of the plant, etc.). There is a remarkable difference in procedures for granting installation permits and environmental requirements regarding desalination units for private and public sectors.

7. Conclusions

This research work discusses the option of desalination of brackish water for agricultural purposes in the Sultanate of Oman and compares it with the Spanish experience within the context of economic and institutional aspects. Case studies from Spain have a long tradition of holistic approach of the use of desalinated water for irrigation, although desalination cannot compete with cheap traditional water sources (transferred, groundwater, etc.) nor can it be used for low-value crops. Farmers' association in Spain own and manage desalination projects for irrigation. There is no exclusive use of desalinated water for irrigation in Spain. The use of desalinated water for irrigation is optimized within the context of economic consideration. Therefore, farmers in Spain are able to maximize net returns through well-defined marketing schemes. On the contrary, farmers in Oman use small desalination units to sustain low-income field crops. Therefore, the use of desalination technology in Oman is not yet feasible and decision makers must consider alternative sources of irrigation water and/or manage desalination option on central basis to maximize net returns and optimize groundwater abstraction to reduce detrimental effects of seawater intrusion into coastal aquifers. One option to reduce the costs of desalination for agriculture is to mix desalinated water with low quality groundwater and follow more efficient irrigation-deficit schemes to irrigate high-value crops. Zekri et al. [19] suggested artificial recharge of saline aquifers with tertiary treated wastewater and charge farmers a reasonable price for it. This option is probably more cost efficient and sustainable than desalination as it will require much less energy and will not add stress on the supply of electricity during summer months. This option requires further elaboration and cost/benefit analysis, which is not in the scope of this current work. Moreover, well injection schemes have other challenges that includes extent of aquifers, temporal rise of water tables, modification of aquifer hydrological properties, and residence time of injected water. Such challenges must be explored and cost/benefit analysis must be executed and compared with desalination option. Both countries (Oman and Spain) issued well defined regulations that regulate the terms of use of desalinated water for agriculture and disposal means of brines. However, not all requirements are met by the farmers in Oman when compared with those in Spain.

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