Irrigation and Salinisation: A Comparison of Traditional and Modern Irrigation Agriculture

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Introduction: Irrigation Agriculture in Oman

Agriculture in Oman is diversely structured and gives, due to its history, examples for traditional agricultural systems which have been sustainable over millennia, as well as for ecological and economical effects of fast and sudden modernization processes.

Although agriculture earns only 3.3% of the country's Gross Domestic Product (FAO 2003), 42% of the small Omani population (2.5 million people) are employed in agriculture and fisheries (MOI 2003). They produced 48% of the food used for human nutrition in 2002 (MOI 2003), thus food security and food imports are a major issue in Oman. The country's area includes only 2.2 million hectares of cultivable land, including arable land, grazing area and forests. For the cultivation of crops, only 61 550 ha (0.2% of the total area) were used in 1993, and all this area has to be irrigated (FAO 1997). This number may have risen since, as there has been a constant increase in irrigated area since 1970 (see figure 1).

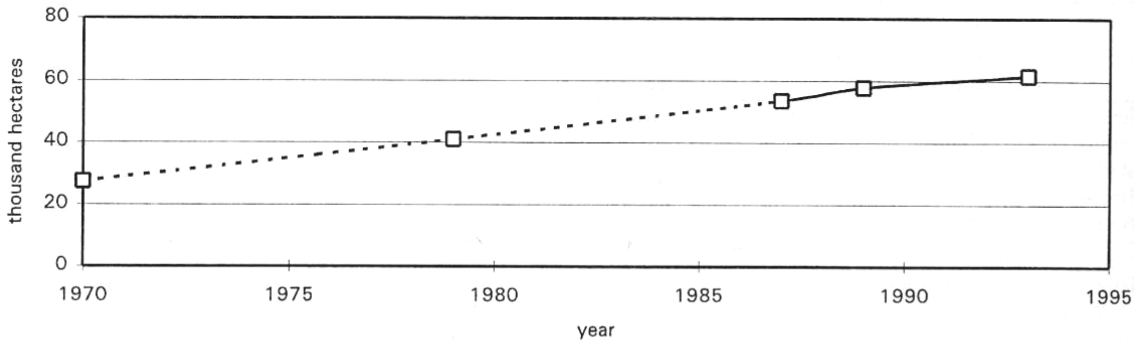

Figure 1: Evolution of the irrigated area in Oman (FAO 1997)

The most important crop grown is dates (44% of the agricultural area in 2000, MOI 2000), followed by 23% vegetables (e.g. tomatoes, potatoes, cabbages), 16% alfalfa, 15% fruit (lemons, mangoes, banana, pomegranate and in Dhofar coconuts) and only 2% wheat and tobacco (FAO 1997).

Distribution of Land Use

Most of the agricultural production is concentrated along the coastal plains (compare figure 2), Al-Batinah in the north being the largest and Dhofar in the south the second largest agricultural region (Nagieb 2004). In these regions, irrigation water is mostly taken from wells, and a fast process of modernization has taken place since the 1970's (Nagieb 2004). In the mountainous region of the north, oases settlements have developed where water from springs can be used through the aflaj irrigation system, which has been preserved up to today to a large extent (Nagieb 2004). Some agriculture exists in the deserts, for example the country's only coffee plantation near the jebel akhdar. Rainwater retention dams and springs provide the source for irrigation (Nagieb 2004).

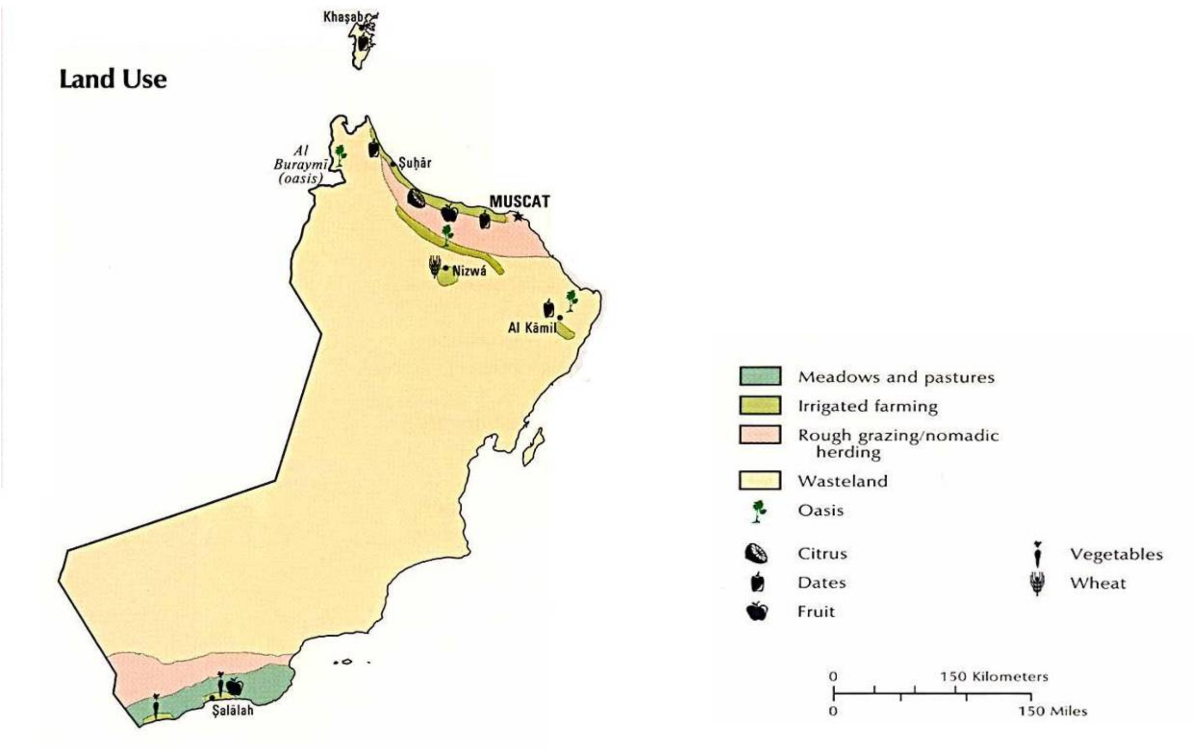

Figure 2: Land Use in Oman (CIA-Atlas of the Middle East 1993)

Water Resources

Natural renewable water resources, which satisfied all water requirements before 1976 (Al-Ismaily & Probert 1998), consist of rainwater recharging aquifers and amount to 985 million m3 in 1995 (FAO 1997). Today, they are supplemented by treated wastewater (26 million m3 in 1991), mainly used for the irrigation of ornamental trees (FAO 1997) and energy-intensive seawater desalinization (34 million m3 in 1995, FAO 1997), mainly used for drinking (Al-Ismaily & Probert 1998). Rainwater retention dams increase groundwater recharge by supporting infiltration (FAO 1997).

The main water withdrawer is with 94% of all water the agricultural sector (see figure 3), while domestic and industrial uses make up only a minor amount. The water withdrawal exceeds all renewable water resources by 181% (FAO 2007). This figure should be expected to have risen since the latest available data of 1991. This leads to an estimated yearly groundwater depletion of 240 million m3 (FAO 1997).

Irrigation

About 160 000 wells (Al-Ismaily & Probert 1998) and 3000 aflaj provide each about half of the agricultural irrigation water (Nagieb 2004), with a growing trend for wells (FAO 1997). Thus, all irrigation water is groundwater, used with powered pumps (FAO 1997). While the spring water lead by aflaj is of very good quality in most springs of Oman (Al-Ismaily & Probert 1998), the water from wells is increasingly affected by salinization. The construction and use of wells underlie strict regulations since 1988 (FAO 1997). Figure 4 shows that the traditional irrigation technique of surface irrigation dominates, while the use of modern irrigation technologies is growing.

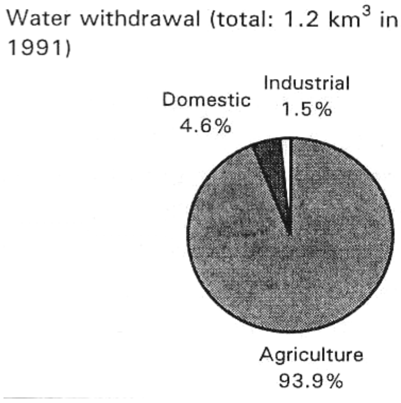

Figure 3: Water withdrawal by sectors (FAO 1997)

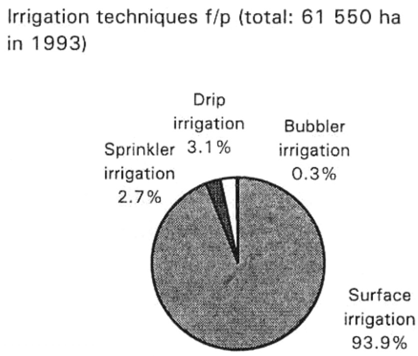

Figure 4: Distribution of irrigation techniques in 1993 (FAO 1997)

A Traditional Irrigation Method: The Aflaj in Mountain Oases Systems

History

The traditional irrigation system aflaj was probably introduced to Oman by the Persians, but may also be an own invention (Nagieb 2004). It first appeared earlier than 500 BC, allowed earlier settlements to grow and largely influenced settlement structure (Seckler & Schindler 2007). Similar irrigation systems exist in Iran, China, Japan, Egypt, Marocco, Spain, Mexico and Peru (Nagieb 2004).

Today, of Oman's about 4000 aflaj, about 3000 are in a healthy state, while about 1000 have more or less dried out because of a lack of maintenance and giving up of oases settlements and mountain agriculture (MOI 2000). Existing aflaj are supplemented by water from wells and boreholes (Al-Ismaily & Probert 1998).

Functioning

The functioning of a falaj (singular of aflaj) is sketched in figure 5. Rocks collect the rainfall of a large area and store it, buffering short-time water fluctuations (Luedeling et al 2005). The size of the catchment area and the retention time of the water determine the stability of water availability (Nagieb 2004). From the aquifers at the foot of the mountain, water is drawn and led to the settlements by open canals 100m-15km in length (Al-Ismaily & Probert 1998), which may be underground and staffed with access holes every 15-30m for cleaning and maintenance (MOI 2000). There are three different types of aflaj: the da'ndi, which is a long underground canal artificially drawing water from springs, producing the biggest and most constant outflow of between 15 and 20 liters/s (MOI 2000). The aini is an open canal above ground, leading water from natural access to mountain springs and producing a relatively constant outflow. The ghiayl is also an open canal above ground; it leads rainwater from wadis only seasonally (MOI 2000).

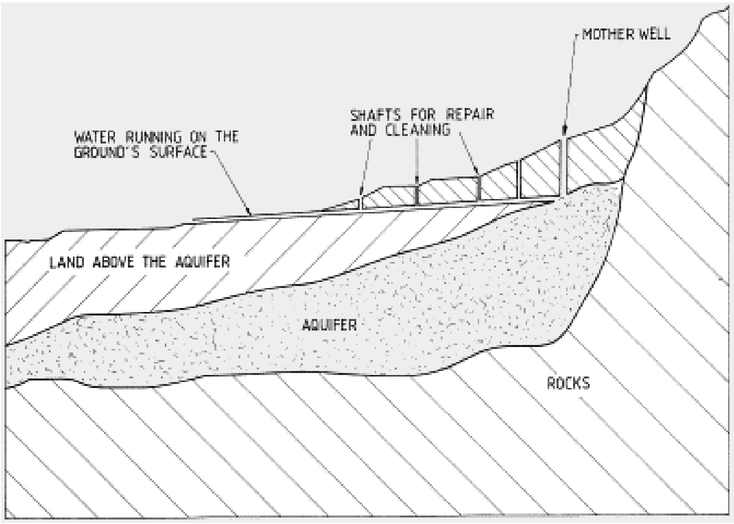

Figure 5: Sketched cross-section through a falaj (Al-Ismaily & Probert 1998)

Water Distribution

In the settlement, the cleanest water is first led to a communal collection point for drinking. Next it passes the mosque, for the ablutions and religious washing before the prayers. After that it is free for domestic use in the settlement, like washing, which is often done in the retention basins called lajal. Only after running through the settlement it may be used for irrigation (Al-Ismaily & Probert 1998). Privately owned wells supplement terrace drainage water and rainwater from wadis for domestic use and irrigation (Nagieb 2004).

For the distribution among farmers, a member of the community is elected. The time needed to irrigate each field belonging to the falaj once is one rotation or dawran and may last 7 to 12 days. The irrigation days (maqfool) are divided into day and night half (badda), which are again divided into half hours (athar) (Al-Ismaily & Probert 1998). Special clocks have been developed for the supervision of these exact time spans. Irrespective of his social importance, each farmer is assigned an exact time span for irrigation, proportional to the area he owns (Nagieb 2004). During nights, palm gardens are irrigated or, if the falaj outflow is poor, the water is left to fill retention basins to be available for irrigation during the next day (Nagieb 2004).

Water availability

Water is the limiting factor for most yields and determines which crops can be farmed in different oases and seasons (Norman et al 1998). As the water led by the falaj can not be drawn by force, the water availability is restricted to the renewable resources (Al-Ismaily & Probert 1998). The water use efficiency (irrigation demand/supply ratio) and water use index (maximum cultivable area/cultivated area ratio) were found to be very high in examined oases of Wadi Bani Kharus and Wadi Bani Awf (Norman et al 1998, Luedeling et al 2005). This may also be explained by the high costs for water share, system maintenance and irrigation labor, which has been estimated to be 0.10 to 0.15 Rial Omani per cubic meter (0.26 to 0.39 Euros) in Wadi Bani Kharus (Norman et al 1998). These costs are paid by a portion of the yield. Close cooperation within the community is needed.

Salinization

The amount and quality of the spring water provided by aflaj is generally very high, although minor salt problems and pollution through domestic use may occur (Nagieb 2004, Luedeling et al 2005, Al-Ismaily & Probert 1998). The upper soils in Wadi Bani Awf are rich in lime and organic carbon through organic manuring (Nagieb 2004), stabilizing the soil structure against the influence of sodium. They have been found to store most irrigation water (Luedeling et al 2005), while the deeper soil layers of the artificially built up terrace soils have a high water leading capacity due to low packing density (Nagieb 2004). This ensures little but regular drainage (30% to 33% of irrigation water), which mainly occurs during the rainy season (Luedeling et al 2005). There is no salt accumulation in the upper 45 cm of soil, but a low build-up of salts below that depth (Nagieb 2004). There are no visible symptoms of water stress on plants in the two examined oases (Nagieb 2004).

Sustainability

Agriculture in mountain oases in Oman has been sustainable over millennia due to avoidance of salinization, prevention of erosion by terrace structures, efficient and adapted water use and production for local consumption and trade (Seckler & Schindler 2007).

Today, the challenge of a rapid population growth, especially in urban areas, leads to a higher food demand, which cannot be satisfied by oases agriculture (Al-Ismaily & Probert 1998). Although mineral fertilization increased yields (e.g. doubled the yield of grain in Wadi Bani Awf, Seckler & Schindler 2007), it also made nutrient losses very likely, due to high nutrient surpluses (Buerkert et al 2005) and high mineralization rates caused by alternate wetting and drying, high temperatures and pH levels (Nagieb 2004). Wells provide a cheaper but less sustainable water supply in many areas. Rising labor costs in other sectors led to labor shortages and a decrease in local investment (Norman et al 1998). The aflaj are in many cases abandoned and dry out, especially when rebuilding is necessary (Al-Ismaily & Probert 1998). The Ministry of Water Resources financially supports the rebuilding of some aflaj, stating to put a high priority on their preservation (MOI 2000). The use of cement ensures a longer durability and lower maintenance costs (Al-Ismaily & Probert 1998).

The key for preserving this millennia-old agricultural system seems to lie in keeping up high organic matter contents in the soils, providing for sufficient leaching of salts and support local investments to keep the aflaj functioning (Seckler & Schindler 2007, Al-Ismaily & Probert 1998).

Agriculture in the Coastal Plains - Modernization of an Irrigated Agricultural System

Agriculture at Batinah Plain

The Batinah Plain is located in the North of Oman, between the Persian Gulf in the North and the Jebel al Akhdar and western Hajar mountains in the south and west. These mountains provide the groundwater resources for irrigation through aquifers. In a narrow strip of 300 km length and 10 to 30 km width, 80% of Oman's agricultural land is located (Cooksen et al 2001). Main crops are dates, limes, alfalfa and vegetables.

Near the coast are the best soils found in Oman. These fluvent soils are deep (more than two meters) with loamy textures. Silt and clay in subsurface horizons provide a high water-holding capacity. They are most at risk of salinization because of their fine texture and an upward movement of water and salts into the rooting zone. Further inland, salts rarely accumulate due to a coarse texture of the soil and good drainage (Cooksen et al 2001).

History

The Batinah Plain is cultivated since the 3rd century AD. Smallholdings ranging between 0.5 ha and 2.5 ha used animal-bailed wells for traditional surface irrigation (Norman et al 2001). A high biodiversity was maintained and intercropping systems were commonly used. The export of limes and dates to markets in East Africa and India, together with local fishing and almost self sufficient agriculture ensured a stable economy to the region (Stanger 1985).

With the economic development in 1970 and higher investments in agriculture, the use of modern irrigation technologies introduced and the agricultural area increased. In 1974, all wells of were mechanized (Stanger 1985). Improvements in infrastructure, e.g. the construction of a coastal road, led to the settling of large scale farms. These changes caused an extraction of groundwater exceeding natural recharge. The irrigation costs are very cheap with 0.03 – 0.05 € for access only (Norman et al 2001). Finally, sea water intrusion led to high concentrations of salt in the groundwater. Farming close to the coast was not possible anymore and even very salt tolerant date palms died due to water scarcity caused by the effects of salt.

Figure 6: Satellite image of the Batinah Plain (www.google-earth.de, 2007)

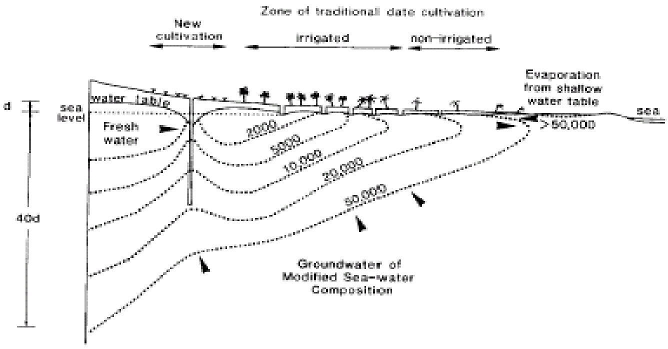

Figure 7: Schematic section of the Batinah coastal area (Stanger 1985)

Coastal Salinization

Salinization is affecting what are potentially the most fertile soils near the coast, leaving poor, stony soils for farmers to cultivate (Cooksen et al 2001). 35% of the cultivated area in south Batinah is considered to be slightly up to very strongly saline (>4 up to 64 dS/m) and 15% are extremely saline (>64 dS/m) (MAF 1990). In 1990, 20% of the date palms where abandoned in south Batinah (MAF 1990). Figure 7 illustrates seawater intrusion, showing the zone of traditional date cultivation and the newly cultivated zone. The numbers indicate the electrical conductivity (EC).

Modern Irrigation Technologies

Modern irrigation technologies are "... considered to be any irrigation system using piped distribution under pressure or gravity at the farm or field level" (Cornish 1998). The general aims of modern irrigation technologies are to increase food production, reduce the demand of labor, improve control and timing and finally the water use efficiency (WUE) (Cornish 1998). Modern irrigation systems are largely confined to commercial, medium and large-scale, high-input agriculture. There is a high risk of miss-matching irrigation hardware, developed for one set of physical and socio-economic conditions, with circumstances in an entirely different environment (Cornish 1998). Therefore the choice of modern irrigation system is very complex and should consider many aspects such as the availability of water, investment, WUE, labor demand (skilled and unskilled), risk of failures etc.

The different modern irrigation technologies can be roughly divided into sprinkler-, micro- and pumped surface irrigation.

Micro-irrigation systems (such as drip lines) can be used to expand agricultural production at marginal desert soils rather than sprinkler irrigation (Cornish 1998). The WUE as well as the investment for micro-irrigation is very high, the labor demand is low. The last criterion explains why such systems are only available for large scale projects.

Smallholders still use the traditional surface irrigation methods, today in combination with pipes and pumps. Evaporation is reduced when pipes replace open conveyance channels between the water source and field plots (Cornish 1998). Pumps allow deeper wells and reduce labor demand. The system is relatively cheap but in general there is a high risk of over pumping water resources if no strict regulations are given and the prices for oil and water are cheap.

Centre pivot irrigation systems are a kind of sprinkler method using a long lateral with a length up to 400 m and an irrigation circle of up to 50 ha. They are suited for large, flat fields of uniform soil texture, little labor is required for routine operation, design, installation and maintenance, but highly skilled staff is required. These systems are high in investment and have a very low WUE. The water is distributed by sprinklers from above the crop canopy and a wets large area, leading to high evaporation and especially interception, and causing high water losses (Cornish, 1998).

Desert Farming

Large scale farming projects at Batinah Plain and in the deserts use centre pivot irrigation and fossil water basins. The production of animal fodder such as alfalfa and rhodes grass at the Batinah is not allowed anymore, but these projects are now transferred to the desert. They are grown according to ecological agriculture regulations for the production of ecological milk, although Oman can only produce about 50% of its consumed food. The use of fossil water, especially with the centre pivot system, is not sustainable but the ecological agriculture regulations do not control it.

Comparison of the Irrigation Systems:

If we compare the traditional Aflaj system with the modern irrigation technologies at Batinah Plain, we come to very opposite conclusions. The problem of salinization at the coast does hardly exist in the mountain oases. Modern systems lead to severe depletion of the groundwater. There is a sustainable management of expensive water in the oases as well as a limited and community based access, in contrast to unlimited and individual access to a lot cheaper water at the coast. The traditionally closed nutrient cycles are very productive on a restricted area, but have no potential for expansion. The high input and area intensive monoculture at the coast has an open nutrient cycle with little recycling and much potential for expansion.

Looking at the end of the food chain with the question “Who eats the yields?” we realize that the traditional system in the mountain oases is used to produce food and animal fodder for local people, goats, sheep and cattle. Agriculture at the coast instead is used for the production of vegetables, fruits and animal fodder for the urban population, milk production (cattle) and export (dates, fruit). The people who profit from the intensive agriculture at Batinah plain are a few business men. The mountain oasis agriculture is community based because of the aflaj system and therefore many smallholders profit.

Conclusion

Agriculture in Oman can be described as intensive in labor and mainly restricted by water availability due to the need for irrigation. It can only sustain if high-quality water resources are used according to recharge, and if appropriate management is followed seriously. There is a conflict between the issue of the currently low food security and costly food imports on the one hand, and the threatened agricultural sustainability on the other.

First of all, productive traditional irrigation methods with high water use efficiency, as the aflaj system, must be maintained for providing income and part of the nutrition for the rural population in the mountains. Governmental support for local investment is needed, although an overall increase in agricultural production cannot be expected of these traditional methods. Still, there are some possibilities for a sustainable increase in food production:

The availability of renewable water resources can be increased. Alternatives to using up excessive amounts of fossil energies, such as desalinization by solar energy, osmosis and wind-power must be considered. The construction of rainwater retention dams as well as the recycling of wastewater are already in use, but may be expanded.

Modern irrigation systems have enlarged agricultural production and productivity significantly (MAF 1995) and enabled farming under very harsh conditions. They must be chosen by their efficiency of water use, labor need, productivity and costs. Water may be saved through improving the efficiency of application.

Even if water is applied in the most effective ways, to sustain agriculture at the Batinah plain under the current threat of salinization, a reduction of farmland up to 3,400 ha in the area of land cultivation is recommended (Cooksen 2001), and may be unavoidable.

The high demand for investment or even fossil water use by intensified agriculture has to ensure high returns with respect to income and food security. Producing fodder crops for milk production should be of second interest to the production of high-value and high-quality crops for the reduction of imports of expensive foods, or for export (e.g. winter vegetables, quality dates and cut flowers, Omezzine 2001). Aspects of traditional oasis farming could make a contribution to modern sustainable farming systems. For example traditional cropping systems, like intercropping of annual and perennial crops, as well as the organization of irrigation water distribution, may be equipped with a modern irrigation technology such as drip irrigation. This can lead to very high water use efficiency and an intensive and sustainable production.

Figure 8: Satellite image of desert farms (www.google-earth.de 2007)

Figure 8: Satellite image of Salalah Coast (www.google-earth.de 2007)

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