Journal of Agricultural Science and Technology A 5 (2015) 811-823
doi: 10.17265/2161-6256/2015.10.004

Integrated Water Management for Aflaj System in Oman —Different Approach

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Abstract: The study addressed the question about modernization of Aflaj's administration, and pointed out the pros and cons of both traditional and modern methods. The traditional management seems powerless and is not eligible to follow the social and economic development, however this development even begins to reflect negatively on the administration of Aflaj. The traditional management system of Falaj by rural communities is still an independent management of the state. However, regardless the efficiency of the traditional management system in the past, this traditional management can not take in consideration waters development projects in their region, considering that the concept of local administration is differing with the concept of integrated water management. Therefore, the questions revolve around the future of traditional administration and the role of modern administration of the Aflaj water system to maximize the use of water. Hence, the need for the use of modern methods of the management of Falaj has become a leading supplier key demand to keep up with challenges. This method begins in the basic data onto the role and importance of water in the area of Falaj and pass through the definition of the region Falaj, wondering about an administrative boundary and the importance of the basin of Falaj and how is developing the database, like data network density of rainwater. The importance here is to choose the appropriate and required methods of the development and optimization of Falaj system management, as well as the scientific levels required by specialists, technicians and observers to Falaj administration. Otherwise, it is difficult, in the 21st century, to define the priorities of geographical surroundings and study the future of Aflaj.

Key words: Integrated water management, Aflaj, Falaj, Oman, virtual water, water footprint, crops.

1. Introduction

Aflaj (it is the plural of Falaj), ancient water channels into Oman, is suffered from a water shortage and scarcity. One of the reasons for this scarcity, in addition of that it can be partly attributed to climate change, is due to lack of integrated water management in these Aflaj. Some of them had stopped flowing, for instance, the famous Falaj Al-Malki, which was designated by UNESCO as one of the five best Aflaj in Oman as world heritage sites. Only two of its 17 channels water are still taking place. At the moment, water to flow has stopped in 27% of the Aflaj, in other hand, 30% of the area experienced a sharp decline in water level [1].

Aflaj oases represent the basic income for thousands of farmers in the rural area that are dependent on agriculture for their basic needs. Therefore, changes in the reliability of Aflaj as a consequence of drought and climate change could have serious consequences for the Aflaj oases communities and the country's economic well-being [2]. To this day, the system of Aflaj provides more than 60% of the country's fresh water supply and irrigates around 55% of its cropped land [3]. The last Aflaj census reported that Aflaj irrigates an area of 26,498 acres and supplies annual waters of 459 million m^3 [4].

The problems lie in the decreasing amounts of water available in the Aflaj, which can be caused by several naturals and human factors, as lack of institutional capacity and collaboration for managing watershed resources. The result is imbalance between the needs and possibilities of water [5]. It is important here to underline that what leads to the tragedy are not only the property regime, like scarcity of renewable water, but also the poor water demands management

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[6]. It was noted that each of these factors has its components and methods of measurement and analysis.

The choice of subject was based on the words of the full conviction of the former regional president of the United Nations Development Programme (UNDP), who has awareness of this dilemma and warned that “the water management of Aflaj may not base on an individual level that needs a radical change, and whole vision and the demand for water management must be part of an integrated process…” [7].

The question on integrated water management system of Aflaj in Oman, raises many questions among these questions, for example, who is the decision-maker in the management of Aflaj system? Is there an integrated and updated information network? Is water data onto Aflaj available consistently? Is there a process of development and modernization management of Aflaj system? How Aflaj management is seeking to optimize the use of water? etc.. The author will try to treat with this research through two axes in the following themes. The first introduces the issue of traditional management of Aflaj system by rural communities, and the second explains the mechanisms for integrated water management system of Aflaj.

2. Actual Situation and Traditional Management in Aflaj System

There are many references dealing with the characteristics and types of Aflaj and explaining the value of traditional management Aflaj system, therefore despite the importance of several studies on this subject, it is important to light on the main of these characteristics and the role of traditional management system of Aflaj in the recent past.

2.1 Utilization of Aflaj Water

The characteristics and types of Aflaj were summarized in Table 1, according to the first Aflaj inventory project in 1998 [8], and showed that the total number of Aflaj found were 4,112, of which 3,017 were operational and the remaining 1,095 were dried Alfaj [9].

Aflaj water represents 43% of the renewable water, the equivalent of 552 million m^3. It contributed to 14% of irrigated area and 35% of the amount of water demand for Oman. These Aflaj systems are arranged in such a way that domestic use is primary and irrigation is secondary.

In most Aflaj, water is first allocated to drinking, and then water will pass respectively through mosques, forts, men and women public baths, washing dishes and clothes area. After domestic use, Falaj is utilized first to irrigate the permanent cultivated lands, mostly date palms, then the seasonal cultivated lands, called Awabi [10]. Falaj has more to flow rates and then more lands will be cultivated with seasonal crops, such as wheat, tomato and onion in downstream of the system. However, if drought occurs, farmers cut the area of seasonal crops.

Available water in Falaj exceeds farmers need; water is allowed to be drained out of the system. So, besides the agricultural and domestic use, Aflaj systems sometimes are used for industrial and other purposes. For an example, Falaj Al-Mutaridh, dry Falaj near Sohar, Northeast of Oman, had four water mills constructed along its channel. This Falaj channels system used as a route way. Numbers of cisterns were constructed in the upper-stream of this Falaj to store water for travelers. The water exceeds

Table 1 Characteristics and types of Aflaj [4-9, 11, 12].

Types of Aflaj	Wet Aflaj		Discharges	Flow rate (L/s)	Length of Aflaj and branches	Areas irrigated	Contribution to water demand
	Number	%					
Ayni	989	28	552 Mm^3/year	34	959 km	22,970 ha or 229.7 km^2 (14% of irrigated area)	35% of the amount of water demand for Oman
Ghaili	592	49		44			
Dawodi	967	23		143			
Total	2,548	100					

the needs of citizens; it goes to the valley named Al Miqlab, outside of water requirement region.

2.2 Factors Contributing to Deterioration of Aflaj System

There are many naturals and human factors that contribute to the deterioration of the Falaj system, as well as on the structural level, such as collapse, erosion and sedimentation, or on the water quality and quantity, as shown in Fig. 1. Many studies had been made for this reason, and Al-Sulaimani et al. [13] highlighted on the problems to maintain Aflaj wet.

2.2.1 Natural Factors

Many natural factors contribute to the deterioration of the structural situation of the Aflaj, as well as the continuous wastage of water Aflaj can lead to the loss of large amounts of Aflaj water.

For example, one of the most important natural factors that adversely affect the Aflaj system is the lack of rain, which will lead to an immediate decrease in the water levels in the drainage network of Aflaj and impede the agricultural planning process, as well as the heavy rains, though rare, will lead to infrastructure deterioration of Aflaj as to soil erosion. In addition, the exposure parts of the Falaj system contribute to the decreasing amount of water due to evaporation and the possibility of contamination.

The water losses also can occur by seepage along the Falaj conveyance, water use and distribution sections. Notably, most of the channels Aflaj, especially those located in the valleys or on the edge of the side, is subject to collapse and fullness their courses with stones and soil, as a result of abundance or rainfall and flow of water to majority of parts Falaj. This may lead to the interruption in water from the main course of Falaj near the plants.

The deep Aflaj was affected by the collapse of the puncture, as a result of erosion and precipitation which leads to fullness bottoms of waterwheel with stones and sand. These landslides may lead to the floodwater and surface runoff in the canals Falaj, where it causes the collapse of the walls of these channels, the fall of stone roofs and the stop of water flowing to the towns. These various factors can result both in a reduction in the Aflaj water discharges and an increase in their maintenance costs.

2.2.2 Human Factors

The human factors existed on the waste water. The water distribution of Aflaj system according to the specific timing could create a surplus or shortage of

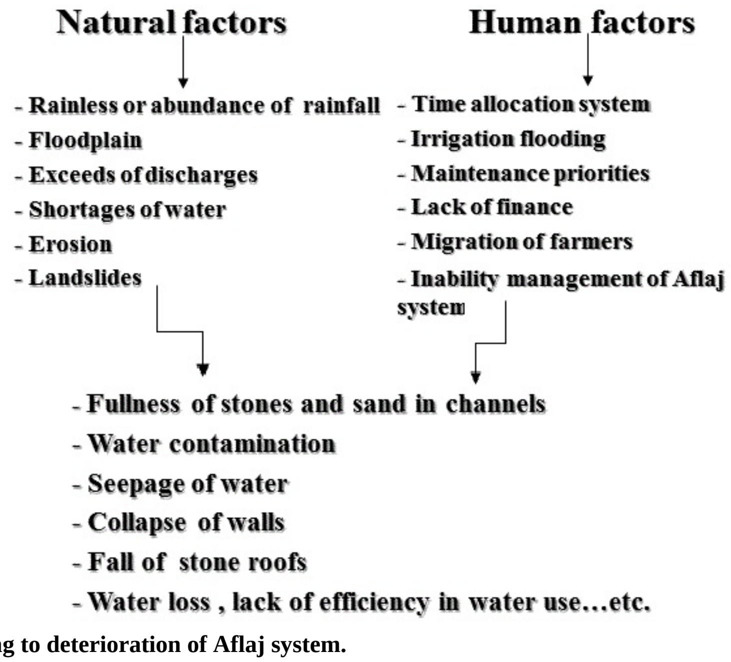

Fig. 1 Factors contributing to deterioration of Aflaj system.

water in many cases. The time of allocation system to distribute water may preclude the use of modern irrigation that can reduce water consumption ways. The irrigation by flooding method contributes greatly to the loss of water through deep infiltration. Also, the use of large basins to irrigate trees in turn lead to wastage of evaporation and leakage deep.

The Ministry of Agriculture estimates losses of water to be about 40%, mainly from distribution networks and flood irrigation methods. Several studies, since 10 years, about Aflaj in Oman, found that Aflaj systems in Northeast of Oman have salinity problem. These systems located in the coastal area of Oman, in the most productive area of agriculture in the country. The intensive pumping of water by new farms reduces the head of the fresh water table, leading the intrusion of salty water from the sea to the fresh water aquifer. Another dilemma for the Falaj system is that unfortunately there is no record (or hydrograph) for the Falaj.

In addition, the maintenance priorities set by the government does not affect all Aflaj. Due to lack of financial savings, there are many requirements criteria put forward by the government to accept the maintenance of Falaj without the other.

Aflaj system faced lots of serious problems at last four decades: rapid modernization, regular maintenance which became less practiced, migration of farmers and many others.

Due to the scarcity of labor, farmers hired non-experienced expatriates labor to work in Aflaj systems. These expatriates neither have the knowledge on the sense of the importance of Aflaj maintain nor the regular service of the system. Government of Oman did intensive efforts to maintain the Aflaj systems. For an example, a special department in the Ministry of Water Resources is allocated to maintain Aflaj. This department did a lot of surveys and researches for developing and maintaining the Aflaj systems. Another reason for the deterioration of Aflac system was due to the developed passive attitude of farmers toward the Falaj; technical knowledge about Aflaj remained only with older generation, and new generations have no interest learn it. Starting from the 1950's, farmers, who get better incomes from working out of the Aflaj communities depart from the community, establish their own farms. These new farms are irrigated by diesel or electric pumps. The large numbers of new farms affect the water table.

Much Aflaj flow is reduced, and even it drought out sometimes. Oman government made lots of efforts and regulations to stop or reduce the effect of this problem on Aflaj. Problems facing Aflaj the first are the shortage or lack of water, the erosion and landslides. Not only this, but there are other problems concerned about traditional management system of Aflaj. It will be treated with the following paragraph.

2.3 Efficiency of Traditional Falaj Management System in the Recent Past

Many of the outstanding studies have discussed the importance of this system in the recent past. The Omani Aflaj is one of celebrated example of the contemporary relevance to ancient. The real genius of Omani Aflaj is not just in the inventiveness and efficiency of its irrigation system, but in tradable water rights and the power of private ownership that it provides [3].

The Aflaj may be the most ancient community-run systems for managing water in the world. The traditional management of Aflaj system remains independent of the state and is to run entirely by village communities, and some capture water in gravel beneath the beds of wadis (valley); the largest "unfailing" are those connected to the tunnels that bring water down from the mountains. Pearce [14] has commented on his research on the status of Al Falaj in Oman and said that Oman's water systems known as Aflaj have brought water from the mountains and made the desert bloom.

Also, Zekri and Easter [15] think that these simple water markets are the key to the long-term success of the Aflaj. The existence of private water rights that can be traded makes the system more efficient and allows the community to be self-reliant. They could offer important lessons for the world in how to manage scarce water. The water entering the village is accessed first for drinking, domestic use, mosque or school, communal bathing cubicles and washing. It was noted that soap is banned. Water from these sources returns to the main channel before heading for the fields along complex networks of channels.

Aflaj can be maintained with locally-available equipment and materials, thereby not requiring the import of such items. Aflaj systems also enhance the spirit of cooperation and teamwork in rural areas.

The management system of Aflaj by rural communities is an independent management of the state. As for the committee of Falaj management (Fig. 2), it consists of chieftain (Sheikh) and members of the Shura board of the region and the state (Majlis Al Shura and Al Dawallah), the prefect (Walis), stakeholders that are from the area of the Aflaj and in partnership with representatives of the ministries. The employees management committee of Aflaj system (Fig. 3) include officials from the within and beyond of Falaj region. As for the Falaj employees, they are distributed in Falaj agents, in support to manage the Falaj, in accounting book, as auctioneer and worker for water pumping.

The heritage and civilization roles in management of the Aflaj have transformed the Aflaj areas to three types of water rights. Al-Marshudi et al. [12] identified three types of water rights, namely, private water rights in its turn including three types (owners of land and water, owners of land and renting water, owners of water and renting land) as shown in Fig. 4, common water rights and quasi-public water rights. Under private water right, it is explicit about formal licenses. Water right which is implicit (without formal licenses) can not be traded.

In the end, it can be seen from the above that the inherited Aflaj system has the need to restructure through a new water law to become part of the modern water sector. Many of questions are raised about the effectiveness of traditional management, as:

How traditional management of Aflaj system will confront future challenges, and will face a growing demand for water? What are the projects and schemes for the traditional management system Aflaj to maintain the water Falaj?

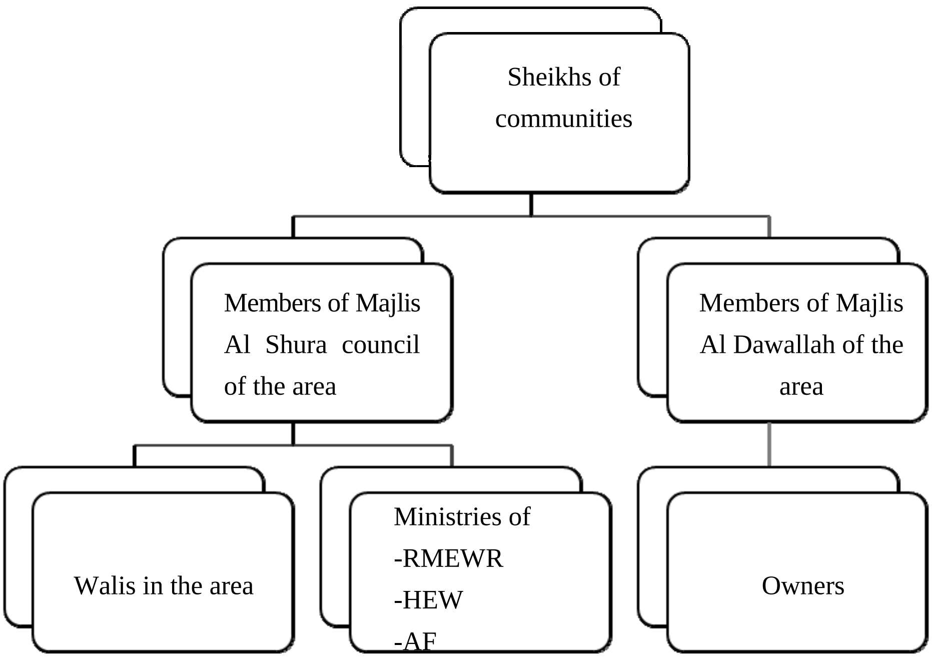

Fig. 2 Committee management of Falaj system.

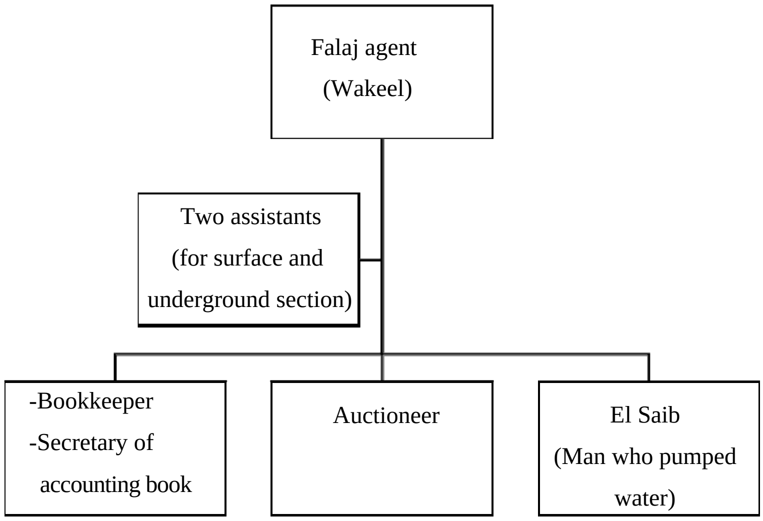

Fig. 3 Employees management committee of Aflaj system.

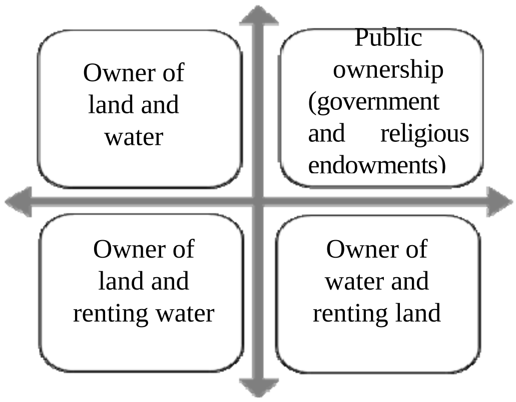

Fig. 4 Distribution of property in the region of Falaj.

Who is the decision-maker in the management of Aflaj system?

Is there an integrated and updated information network?

How can the traditional management system for Aflaj to provide continuously accurate water data?

These questions and also many others about the need of managements of Aflaj, taking into account the requirements and challenges, in the 21st century will be treated successively.

3. Access to Integrated Management of Aflaj System

To achieve an integrated management system for Aflaj, there must be two lanes inseparable. The first track requires gradual modernization management of Falaj for gaining the modern scientific way, and become able to put progress future plans for the entire watershed Falaj, not only the watercourse of Falaj. The second track requires methods to maximize utilization of produced water; this is subject to the accuracy of indicators and criteria for the measurements of water. These two lanes will be discussed in the next paragraphs, a view on reaching the methodology of the optimum for management of Falaj, called the integrated water management of Aflaj system.

3.1 Modernization Required for Aflaj Management System

The Falaj is facing several problems and challenges due to the recent progress and development. The change in the current life patterns and attitudes has economically influenced the agricultural societies, especially the communities of Falaj. With each coming generation, each legacy is liable for further smaller division, so more legacy by the succession are dispersed and fragmented. As a result, more difficulties confront the system so that technical, financial obstacles could lead in the end to deterioration of the production.

Water right was a major challenge to improve water management; the farmers' concern was about the private owners of Falaj water rights, such as investors, endowments and charity, and the Falaj water rights which were typically employed to maintain the Falaj. It is true that there is a lot we can learn from these farmers, but it is not sufficient for modern challenges. Due the growing needs of water, the unregulated pumping of groundwater especially is depleting aquifers and causing the long-reliable channel to run dry [13].

It was noted that through function distribution of traditional Aflaj management system, there is a lack of technical aspects or scientific disciplines, e.g., planners, land users, individual specialists, agricultural advisors, teachers, students' politicians, decision makers and land users groups, etc., as well as the lack of institutional capacity and cooperation (lack of inter-institutional collaboration) as previously noted for the management of watershed resources. This mechanism, shown in Table 2, will help in the development of future plans and overcome the constraints.

Technical and institutional constraints might hinder implementation of water projects and environment, allowing to move to effective treatment and training in new technologies, to ensure cooperation and to approach the cost of multi-sources.

In terms of the distribution of tasks (Fig. 5), select the appropriate technology, so the method of implementation can be assigned to the local specialists after a discussion by the land users. Also the design approaches can be vested to the prerogative of national specialists or international specialists. Finally, the implementing entities are government, international non-government, local community, land users and national non-government.

This functional distribution must be followed by a technical support, as training, awareness raising. The training is provided for land user, or for demonstration areas with public meetings or site visits farmers. The

Table 2 An example of the structure of constraints and possible treatments of Aflaj management system.

Constraint		Treatment
Technical	Lack of new options	Training and new technologies
Social-cultural-religious	Following conventional top-down approaches	Introduction of improved methods with more participation, involvement of land users
Institutional	Lack of inter-institutional collaboration	Building and ensuring collaboration
Participation	Decision making	Approach costs met by:
Stakeholders-target groups	Planners, land users, individual specialists, agricultural advisors, teachers, school, children, students, politicians, decision makers	Government …% Local community-land user(s) …% International …% Total 100%

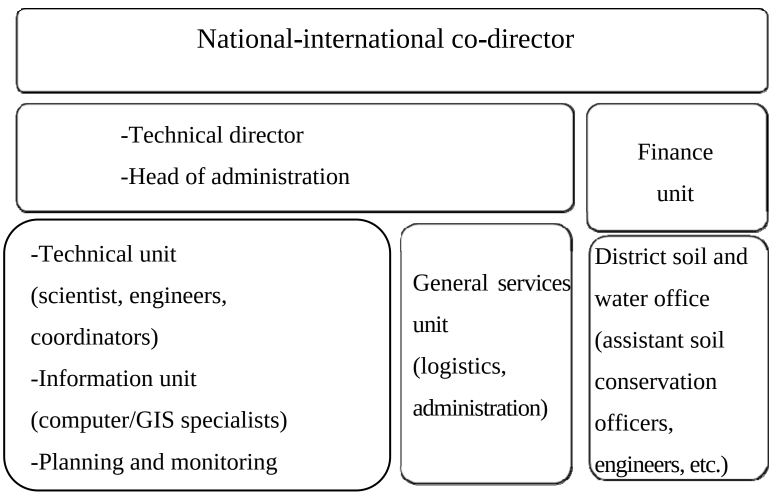

Fig. 5 An organogram visualization of integrated management of Aflaj system.

training focused on soil and water conservation. Advisory service was carried out through government's existing extension system and staff mainly government employees. The extension system is quite adequate to ensure continuation of activities. An extension worker is able to cover the areas, where activities are implemented in small scale, as sub watersheds, micro sub watershed level program, and research of topics is covered to include sociology, technology, economics, marketing and ecology.

In order of the success of integrated management, it must be accompanied by a fundamental data support, as infrastructure, support to local institutions, monitoring and evaluation. Some indicators need accurate measurements, and some others require the constant monitoring (Table 3). This hard work requires, sometimes, as changing as result of monitoring, and an evaluation (fair, good, excellent or greatly, moderately) is also needed to evaluate the impacts on the approach (improved sustainable land management, adoption by other land users and projects). It requires also training, advisory service research, advisory service effectiveness, land, water use rights and long-term impact, and finally a concluding statement.

3.2 Indicators

These indicators developed by Cap-Net (Table 4, modified) have been working with River Basin Organizations (RBOs) at national, sub-national levels to assist in their development as effective managers of water. The integrated approach to the sustainable management of water resources with these indicators was presented as a minimum set. For this reason, the indicators are grouped by water management function. The indicators may be used to:

(1) Measure progress with integrated water resources management;

(2) Identify weak areas of regulation, institutional arrangements, management systems (financial and operational), capacity and authority, and therefore to guide corrective action by the water management agency.

Table 3 Methods and indicators of observation aspects [16].

Aspects of observation	Methods	Indicators
Bio-physical	*Ad hoc*	Measurements
Area treated	*Ad hoc*	Measurements
Technical	Regular	Observations
Socio-cultural	Regular	Observations
Economic/production	Regular	Observations
Management of approach	Regular	Observations
No. of land users involved	Regular	Observations

Table 4 Some indicators of water management by UNDP.

Function	Objectives	Measure indicators
Water allocation	Water allocation is in line with sustainable use, economic efficiency and social equity principles	Number of users; % of time in environmental and social reserve.
Monitoring	Knowledge of water resource availability is a basis for management	Number of stations; Water storage capacity; Comparison of water levels.
Basin planning	Basin planning synthesizes technical and social priorities	Water management activities driven by Falaj plan.
Information management	Essential information	Data base is established in formats compatible with other Falaj organization.
Stakeholder participation	Cooperation between government agencies with responsibilities for water management or water use	Formal stakeholder structures established with clear roles and responsibilities; Falaj stakeholders represented in decision making bodies at all levels.

The resource is modified from Cap-Net [16].

In conclusion, big challenge remains are not in the development or creation of modern management of high technologies, but in the principle of approving the transition from traditional management to another, and respond to the contemporary requirements over time and space. The question is how can an individual or small group to decide in favor of a water policy rather than the state, and whether the water resources in the twenty-first century are still private property.

3.3 Water Loss Control—Methods of Efficiency in Water Use of Aflaj

There were different techniques used to maintain the sustainability of Aflaj waters flow and reduce water losses. To enhance water uses efficiency, including artificial nutrition, a dig artesian wells was constructed, paralleled of Aflaj streams or also lining of the water conveyance components, as well as utilization of the advance irrigation methods. Unfortunately, Aflaj system remained susceptible to deterioration and declining amounts of running water, that was due to exposure to water loss (about 40% of Aflaj is lost water), either by the distribution network or the excessive irrigation. The two issues will be the subject of research in the following paragraphs.

3.3.1 Metering and Control Water Loss in Aflaj Watershed

Water resources are limited, and thus there is a limit to how much water can be supplied. One of the ways to make water resources go further is to convince consumers to use water more efficiently. Also, the initiatives of water demand management and conservation in the community of Falaj are hampered by a lack of good information. In addition, lack of the proper management of water meters and meter data gives to rise to levels from water losses. It is impossible to manage the water of Aflaj without knowing how much waters it has and what is its fate? The professor Zekri [17] had addressed the issue by "looking for a village that will try replacing traditional timeshares with smart meters to encourage water conservation".

The water meter has to play a critically important role. It is used to measure how much raw water is taken from a resource or a water pumping station, how much is purchased from communities to another, how the water is distributed over the water distribution system and how much of the water is delivered to individual consumers [18].

Water metering is an application of the principle "to measure is to know". Water metering has many direct, indirect benefits; there are four fundamental drivers for a comprehensive metering program as follows: equity, waters efficiency and losses, economic benefits, and water management system.

Metering shows the value of water to the consumer and creates strong incentives for consumers to use water more efficiently. Also by comparing the readings on network and consumer's water meters, communities' engineers are able to estimate the level of water losses in a water supply system and identify loose connections. All water networks lose some water, but the level of losses has to be carefully monitored and managed to avoid them reaching unacceptably high levels.

3.3.2 The Importance of Water Management Meters on the Aflaj

Through measuring the distribution of water to different parts in the Falaj, the data obtained from a good metering system allows later to take decisions on capital investments, maintenance, staffing and various other aspects of the water supply system in Aflaj.

Data are essential for many technical and management functions, including the estimation and management of water losses, pumping patterns, water to demand patterns and hydraulic network calibration. All data related to water meters are held in the same database, and the data in turn are used for various purposes, such as, billing, system management and future planning. Otherwise, water meters not managed correctly, can have a negative impact on the income of the communities of Falaj.

The supposed integrated management of water meters in a watershed of Aflaj affected by water meters is discussed in four main categories: (1) strategic planning, (2) information management, (3) asset management and (4) water management.

The water management in its turn, which deals with the way data water meters stored, can be used to manage water in the most efficient way, addressing issues, such as water demands and non-revenue water management, so the application of meters to water management can be divided into three categories: (1) the community water balance, (2) water to demand management and (3) non-revenue water management.

Finally, the implementing an integrated water meter management for Aflaj system is a necessary need to communities, because they currently have a lack of proper water meters management and suffer by the consequence of water efficiency and losses, and poor economic return, too.

3.3.3 Evaluation of the Volume of "Virtual Water" in Agricultural and Export Products and Its Impacts on the Water in the Aflaj

The virtual water is an innovative concept to analyze water consumption, assess the sustainability of water uses and explore the best way that water use can be reduced. Especially, in those areas where Aflaj began to dry up, it was desperately needed to introduce this concept to reduce water losses. This can be achieved through "virtual water" of agricultural and industrial product concept, which was introduced by Allan [19], Hoekstra and Chapagain [20].

What is the concept of virtual water? "By definition, virtual water is the water embedded in a product, i.e., the water consumed during its process of production" [21].

Knowing the "virtual water" values of a good or service, it can be useful for determining the best to use the scarce water available. In other words, the realization of "virtual water" content of various consumption goods will increase the water awareness of farmers to assist in the water efficiency use. The concept of virtual water has transformed from a broad focus on national resource endowments to drawing sharper comparisons between specific forms of production.

The abuse of water resources in Oman compared to Qatar and Jordan was shown in Tables 5-8. Table 5 reveals the renewable water volume in addition to the distribution of water consumption as domestics, industrial or agricultural in Oman in comparison with Qatar and Jordan. This table showed also that, the water withdrawn for agriculture surpassed the total renewable water resources in Oman, contrary to what seems more reasonable use of water in Jordan.

Notable is the overcome of agricultural water consumption of renewable volume of water in Oman and Qatar, in spite of the limited agricultural area in these two countries, in relation to Jordan. It was noted here that the volume of water used in agriculture in Oman, exceed the total volume of water used in agriculture in Jordan and Qatar.

The details of this extravagant water consumption of agriculture were shown in Table 6. First, the crop water requirements (mm/crop/period), such as wheat, bananas and lemons, etc., are more in Oman than in Jordan. Second, the cultivation of some tropical species, as mangoes, bananas, papayas, needs higher water requirement, while it was avoided in Jordan and Qatar. Also, the amount of water consumption of the same crops in Oman as well as in Qatar exceeds those in Jordan.

Knowing that the estimate of the virtual water content of agricultural products reveals a wide variation in relatively low water-using products, such as wheat and rice, through to relatively higher virtual water content products, such as beef. In Oman growing more alfalfa for sheep is consuming water heavily.

Table 7 shows a significant increase in the volume of the virtual water for some crops in Oman, compared with the global average. It showed that the volume of water in 10 from 11 crops (except dates) in

Table 5 Renewable and withdrawals water in Oman compared to Qatar and Jordan (1997-2001).

Country	Population	Arable land (1,000 ha)	Total renewable water resources (Gm^3/year)	Agricultural water withdrawal (Gm^3/year)	Domestic water withdrawal (Gm^3/year)	Industrial water withdrawal (Gm^3/year)	Total withdrawal (Gm^3/year)
Jordan	4,813,708	242	0.88	0.76	0.21	0.04	1.01
Oman	2,384,500	37	0.99	1.23	0.08	0.02	1.33
Qatar	573,388	18	0.05	0.21	0.07	0.01	0.29

The table is extracted from Ref. [20].

Table 6 Water requirement per crop in Oman, Qatar and Jordan (1997-2001).

Country	Water requirement per crop (mm/crop/period)												
	Wheat	Sorghum	Cereals	Potatoes	Tomatoes	Onions	Vegetables fresh nes	Bananas	Lemons	Watermelons	Mangoes	Dates	Papayas
Jordan	540	-	-	787	542	632	293	1,951	1,164	621	-	1,632	-
Oman	608	518	421	560	691	928	488	2,097	1,266	686	1,864	1,758	1,461
Qatar	423	-	-	1,046	779	975	487	-	-	820	-	2,246	-

The table is extracted from Ref. [20].

Table 7 Virtual water contents of some crops in Oman compared with the global average (1997- 2001).

Country	Virtual water contents of crops (m^3/ton)									
	Wheat	Onions	Vegetables fresh nes	Bananas	Lemons	Watermelons	Mangoes	Dates	Papayas	Fruits fresh nes
Oman	2,105	508	339	1,752	2,031	201	2,796	2,375	861	2,242
Global average	1,334	346	273	859	559	160	1,583	3,030	662	1,404

The table is extracted from Ref. [20].

Table 8 Average of virtual water related to the trade industrial products of Oman, Qatar and Jordan (1997-2001).

Country	Average industrial water withdrawal ($\times 10^6$ m^3/year)	Average of virtual water export related to the export industrial product ($\times 10^6$ m^3/year)
Jordan	39	25
Oman	23	20
Qatar	8	7

The table is extracted from Ref. [20].

Oman is more than the overall global average; this means a loss of irrigation waters to exceed 5,487 m^3/ton for a period of growth of these crops. Therefore, the greater the agricultural area of these crops, the greater the volume of water lost. As results, the issue of local virtual water in crops compared with to the global average (m^3/ton) aimed to make the most of the water resources of the Falaj.

On the other hand, the problem does not only depend on the extravagant water consumption, but also to the so-called water footprints [22, 23] by water consumption of industrial and agricultural export products as shown in Table 8. This table indicates the average consumption of water in industrial products, and the average virtual water exported via industrial products in Oman, Jordan and Qatar. It showed that Oman exports approximately 80% of the virtual water consumed in the industrial sector, as well as Qatar.

In summary, Tables 5-8 show abuse managements of water resources in Oman as whole and in Aflaj particularly in terms of extravagant and wastefulness irrigation process, not knowledgeable of the selection of varieties of crops and export of water consumption products. It should be noted that the evaluation of virtual water in agricultural and industrial exports will inevitably contribute to the integrated management of water Aflaj process, especially as 90% of its water goes to irrigation [24].

As seen, the water shortages of Aflaj are due to excessive use of irrigation. This requires identifying the most water-intensive agricultural products to study the extent of their economic return, especially in the areas of Aflaj. In this case, it is advisable to replace an agricultural product with the ones consuming less water and with the best economic benefit. Water of Aflaj is more frequently used to export goods. So, it is important to know about the "virtual water" flows of entering and leaving the watershed of Aflaj, as this can be one of the reasons for the scarcity of actual water Aflaj. At the same time, it becomes increasingly important to consider the linkages between consumer goods and impacts on freshwater systems. In case of these impacts not taken into consideration, the degradation and scarcity of some Aflaj will make them in critical condition [25], and consequently the system of Aflaj will be difficult to continue.

4. Conclusions

In conclusion, the actual management of Aflaj system resulted in losses of water reaching about 40%, mainly from distribution networks, flood irrigation methods and emerging agricultural pattern, all of which contributed roughly to drought or lack of effectiveness of some Aflaj. Moreover, the lack of agricultural extension policy by the development of tropical crops aggravated the virtual water in plantings, which contributed to the acceleration of the scarcity of Aflaj with the amount of deficit reaching 0.34 Gm^3/year in the period 1997-2001. The cultivation of some tropical crops (10 crops) in Oman in comparison with the global average for a period of growth, reveals the losses in a virtual waters exceeding 5,487 m^3/ton.

The problem does not only depend on the extravagant water consumption of Aflaj, but also on the water footprints by exporting the virtual water consumed in the industrial sector in Oman, so an integrated water management of Aflaj system becomes increasingly important to consider the linkages between consumer goods and impacts on freshwater systems from two aspects. First, requires gradual modernization management of Falaj for gaining the modern scientific way for the entire watershed Falaj, and second, requires methods to maximize the utilization of producing water.

The advantage of the integrated water management of Aflaj system methods will be assisted in creating a basic data onto the area of Falaj. However, the development of the database is principle, as well as documentation of information and publications on the region of each Falaj. Finally, an integrated water management is a set of multiple solutions to one template for the problem of the Aflaj system in Oman, starting by administration up to maintenance to cessation of waste, and optimized use of water by assessment of virtual water and water footprint should be a different approach to manage the water resource.

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