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Optimal Operational Management of Aflaj Watering System in the Sultanate of Oman: A Review

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Abstract *- This paper discusses the traditional operational management of the aflaj water distribution system in the Sultanate of Oman in terms of real water value. It compares it with the quantity and value of crops in three main aflaj in the North A'Sharqiyah Governorate. The study also covered the method of improving the management of the Aflaj water distribution system, the actual water needs of palm trees, and the method used to irrigate the crops. The approach of this study is inductive, and to some extent, qualitative. This study examines the issue of the traditional management of the Aflaj water distribution system and its allocations preferences. The approach of this study is inductive, and to some extent, qualitative. It begins with the related current and historical available data within Oman repositories and archives, which were used to draw recommendations, and conclusions. The results indicate a large surplus in the irrigation process of crops and mismanagement of the Aflaj water distribution system. The paper included some recommendations for restructuring the management of the falaj water distribution system, improving the procedures used to reach balance and obtaining a more significant economic value than the current traditional water management, and the obstacles facing the improvement process, the most important of which are the prevailing social customs that control the process of managing the operation of the falaj water distribution.*

Keywords *- Oman; Aflaj; Traditional watering systems; Water market; Athar; Badda; Irrigation scheduling; Water requirements; Date production.*

I. INTRODUCTION

The Ministry of tourism in the Sultanate of Oman (2016) describe The falaj that runs through a channel dug in the earth. The source of falaj water is groundwater found in the subsoil or valleys. The plural of the word 'falaj' used in Oman is 'aflaj', a broad term used to denote a irrigation system. The falaj is an original Omani irrigation system, deep-rooted in the country's land and history.

Traditional agriculture has played an essential role in Omani civilization and has provided a way of life to people living under challenging environmental conditions(Al-Marshudi, 2001). The Omani man was thousands of years ago when he invented the engineering of aflaj using this traditional irrigation system to irrigate different crops in all regions with different geography, as this constituted stability for the Omani people from all sides, whether political, economic and social and to live in a stable situation despite the challenging environmental conditions and the volatile climate (Al-Ghafri, 2004).

The water technology used to irrigate crops does not cost the huge individual sums, as the effort and participation in creating the falaj is the capital of one person, where the capital is inherited from the father from the grandfather and sometimes the person's share is bought and sold among members of the community, and in return, the annual production process of crops continues. It has been a sustainable process over the years (Mccann, 2016).

The number of aflaj in Oman reached about 4,112 falaj, and their total discharge of water was approximately 680 million cubic meters annually and irrigated about 30% of the cultivated area in the Sultanate of Oman (Nizwa, 2017).

Established traditions and laws regulate the process of allocating water rations to the beneficiaries, and it is based on ownership or at the end of each week the falaj is opened for rent in a meeting in which the price of an hour of water from the falaj is contested. This paper deals with a comparison between the operational management of the irrigation system through the traditional aflaj system that takes place It is currently being used and among a new economically feasible mechanism for the operational management of the irrigation system through the aflaj system, comparing the financial aspect and the ownership of water in addition to the total production per year, as palm crops are cultivated at a rate sometimes up to 98%. It needs a small percentage of water, so it must be creating a new economically feasible optimal operating management.

Aflaj in Oman can be classified into three types depending on its source of water; ghaily, daudi, and ainy. However, the methods of administration and management are

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very similar. Ghailyaflaj represents about half of the total aflaj in Oman. The water of these aflaj comes from the base flow of wadi (dried river). Aflaj in Oman can be classified into three types depending on its source of water; ghaily, daudi, and ainy. However, the methods of administration and management are very similar. Ghailyaflaj represents about half of the total aflaj in Oman. The water of these aflaj comes from the base flow of wadi (dried river). According to (Al-ghafri et al., 2000), Aflaj in Oman can be classified into three types depending on its source of water; ghaily, daudi, and ainy. However, the methods of administration and management are very similar. Ghailyaflaj represents about half of the total aflaj in Oman. The water of these aflaj comes from the base flow of wadi (dried river).

Aini falaj: The source of Aini aflaj is a natural source called (Ain). Aini aflaj represents 28% of the total aflaj. Examples of this aflaj are the Ain Al Kasfah falaj in Rustaq in the Al Batinah region and Bousher falaj in the Capital region. Water is transported from the spring to the village through canals for domestic and agricultural use (Figure 1) (Al-Ghafri, 2004).

Gili Falaj: Al-Ghafri, 2018 mentioned that Gili Falaj The closest type irrigation in other countries to Gili aflaj is flood irrigation. Gili aflaj represent 49% of the total aflaj in Oman. The water of these aflaj comes from the main flow of the upper stream of the Wadi (Dry Valley) (Figure 1).

Daudiaflaj: Daudiaflaj represent 23% of the total aflaj in Oman (MRMWR, 2001). The water source is a mother well that has been dug in the depths of the valley floor. Compared to other types of falaj, Daudiaflaj has a more stable flow rate throughout the year (Al-Ghafri, 2018).

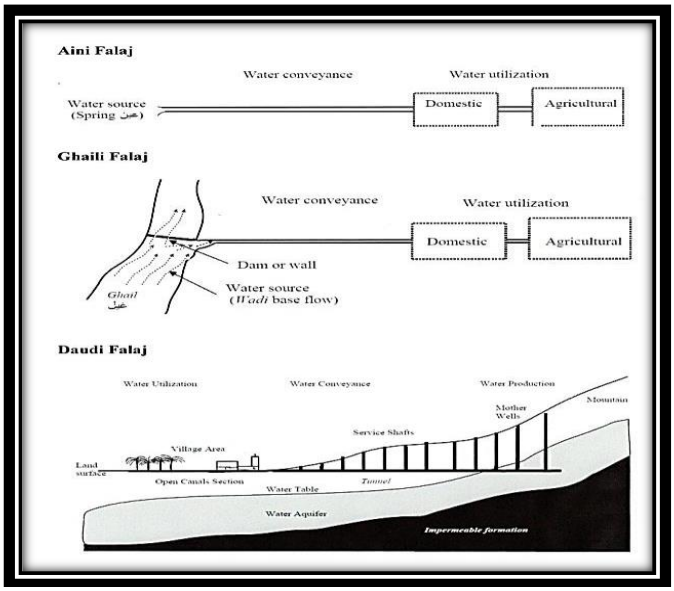

Figure 1 Types of Aflaj in Oman (Abdullah Al-Ghafri, 2004).

Through what has been mentioned, the Ministry of Agricultural Wealth, Fisheries and Water Resources is the government institution responsible for taking care of the water resources sector, as it supervises the maintenance of aflaj and helps citizens benefit from the expertise of the Ministry's engineers in the field of aflaj and their maintenance.

As for operating the falaj and distributing water to the beneficiaries, it is essential for the people and owners of the falaj.

We can briefly explain the operation and design of the water distribution processes for the falaj, as the water distribution is based on the share and share of each individual from the falaj water, which has been dependent since ancient times on the individual's contribution to constructing the falaj, whether with money and if he does not have money, then he does the construction and periodic cleaning And other works that help the falaj flow and reaches the town by gravity and at previously studied levels.

The water is distributed for 24 hours, and the water is divided every half hour. It is called "Athr", which means that one of the individuals has five "Athr", meaning two and a half hours.

The aim of this study is when check the distribution of water because there is an irregular distribution and the much water is wasted without benefit or economic value, so we are looking for solutions that support the distribution of water based on the need of the crops, especially the palm trees, and the surplus is used by increasing the cultivated area.

The share of a person makes him irrigate his farm every day, and this means that the crops do not produce all that amount. The farm owner must cultivate different types of crops because of the water surplus he has, and there is a tremendous economic benefit for his cultivation.

This study focuses on finding an ideal way to manage water distribution in the aflaj of the Sultanate of Oman, as the operational management of the aflaj irrigation system is currently an old system and has no economic value and is not feasible because this system is temporary and is valid for that time in which it was invented because it does not exist at that time. The machinery and equipment required for extracting groundwater and using it for surface irrigation.

Therefore, the optimal method must be found that will benefit the people economically and financially in every village in the Sultanate of Oman and represent a value in the Sultanate's local product, and this is what we will discuss in this study.

We expect through this paper to come up with recommendations towards improving the use of the aflaj water and the method of distributing the water resources of the aflaj, can the operational management of the aflaj water distribution system be re-managed and what is the economic feasibility through the new operational management of the aflaj water resource distribution system as well as studying the degree of acceptance of citizens who own shares of the

aflaj water and what is their opinion about leaving the traditional system that is not economically feasible at present and switching to a new distribution system, and the new operational management of the irrigation system using the aflaj will enhance the water reserve in addition to using the surplus water in the process of growing new crops.

This study aims to find out the reasons for the continuation of the people of Al Aflaj in the Sultanate of Oman using the old traditional irrigation system, what are the solutions and other alternatives to that system, and to find a system for managing the operation of water distribution, where three main objectives were identified, as follows:

-Investigate the reasons for the residents' continued use of the traditional irrigation system for the Aflaj system.

-Determine the relationship between the traditional irrigation system and the modern irrigation system in terms of economic value and market value of water.

-Determine the relationship between the total value of crops produced by the falaj owners and the value of water.

The following research questions are to be answered by this research:

-What is the future impact of the people continuing to use the traditional irrigation system for the Aflaj system?

-What is the relationship between the traditional irrigation system and the modern irrigation system in terms of economic value and market value of water?

-What is the relationship between the total value of crops produced by the falaj owners and the value of water?

II. Operation & Management of the Aflaj System

Al-Marshudi (2001) discussed the comprehensive vision of the Aflaj system in terms of the administrative, financial and ownership structure. He focused on identifying the problems facing the traditional falaj water distribution system.

A unique approach was adopted to examine the operating system and management of the aflaj system between the past and the present and the importance for traditional agriculture in the Sultanate of Oman. (Al-Marshudi, 2001) various sources were used, such as secondary sources, which are based on previous reports and statistics. Primary sources on the organization and current structure were structured using the author's observation collected through random field observation throughout Oman.

These sources were used to discover and examine the

The most important results and outputs that can be enumerated through this study are that the al-Khatimayn falaj faces several issues, the most important of which is the low level of the halal water that the falaj feeds from due to drought, which led to an increase in the number of wells that affect the feeding of the falaj. The waste of freshwater flowing from the falaj due to irresponsible human uses such as washing cars. The pollution of the falaj water due to the use of chemicals and the urban expansion near the falaj threatens the agricultural lands. The young generation's lack of interest in the falajs due to the economic boom caused by oil, experience in this field is seldom passed down through generations, the Bayadir (expert workers) are replaced by expatriate workers (Nizwa, 2017).

management of the aflaj and the approved structure for water distribution in the aflaj and to know the ownership of water and the production of crops. New technology can be introduced to increase the efficiency of water management.

The results revealed the general picture derived from a general examination of traditional agriculture in Oman about the great importance of this Aflaj system. Thus, some development or changes may be required to find solutions to some high priority problems. However, attempts to undertake these measures require careful consideration of prevailing social norms and customs. It is well known that any proposed changes to an existing system may lead to more complex problems. One of the suggestions that emerges from this study is to create an entire market for the right to navigable water as an alternative to the current system. This will include financial burdens that may outweigh the benefits, widen the gap between the rich and the poor, and lead to excessive water transfer outside agriculture. On the other hand, proposing to allocate property rights to communities or societies with the right to allocate internal waters and external trade would raise the well-accepted social base of inheritance and entail financial and legal battles (Al-Marshudi, 2001).

Nizwa (2017) studied one of the famous Dawoudiaflaj in the Sultanate of Oman, which is Falaj Al Khatimin in Birkat Al Mozz area in Nizwa state, which is located in Al Dakhiliyah Governorate. His study aimed to present the Dawoodiaflaj as an environmentally friendly and sustainable groundwater holding system by exploring its management systems by studying the case of the Al-Khatimin falaj and determining the actual condition of this falaj to the issues that may threaten its survival and existence.

Primary data on the aflajchanal was collected through a literature review and presentations at international conferences, and the selection of al-Khattameen falaj came because it is one of the five Omani aflaj that was included in the World Heritage List in July of 2006, as well as its importance from the social survivor. And the division for the water for which the Al-Khatmeen falaj is famous, as well as the flow of the large falaj in one year. All data were collected from the Ministry of Regional Municipalities and Water Resources in the Sultanate of Oman, expert papers, and site visits and interviews with experts and the agent of Al-Khatimayn falaj (Nizwa, 2017).

Abdel Rahmnn&Omezzine (1996) focused on the issues of navigable water in the aflaj system and knowing how to operate the current water rights trading system within the overall process of managing the falaj. Through (Abdel Rahmnn & Omezzine, 1996), they identify the strengths and weaknesses of the water trade system to raise special

recommendations to improve water use efficiency. The researcher tries to search for opportunities that lead to improving the use of water and its distribution system in the area of the two falaj canines—evaluating the potential laws that impede the improper use of water resources in the Aflaj system, which are based on the traditional social customs and rules adopted for renting water and its pricing system.

Abdel Rahmnn&Omezzine (1996)used primary and secondary information sources as the secondary sources were the past studies related to the aflaj system in the Sultanate of Oman. All data and information were made from the statistical reports available in the relevant ministries such as the Ministry of Water Resources and the Ministry of Agriculture and Fisheries. As for the primary sources were collected through random and field observations throughout the Sultanate of Oman, which was about organizing and operating the water rights circulation system. All of this information includes the rules for water trade, water prices, the nature of water tenants, and the conditions related to selling water shares. Many criteria for the efficiency of the operational management of the water sale system are based on technical and economic efficiency, rules and customs of the community, and it also includes standards for the effective use of irrigation water and special costs by distributing water.

The ownership of water for all collective aflaj in the Sultanate of Oman is subject to social rules, which in turn led to the existence of a robust administrative system under the responsibility of the "Aflaj Management Committee", where the "Wakil" is responsible for the administrative aspects of the falaj. Individuals own the water through their inheritance of that water, and it is an asset for the Falaj Foundation and the village's mosque and the community's property in general (Abdel Rahmnn & Omezzine, 1996).

According to Abdel Rahmnn&Omezzine, 1996, water is sold and rented from surplus water owners and the Falaj institution. The water renters are the ones who enjoy extensive rights to the falaj water, and the tenants are the smallest who need an increase in the amount of water to irrigate their farms.

(Al-Marshudi, 2007) examines the temporary markets dedicated to selling water and identifies the obstacles that direct these markets. As the temporary market for Aflaj water in Amman is considered a unique experiment, the experiment will be evaluated and its effects on the water distribution of the Aflaj system.

Al-Marshudi, 2007, collected all data for four years to describe how to assess the water markets for four aflaj in northern Amman. The study focused on the Walayat of Samail, especially in the old city. All information about the financial revenues of selling the aflaj water was collected, and the dividends were made for the winter and summer seasons, as the water levels in the aflaj rose in the winter season and the revenues from selling water decreased because the crops did not need much water. Water levels decrease in the summer due to the high temperatures, which leads to a great need for water for crops, which leads to an increase in the value of water.

Al-Marshudi (2007)revealed essential characteristics of the rents in the traditional Aflaj system. As farmers participate in these markets, they need to increase their share of water. There is only one vendor, and the falaj management committee represents it. Shareholders are not allowed to sell their water individually at the Falaj Water Market. Prices are determined by the auction that is managed by the first official in charge of the falaj. These results lead constructively to the subject of the theory of demand and supply. The study also led to the discovery that water ownership is utterly separate from land ownership. A unique and straightforward water unit that can be compared with the unit of time is used, contributing to the success and sustainability of water markets in the Aflaj system.

Table 1 : Total Aflaj in each Governorates in Oman and their types, Reference: MWR (2000) National Aflaj inventory report, Ministry of Water Resources.

Governorates / Regions	Aflaj type			Total Aflaj	Operational Aflaj
	Daudi	Ghayli	Ainy		
Mu scat	25	84	130	239	173
Al Batinah	193	925	443	1561	1209
Dakhiliya	279	275	196	750	501
Dhahirah /Al Buraimi	152	419	145	716	473
Ash Sharqiyah	318	290	238	846	661
Total	967	1993	1152	4112	3017

III. Falaj Management

The aflaj is distributed in the Sultanate of Oman in all its walayat, especially those villages, the northern mountainous regions, and in the plains, as shown in the following table.

There are traditional units to know the time of water distribution in all aflaj of the Sultanate of Oman, where the parents and grandparents invented specific names to know the share of each individual and the method of distributing water to him according to his ownership. Each is named for

equal to 24 athars. Usually the day is divided to two badda,. the day badda and night badda(Al-ghafri et al., 2010). According to Wilkinson (1977), if a falaj has three badda each day, in this falaj, each badda has sixteen athars, so a the appropriate time, which is the method that can be agreed upon in all aflaj.

According to Al-ghafri et al., 2010, In all aflaj of Oman, the dawran is divided into many subdivisions of time. After dawran is decided, water share is divided between falaj owners using the unit of share athar. Each full-day is divided into one or two badda. Each day should be equal to forty-eight athars, so if the day is one badda, badda will be equal to forty-eight athars. If it is two badda then, each badda will be

whole day is also equal to 48 athars. The number of badda per day varies from one area to another in Oman, as there are rarely three baddas per day, Al-Hajri (1998).

Table 2 Traditional water share units with Equivalent time length (hr), (Referance: Al-ghafri et al., 2010).

No	Traditional water share units	Equivalent time length (hr)
1	Badda	12 Hr
2	Rabia	3 Hr
3	Athar	30 Minutes
4	Qama	7 Minutes
5	Qiyas	1.15 Minutes

Al-ghafri et al (2010) mentioned that the method of Athar is commonly used in Oman's aflaj, where each Athar is divided into 24 Qyas, where one Athar is measured in thirty minutes in practice. The Qyas is considered the smallest unit in the water share in the Sultanate of Oman, which is roughly equivalent to the time required to irrigate one palm tree with a good flow of falaj (Al-ghafri et al., 2010).

Figure 2Scope of Study (A'Shrqiyah North Governorate).

IV. Types of Oman Falaj

Falaj Adhahir:is located in the town of Al-dhair, in the Wilayat of Bidiyah. It is one of the Dawoodiaflaj, as it draws its water from the "Al-Fajra" valley and the "Al-Najd" valley. The total length of the falaj is estimated at 5354 meters from "Sharia", which is the place through which the water appears to the surface of the earth and the end of the falaj at "Umm Al Falaj", which is the last point of the underground falaj channel, where the people benefit from it to irrigate their palm groves, which are estimated at 11,000 date palms.

Falaj Annab: is located in the town of "Annab'a" in the wilayat of Al-Qabil. It is one of the Dawoodiaflaj, as it draws its water from Wadi "Sui" and Wadi "Hadad". The total length of the falaj is estimated at about 4328 meters from "Sharia", which is the place through which the water appears to the surface of the earth, and the end of the falaj at "Umm Al Falaj", which is the last point of the underground falaj channel. The people benefit from it to irrigate their palm groves, which are estimated at 10,000 palm trees.

Yahmadi Falaj:is located in the town of "Al-Yahmadi" in the Wilayat of Ibra. It is one of the Dawoodiaflaj, as it draws its water from the "western" valley. The total length of the falaj is estimated at 5136 meters from "Sharia", which is the place through which water appears to the surface of the earth and the end of the falaj at "Umm al Falaj", which is the last point of the

underground falaj channel, where the people benefit from it to irrigate their palm groves, which are estimated at 8,000 date palms.

All falajs mentioned above are using the same system for distributing water, which is limited to the presence of ownership of the falaj water for some people from the owners of each village, who were in the past wielding significant influence and have capital, and after that their children inherited it generation after generation. A group of people have a small share of water that does not correspond to the number of their crops, while others do not have a share of water, so they buy water from the falaj.

The management of the aflaj in all the aflaj included in the study, which is considered as a model, is based on the presence of a "wakil" for the falaj or "2 wakils" depending on the demographical situation and the composition of the living population in that village, as there is a "one wakil" for the al-Dahir falaj, and the number of a "two wakils" for the falaj Al-Nabaa, and there is "one agent" for Falaj Al-Ahmadi. The objective of Al-Wakeel is to manage the financial and technical affairs of the falaj fully. In Falaj al-Naba, "one agent" is responsible for the financial affairs of the falaj, and another "wakil" is responsible for the technical affairs related to the maintenance of the falaj, assigning projects to maintain the falaj channels, and monitoring the falaj periodically to ensure the presence of any effect that can be done for urgent maintenance, as well as following up the bodies supporting the falaj Which can provide financial, logistical and technical support to the falaj. As for the rest of the aflaj mentioned, the mission of the "wakil" includes all responsibilities in one person.

The distribution of water for the previously mentioned falajs depends on a traditional system for each falaj, but the general idea is the same only, the difference in the names of the water shares. According to the Ministry of Agricultural Resources, Fisheries and Water Resources, palm trees can live in arid conditions compared to other fruit trees, but obtaining abundant Date's production and prosperous growth requires more water than most trees.

By reviewing the average water that a palm receives according to the estimates of the water needs of the date palm tree in the different governorates of the Sultanate issued by the General Directorate of Agricultural and Animal Research, we find that it is 55 m3 / year for each tree.

Each tree = 55 m3 / year = 0,151 m3/day = 150,7 L/day

V. Methodology

This study examines the issue of the traditional management of Aflaj water distribution system and its allocations preferences. The approach of this study is inductive, and to some extent qualitative in nature. It begins with the related current and historical available data within Oman repositories and archives, which were used to draw recommendation, and conclusion.

This study used various primary and secondary sources of information, as the secondary sources were used more through previous studies related to the falajs and data by the Ministry of Agricultural, Fisheries and Water Resources, while the primary sources for the study were collected by randomly selecting the aflaj and collecting data and information about them for use in this search.

Table 3 Physical information of Aflaj and cultivated area (m2), (References: Database of the Ministry of Regional Municipalities and Water Resources 2020).

	E.C. (µmos/cm)	pH	Temperature	Total length (m)	Cultivated area (m^2)
YAHMADI	678	8.372	35	5136	707,672
ANNAB'A	413	8.146	33	4328	583,975
ADHAHIR	421	8.214	34	5354	569,545

Table 4 The No. of palm trees and water requirements of AFLAJ, (References: Database of the Ministry of Regional Municipalities and Water Resources 2020).

	The No. of palm trees	Water requirements m^3/ Day	Water requirements m^3/ year
YAHMADY	8,000	1,208	440,920
ANNAB'A	10,000	1,510	551,150
ADHAHIR	11,000	1,661	606,265

VI. Results and Discussion

According to Figure 3, we note that the water flow in Al-Yahmadi falaj is unstable during the years from 1983 to the current year 2020, and there are some periods in which the flow jumps to its highest levels due to the occurrence of heavy rains during the year 1998, where the flow equals 177.25 liters / second . As for the lowest flow recorded in Al Falaj was in 2004, when it recorded 11.40 liters / second as the average flow for that year. When reading the flow of Al-Yahmadi falaj and comparing it with the water needs of the palm trees, there is a significant increase in the needs, and this means that the surplus water is used for intensive irrigation of crops and cannot be used to increase the cultivated area, and this is due to the traditional administration of managing aflaj in the Sultanate in general because the management system The operational water distribution is very similar.

Through the interviews we conducted with the "Wakil" of each falaj from the aflaj that were included in this study, the distribution of the falaj water depends on the ownership of each person who has known shares of water. But there are some people who own a more significant share of water, so that some of them have the flow of water in the falaj for 48 hours, which is a large amount of water compared to the number of palms they own. On the other hand, some people do not own a share of the falaj, but they have several palm trees, and they irrigate these palms by purchasing water shares from other people. There is one day devoted to trading the falaj water for 24 hours, and the return from the market for selling the water of the falaj goes to the maintenance of the falaj, which includes the technical maintenance of the falaj channels, the ventilation rooms and the maintenance of the internal channels of the falaj. According to the "Wakil" of each falaj, in the past, some of the money that came from selling the falaj water went to the maintenance of the village mosque and the place designated for bathing, washing clothes and utensils for all residents of the village.

Regarding the operational management of the water distribution operations of the falaj, all aflaj in the North A'Sharqiyah Governorate and the Sultanate of Oman in general are based on ownership of the falaj water. On the other hand, the crops are irrigated for the owners of the falaj according to the well-known and traditional water distribution, which is called "circulation" which means the beginning of the distribution of water to the first person and the rotation of the distribution of rations for each person until all is completed so that the distribution begins again according to the same system and routine. This traditional system for distributing the falaj water in every town, we can call it the "life cycle of the falaj water distribution."

Table 5 Discharge of AFLAJS from 1983 until 2020 (L/Sec), (References: Data for monitoring the water situation in the database of the Ministry of Regional Municipalities and Water Resources).

Falaj / Year	ADHAHIR (L/Sec)	ANNAB'A(L/Sec)	YAHMADY (L/Sec)
1983	122.80	103.29	101.40
1984	123.50	62.80	125.00
1985	95.75	47.80	75.80
1986	63.00	32.40	35.50
1987	52.00	69.00	50.25
1988	54.00	54.00	90.00
1989	60.93	33.00	73.00
1990	75.00	99.40	73.60
1991	105.64	68.30	129.36
1992	133.36	68.88	82.09
1993	114.67	101.64	63.90
1994	100.46	53.80	45.91
1995	85.00	83.50	53.36
1996	88.42	148.30	118.25
1997	146.75	231.50	154.46
1998	199.56	305.73	177.25
1999	212.08	130.16	153.46
2000	153.94	48.37	80.09
2001	114.14	33.98	32.55
2002	61.33	20.53	23.83
2003	37.42	17.52	12.67
2004	14.59	10.88	11.70
2005	13.65	29.29	18.17
2006	39.18	61.58	17.25
2007	92.17	114.82	29.20
2008	60.36	65.70	80.09
2009	99.44	39.00	50.00
2010	68.38	118.00	25.00
2011	72.67	47.50	26.00
2012	138.18	73.50	43.90
2013	128.33	111.00	66.00
2014	139.08	132.29	84.89
2015	121.82	64.40	113.60
2016	141.36	57.00	96.75
2017	152.70	32.25	84.27
2018	144.17	19.00	40.86
2019	83.33	34.25	13.20
2020	52.50	72.00	11.50

Table 6 The Number of palm trees in North A'Sharqiah Governorate with Palm yield average & Date production quantity (tons) / year, (References: Report of the Results of the Agricultural Census 2012/2013, Volume (10), North Sharqiya Governorate, Deposit Number:

	Number of palms	Palm yield average (kg) / Palm	Date production quantity (tons)
North A'Sharqiah Governorate	494,128	46.57	41,781

Table 7 The Number of palm trees in three villages with Palm yield & Sales value of dates production / year, (References: database of the Ministry of Regional Municipalities and Water Resources & Report of the Results of the Agricultural Census 2012/2013, Volume (10), North A'Sharqiya Governorate, Deposit Number: 135/2014.).

Aflaj Name	The No. of palm trees	Palm yield average (kg) / year (The average palm yield per kg is 46.57)	Sales value of dates production / year (Average price: 0.5 kg RO)
YAHMADY	8,000	372,560	186,280 R.O
ANNIBA	10,000	465,700	232,850 R.O
ADHAHIR	11,000	512,270	256,135 R.O

Table 8 The Discharge of ADHAHIR falaj with The value of the falaj water price compared to the desalination water production price, (References: database of the Ministry of Regional Municipalities and Water Resources & The annual report of the Public Authority for Water 2019).

Falaj / Year	ADHAHIR (m^3/year)	The value of the falaj water price compared to the desalination water production price (2.282 R.O per m^3/year)
2015	3,841,715.52	8,766,794.817
2016	4,457,928.96	10,172,993.89
2017	4,815,547.2	10,989,078.71
2018	4,546,545.12	10,375,215.96
2019	2,627,894.88	5,996,856.116
2020	1,655,640	3,778,170.48

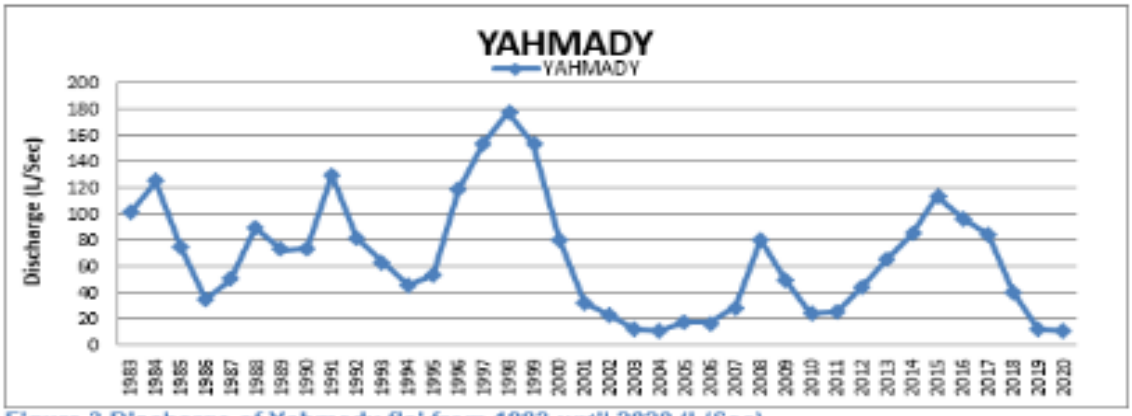

Figure 3 Discharge of Yahmady flaj from 1983 until 2020 (L/Sec).

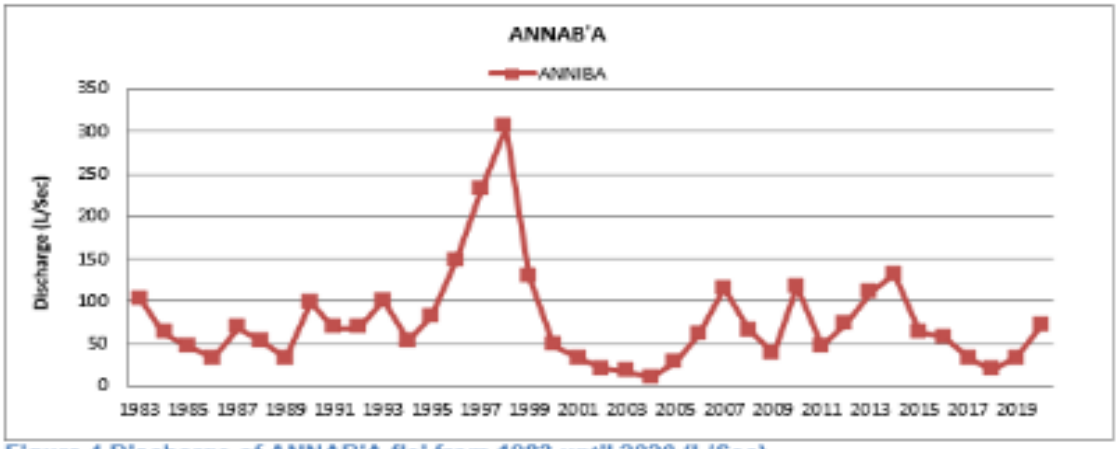

Figure 4 Discharge of ANNAB'A flaj from 1983 until 2020 (L/Sec).

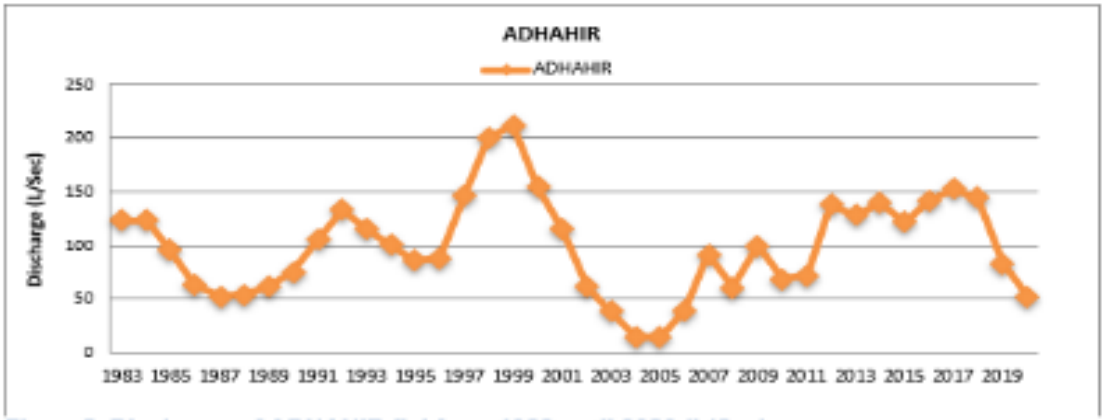

Figure5 Discharge of ADHAHIR flaj from 1983 until 2020 (L/Sec).

Table 9 The Discharge of ANNIBA falaj with The value of the falaj water price compared to the desalination water production price, (References: database of the Ministry of Regional Municipalities and Water Resources & The annual report of the Public Authority Water 2019).

Year	Falaj ANNAB'A (m^3/year)	The value of the falaj water price compared to the desalination water production price (2.282 R.O per m^3/year)
2015	2,030,918.4	4,634,555.8
2016	1,797,552	4,102,013.7
2017	1,017,036	2,320,876.2
2018	599,184	1,367,337.9
2019	1,080,108	2,464,806.5
2020	2,270,592	5,181,490.9

Table 10 The Discharge of YAHMADY falaj with The value of the falaj water price compared to the desalination water production price, (References: database of the Ministry of Regional Municipalities and Water Resources & The annual report of the Public Authority Water 2019).

Year	Falaj YAHMADY (m^3/year)	The value of the falaj water price compared to the desalination water production price (2.282 R.O per m^3/year)
2015	3,582,490	8,175,241.3
2016	3,051,108	6,962,628.5
2017	2,657,539	6,064,503.4
2018	1,288,561	2,940,496.1
2019	416,275.2	949,940.01
2020	362,664	827,599.25

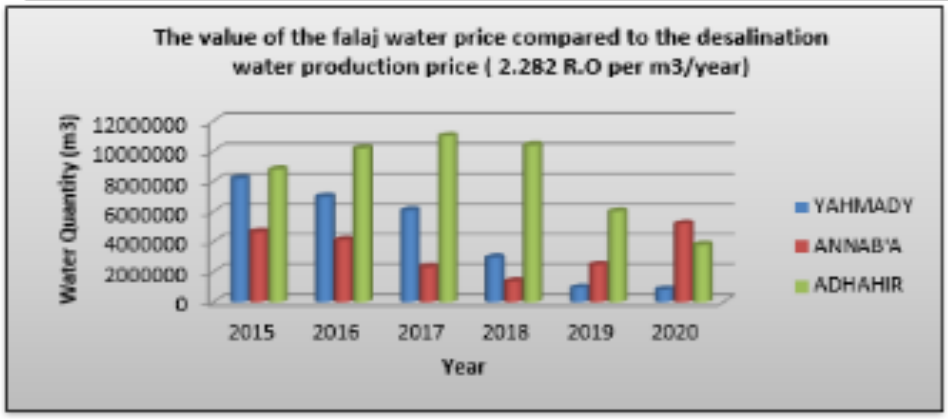

Figure 6 The value of the falaj water price compared to the desalination water production price (2.282 R.O per m3/year).

Table 11 Sales value of dates production / year and The value of the falaj water price compared to the desalination water production price and The difference between them, (References: Report of the Results of the Agricultural Census 2012/2013, Volume (10), North A'Sharqiya Governorate, Deposit Number: 135/2014. & The annual report of the Public Authority for Water 2019).

Aflaj Name	Sales value of dates production / year (Average price: 0.5 kg RO)	The value of the falaj water price compared to the desalination water production price (2.282 R.O per m³/year)	The difference between the water value and the annual crop yield per falaj
YAHMADY	186,280 R.O	949,940.01	763,660
ANNAB'A	232,850 R.O	2,464,806.5	2,231,957
ADHAHIR	256,135 R.O	5,996,856.116	5,740,721

Table 12 The Drinking Water Production from Jan 2020 to Aug 2020 with Water Production (m3/month), (References: The annual report of the Public Authority for Water 2019).

Time (Month of 2020)	Water Production (m³/month)
Jan 2020	36,403,601
Feb 2020	34854,312
Mar 2020	37,706,876
Apr 2020	38,547,051
May 2020	40,951,348
Jun 2020	41,415,027
Jul 2020	41,918,142
Aug 2020	42,411,790

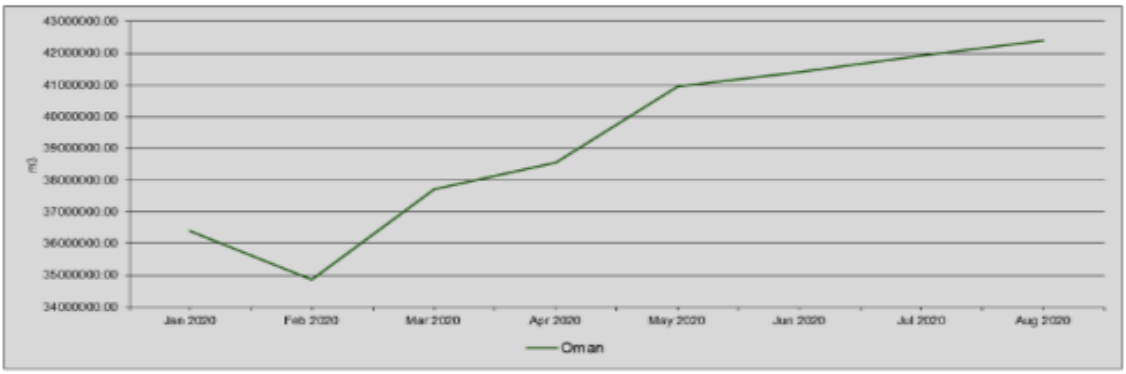

Figure7 The Drinking Water Production from Jan 2020 to Aug 2020 with Water Production (m3/month), (References: The annual report of the Public Authority for Water 2019).

The method that is currently used to irrigate crops in all Omani villages is the traditional method (the water immersion method), which is one of the methods that drain large quantities of water as the date palm does not benefit from it so that some of it evaporates while others penetrate the ground.

According to the National Center for Statistics and Information in the Sultanate of Oman, the average production the Sultanate of desalinated drinking water for the first 8 months of 2020 (January 2020 - August 2020) amounted to (39,276,018.38) million cubic meters of water.

The data and information of the Public Authority for Water in the Sultanate of Oman indicate that the average cost of producing one gallon of water is (0.00595455 RO). This means that the average production costs for drinking water desalination are equal to the following equations:

The average cost of producing 1 m^3 :

1 m^3 = 220 gal

1 m^3 = 220 gal × 0.00595455 R.O = 1.31 R.O

APC = 39,276,018.38 Mm^3 × 1.31 R.O

APC = 51,451,584.071 R.O

Where APC = average production costs

In addition to the distribution cost per cubic meter (0.972 RO), it means that the total costs until the water reach the consumer's place is:

TC = 1.31 RO + 0.972 RO

TC = 2.282 RO

Where TC = Total Cost of Water Production & Distribution

According to the General Authority for Water in the Sultanate of Oman, the value of one gallon of water equals 0.0020 Omani Rials, which is the price of drinking water, which means that one gallon is equal to 3.8 litres, meaning that the value of one litre is equal to 0.000526 Omani Rial

1 m^3 = 220 gal

1 m^3 = 220 gal × 0.0020 R.O = 0.44 R.O

According to a statistic issued by the Ministry of Wealth, Agriculture, Fisheries and Water Resources for 2019, the North Sharqiyah Governorate production of dates amounted to 41,781 thousand tons.

Table 11 shows the sales value of date palm crops in each town during 2019, with an average value of 0.5 RO / kg. By comparing this with the production of the falaj from water (the flow of the falaj during 2019) and calculating the value of the water for that quantity, the difference between them is substantial, and this leads us to conclude that the economic value of the produced crops does not cover the actual value of the water, which is priceless. And when we look at Al-Yahmadi falaj, which is the lowest in terms of the annual production value of crops and the amount of water produced. The difference between the sales value of date palm crops and the actual water value of Al-Yahmadi falaj amounted to (- 763,660 RO). It can be measured for the rest of the falaj, and this is a good indication that the current management of the falaj water distribution is not economically feasible.

The government of the Sultanate of Oman is making many efforts by building seawater desalination plants to provide drinking water to the citizens and residents of Oman. According to the Water Authority, the Total Cost of Water Production & Distribution is equal to (2.282 RO), but in return, it is sold to the consumers at an amount of (0.44) RO per m3. The government should cover the rest of the costs, which are estimated (1.842 RO) through the support that the government provides to citizens and residents (consumers).

Table No. (8) shows the flow of the falaj water during the past 6 years (from 2015 to 2020), where when compared with the water needs of the town of al-Dahir, there is a big difference, meaning that the flow is greater than the needs, and this means that there is a surplus of water that is not being used. If we take the flow of Al-Dhahir falaj for the year 2020 (1,655,640 m3 / year), and the total water needs (606,265 m3 / year), meaning that there is a water surplus estimated at:

= 1,655,640 m 3 / year - 606,265 m 3 / year

= 1,049,375 m3 / year

By referring to the value of the cost of desalinated water in the Sultanate of Oman, which is shown in Table No. (8), each m3 costs the government of the Sultanate of Oman an amount of 1.31 Omani Rials, meaning that the water surplus from the flow of Al-Dhahir Falaj equals costs estimated:

= 1,049,375 m3 / year × 2.282 RO

= 2,394,673.75 OMR

Land and water resources are primary capital for humanity. They are mainly location-specific. Although water is transferable to some degree, its transferability is governed by physical, economic, social, political and legal constraints. Oman is an arid country. Water abstraction exceeds the annual recharge. Limited possibilities for new water sources exist. The government is working on augmenting water supplies, adopting conservation and improved management policies. (Abdel-magid, 2017).

VII. Conclusion and Recommendation

Water is of high value, especially in the Sultanate of Oman, where this country is located within impoverished water areas. This made the Omanis look for various solutions to bring water to their areas and crops, and the best example is the aflaj. In the past, the Omanis introduced an operational management method for distributing water to the beneficiaries, and that administration has remained in place to this time. Presently, that administration must be changed to an optimal operational administration whose goal is to preserve the value of water from waste compared to the needs and the traditional irrigation method. There are efforts exerted to persuade the owners of the falaj to apply modern irrigation, but the elderly are the ones who are against those ideas, but when reading the current administration of the falaj in terms of numbers, the water waste that the owners of the falaj make is a waste of millions of riyals without interest.

There is an annual surplus of Aflaj water that is wasted and a victim of the traditional management of the Aflaj system. Traditions, customs, and internal laws in each town

stand as obstacles to changing the aflaj system's operational management, and the government cannot interfere with these agreed-upon norms. On the other hand, I see the need to educate the owners of the aflaj in all regions of the Sultanate that the traditional administration of the Aflaj system is not commensurate with the present time because of its disadvantages issue of wasting water. The date palms are irrigated randomly, and some people have shares of aflaj water that exceeds the number of palm plantations, but the palm trees are irrigated periodically during comparable periods throughout the year. The traditional operational management of the falaj water distribution should differ during the year's seasons, as the summer season differs from the winter season through irrigation and the palm's need for water quantities.

According to the Ministry of Agricultural, Fisheries Wealth and Water Resources, the water needs of the palm tree vary according to the climate and season. Low temperatures, as in winter, slow down growth and reduce evaporation, reducing or stopping the need for water. With the rise in low temperatures over time, growth, evaporation, transpiration increase, and thus the need for water reaches its peak in June and July.

In general, it is recommended to irrigate palm trees once every 4-7 days in summer, 10-14 days in winter, and 8-9 days in moderate heat. Naturally, these estimates are affected by soil factors, the variety and the size of the date palm (MAFWR).

We recommend changing the current traditional operational management of the Aflaj water distribution system to a modern system that saves the actual water value from waste. We also recommend that the owners of the falaj should tend to use and apply modern irrigation for their farms and take advantage of the surplus water to increase their crops in the lands surrounding the village. The government should grant the owners of the falaj, who own the most significant shares of water from the falaj, lands and areas to grow economically feasible crops, which would achieve a more significant contribution to the agricultural sector in the GDP in the Sultanate of Oman.

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