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TRADITIONAL IRRIGATION SYSTEM AND METHODS OF WATER HARVESTING IN THE OASIS OF SFISSIFA KSOUR MOUNTAINS - ALGERIA

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ABSTRACT

Groundwater serves as the most reliable source of water both for domestic use and for irrigation in arid zones, which are characterized by low rainfall and high evaporation. To overcome the water scarcity in these regions traditional water management systems were locally developed. This study was conducted on the oasis of Sfissifa, which is situated in the Wilaya of Naâma in the southwest of Algeria. The main objectives of this study are to present the ancestral agricultural system of the region named "Tissfalt" and to assess the suitability of groundwater for drinking and irrigational purposes. The essential idea of Tissfalt is that of a gently sloping tunnel, often along the radius of an alluvial fan, which extends upslope until the water table is tapped and emerges at the downslope end to supply the oasis. It plays an important role in the social and economic development of the oasis. It's considered also as a factor of stability enabling and regulating social interactions. Groundwater samples were collected and analyzed for major anions and cations. Physicochemical parameters such as electrical conductivity (EC) and total dissolved solids (TDS) were also measured. From the results of the analyses and measurements, the assessment of water potential for drinking uses was evaluated using physicochemical parameters, while the suitability for irrigation was evaluated based on the sodium adsorption ratio (SAR) and the percentage sodium (%Na), Wilcox diagram was also applied. The results show that all water samples analyzed fell within Algerian Standards' guidelines limit, and also classify the groundwater as excellent for irrigation purposes.

Keywords: Water, Tissfalt, Sfissifa, Ksar, Irrigation

INTRODUCTION

In semi-arid regions, where rainfall is scanty, many water management systems were developed to provide irrigation water for agriculture through the centuries ago, such: Foggara in Algeria, Qanat in Iran, Faldj in Oman, and Khettara in Morocco (El Faiz and Ruf, 2010; Remini, 2018; Wulff, 1968). To overcome the water scarcity in these regions traditional water management systems were locally developed. These practices traditionally used by local people made the best possible use of the scarce water resources and difficult conditions created by the aridity of the climate (Steduto et al., 2018). Foggara is built by a small group of skilled workers by hand. With proper maintenance, the Foggara create self-sufficient agriculture in enclosed gardens. The foggara in Algeria has played an important role in the growth and stabilization of oases in the Algerian Sahara for over a millennium. The foggaras are a succession of wells linked by underground canals going to the fields. The canals should provide enough water for upstream palm groves ensuring enough for those downstream, according to the tradition and the water rights prescribed by ancestral contracts. Their primordial role is to discharge water from the non-renewable aquifers to the gardens. The ingenuity of Foggara in Algeria systems has been recorded by many authors in various areas (Remini and Achour, 2013; Remini et al., 2015; Remini et al., 2012; Remini et al., 2014). However, the Foggara is more than an irrigation system: It embodies the traditional social structure of a Ksar, enabling and regulating the social interactions that are based on the most precious element, freshwater. Whether it is Qanat, Khettara, Falj, or Foggara, all these techniques have the same operating principle; this involves collecting water using drainage galleries fitted with aeration shafts. However, the source of water collected differs from one process to another. Remini et al. (2010) identified seven types of foggara in Algeria, namely: those that receive water from the water table at the foot of a mountain range; those that drain the waters of the intermittent streams; which receive waters from the "Continental Intercalaire" aquifer; which receive water from a spring; which receive the waters from the Occidental Great Erg aquifer; which capture drainage and infiltration; and finally, those that capture only floodwaters. The Wilaya of Naâma situated in the southwestern of Algeria has several Foggaras which play a major role in the socio-economic life of the oases. The distribution of foggaras is mainly located in the Ksour region (Ksar Sfissifa, Ksar Moghrar, Ksar Ain Sefra, Ksar Asla). This study was conducted on the oasis of Sfissifa, which is situated in the Wilaya of Naâma in the southwest of Algeria. The main objectives of this study are to present the Foggara of the region named locally "Tissfalt", and to assess the physicochemical properties of water.

DESCRIPTION OF THE STUDY AREA

The region of Sfissifa is situated in the Ksour mounts, at the southwest of Algeria. The geographic situation is between 3659662 to 3663227 m N and 648,062 to 719,500 m E, and it covers an area of 2438.61 km^2, representing 08% of the territory of the Wilaya of Naâma (Figure 1).

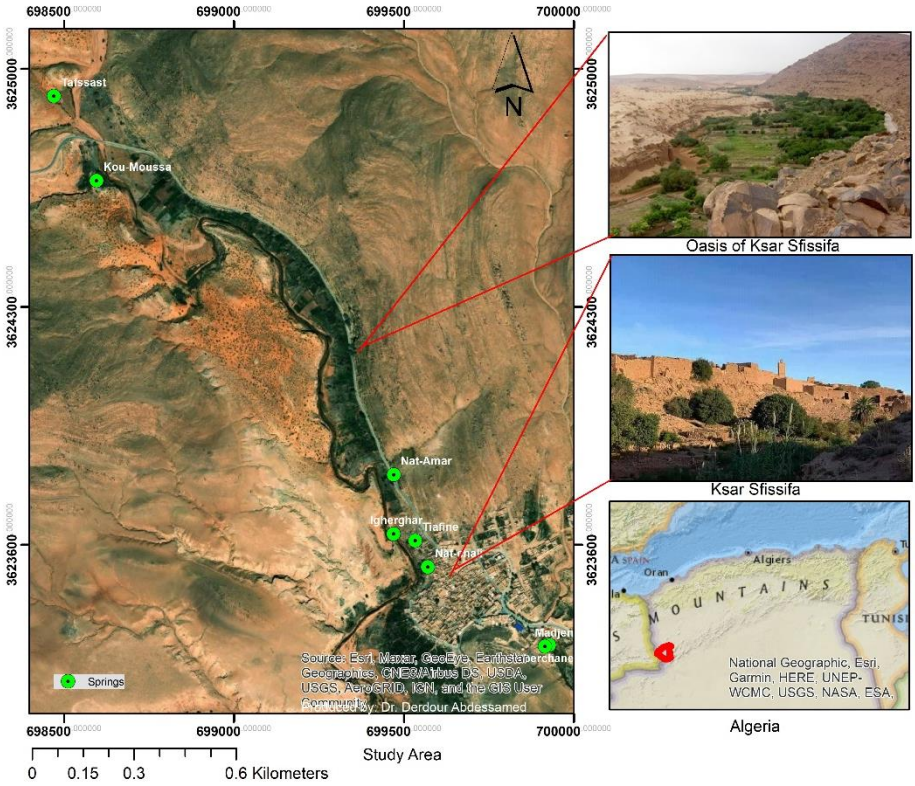


Figure 1. Study area (Derdour, 2021)

According to the Directorate of programming and budget monitoring of the Wilaya of Naama, the total population of Sfissifa is around 7,704 inhabitants, with a density of 3.16 (Hab/ km^2) where, the nomadic population is greater than the sedentary population, which represents nearly 60% of the total population. The majority of the population depends on groundwater resources for drinking and agriculture (Derdour et al., 2017; Derdour and Bouanani, 2019). The study area is characterized by an arid climate, with a high temporal and spatial irregularity (Derdour et al., 2018; Derdour et al., 2021). Our study focuses on

the oasis of Sfissifa, which is located in the center of the municipality of Sfissifa; characterized by its high agricultural activity, and was built in the middle of the 10th century. The agricultural area of Sfissifa represents an important agricultural field in the region that feeds locals with vegetables, tree crops, and cereals. More than 190 farmers irrigated their garden daily by natural springs (Ayounes), of an area of 59 ha, with a length of more than 03 km. This zone represents practically the only green zone in the region. For centuries, agriculture was practiced on alluvial deposits on the banks of the wadi. The traditional irrigation system in the oasis is called "Tissfalt". Tissfalt is for the inhabitants of the region of Sfissifa, a factor of stability, a permanent source of water, and the main component of economic and social development.

WATER RESOURCES

Sfissifa is a region with a pastoral and agro-pastoral vocation that has quite significant water resources.

Surface water resources

The surface water mobilized through the Wilaya of Naâma is estimated at 11 million m^3 /year (DRE, 2019). The surface water in Sfissifa is classed as a semi-permanent (ephemeral) surface water, which refers to bodies of water that are only present at certain rainy times of the year including seasonally dry Wadis. The large wadis that cross the region of Sfissifa are:

- Wadi Allel: which crosses the area from north to south.
- Wadi Ouzeght: Which originates in the part which divides it between the basin of Djebel El-Oust and that of El Gouachiche.
- Wadi Tala: Which takes its departure from Djebel Hadjer to join downstream near the locality of Ouzeght.
- Wadi Rouis el Abiad: Which also starts from the dividing line between Djebel El-Oust and that de Gouachiche and joined on his part Ouzeght region

Groundwater resources

Groundwater is an important part of the water resource. They have the advantage of their regularity, their low mobilization costs, and their good spatial distribution. It is also resourceless vulnerable to climate hazards and pollution. This resource is unique, which gives it an exceptional value. The majority of the population in arid and arid areas depends on groundwater resources for drinking and agriculture. The dominant geologic formations in the region are the sandstone rocks (Jurassic and Cretaceous), but they are usually clayey interspersed by marl or compact quartz, their permeabilities are generally very low,

except for the Albian sandstone which constitutes the most important groundwater aquifer in the region which is characterized by confined to semi-confined conditions (Rahmani *et al.*, 2017). Groundwater is exploited by wells, springs, and boreholes by various traditional and modern methods.

MATERIAL AND METHODS

This study was based on two parts. The first part is field trips and surveys carried out with oasis inhabitants and springs owners, where around ten prospecting trips were carried out. Interviews and investigations were conducted with the local population to identify the water sources and to understand the method of water sharing. The questionnaire addressed to the farmers who use irrigation, in the oasis of Sfissifa is presented in Figure 2. In addition, also an interview was conducted with the local associations in charge of agriculture in the study area. The farmers responded to the different questions, which helped us to get the primary data. The questions were related to demographic data (Name, Family, Age, Education level), Main activities, and the source of water they use in irrigation. They also provided the response to the questions related to the system used for sharing water for irrigation, the variations of flow rates of water, they also provided their view on the satisfaction of these sources of water. However, the second part was based on sampling and physicochemical analysis of spring waters. The samples were analyzed in the laboratory of the Algerian water company (ADE Naâma), and the laboratory of the University of Naama. Given the future development of agriculture in the study area, the evaluation of water quality for irrigation purposes was assessed using the sodium adsorption ratio (SAR) and Wilcox diagram.

Farmers' questionnaire

Reference: ---/------

Date: --/--/2021

Place:.....

Name of the farmer (optional): .....

1. Age: .....
2. Family: .....
3. Academic level:

☐ Illiterate
☐ Primary Education
☐ Secondary Education
☐ University

4. Main activity of the farmer:

☐ Agriculture
☐ Livestock breeding
☐ Mixed

5. Which is the source of water do you use in irrigation?

☐ Tafssast ☐ Tiafine
☐ Kou Moussa ☐ Igherghar
☐ Nat Chali ☐ Madjen
☐ Nat Amar ☐ Niberchane

6. You use the source for:

☐ Agriculture purposes
☐ Drinking purposes
☐ Mixed purposes

7. What system do you use for sharing water for irrigation?

☐ Kharouba (45 min)
☐ Thamna (90 min)
☐ Rabaa (3 hours)
☐ Tnina (12 hours)

8. in your opinion, have you noticed a change in the flow of the source?

☐ Yes
☐ No

9. Is the source of water, that you use, enough to irrigate your crops?

☐ Yes
☐ No

Thank you

Figure 2: Farmer's questionnaire

RESULTS AND DISCUSSION

Data analysis

The oasis of Sfissifa was built on water springs. From these buildings, a high irrigation network named « Tissfalt » carries water to the garden of Ksar. Thus, each region in the oasis exploits its springs, which reach the gardens through a network of canals managed by various social devices rooted in the mores. The group of wise men (Djamaa), a figure of traditional knowledge and social water management, ensures the fair distribution of water shares by Nouba, unlike the oases of the Sahara (Gourara, Touat, Taghit ... etc) where the sharing of water is charged by the Kial El Ma (the one who measures the water shares). A respectable person (usually the Mkaddem) is appointed by the Djamaa to

control the sharing of water. The oasis of Sfissifa is distinguished by its many gardens where many fruit trees, cereals, fodder plants, and vegetables are still cultivated. The fine spatial organization to distribute access to water and sun according to the needs of each plant illustrates another facet of the traditional knowledge of the people of Sfissifa. The inhabitants of the oasis exploit the waters of the springs by an ancestral system. Over the years, families and gardens multiply; the water of each spring becomes the property of several families or a tribe. Sharing water becomes a necessity between co-owners. Ancestral rules and laws have been established in the oasis to share water between the co-owners with rigor and justice. The principle adopted is that the water share depends on the contribution of each owner.

A total number of 43 questionnaires were administrated to the irrigation farmers selected randomly as well the association of Tnant was interviewed (Figure 3). The original questionnaire was written in the Arabic language, then translated into the English language. The characterization of socio-economic activities of the respondents was based on the identification of their name, family, age, and level of education. Hence based on the results, a total number of 43 respondents participated in this research, 32.8% were old adults (> 60 Year); while 34 % were middle-aged adults (40-60 years), and 17.2% of the respondents were young adults (20-40 year). During this study, 5.2 % of the respondents did not attend any school and they did not have any basic knowledge on how to write and to read, whereas 46.1 % of the respondents attended primary school; 45.3 % of the respondents attended twelve years of basic education and 4.4 % were the university graduate. All farmers who participated in this study used water for both drinking and irrigation purposes, and the main activities of the farmer are agriculture and livestock breeding. According to the survey, the water is shared in the oasis of Sfissifa by an hourly sharing called “Nouba”. Like many oases in foggaras, the unit of sharing adopted in the oasis of Sfissifa is the time called "Kherrouba" of 45 minutes. In the study area, eight (08) springs were inventoried namely: Tafssast, Kou Moussa, Nat Chali, Nat Amar, Tiafine, Igherghar, Madjen, Niberchane. Each spring has its owner as shown in Table 1. The distribution of the water from each source is ensured between the owners by water round as a function of time. This technique requires the obligatory presence of the person concerned with the distribution of water, some people may have their turn after sunset and some trees in the garden do not need water the excess of irrigation can affect the profitability of some plants. To remedy these problems, irrigators have opted for water storage in “Madjen” (volumetric sharing) accumulation basins, as is the case for the “Tit Niberchane” spring and the “Nat Chali” spring. There are significant advantages to this ancestral system including putting the majority of the channel underground reduces water loss from seepage and evaporation; since the system is fed entirely by gravity, the need for pumps is eliminated; and it exploits groundwater as a renewable resource. Different from Tissfalt from the Foggara of other regions of Algeria is that Tissfalt was built in stones.

The Tafssast spring

The Tafssast Spring called also (Ras El Oued) is located at the upstream part of the oasis of Sfissifa. It was listed as the most important spring in the region. The spring UTM geographic coordinates are 3624920.00 m N and 698471.00 m E. The spring emerges on top of the hill at a height of about 1239.00 m above sea level. Based on field visits, it is clear that this hill is mainly formed of sandstone and limestone. The technique of transporting water from this source is subdivided into two parts: An underground part called "Tissfalet" with more than 1400 m in length and contains 18 aeration wells to remove excavated material and to provide ventilation and access for repairs, and the second surface part with surface canals called (Seguïas), the length of Seguia ranges from a few meters to hundred meters (Figure 4). They transfer water from the spring to the gardens to ensure gravity flow, with low slopes varying from 1% to 4-5%. The flow rate of this spring is of the order of 2.00 l / s, the flow rate of the source varies according to the season and the rainfall. The "Tafssast" spring is used for irrigation in the area called "Elghabate" up to the "Oudjik" plot over a length of 02 km for an area of 14.5 ha.

a) Hadj Keftouna Yahia (Ancient “Kial El Ma”)

b) Lessehal Chikh

Figure 3: Some farmers participating in the survey (Derdour, 2021)

Table 1. The owners of springs in oasis of Sfissifa

Spring	Owners (Family)	Observation
Tafssast (Ras El Oued)	Ouled Mouloud, Ouled Kaddour, Ouled Abbas, Ouled Chikh, Ouled Larbi, Ouled Kerfis, Ouled Habbou, Ouled Chali, Ouled Hellou, Ouled Mostefa	Operational
Kou Moussa	Ouled Kabou, Ouled Dahou, Ouled Benalia	Operational
Nat Amar	Ouled Amar	Out of service
Tiafine	Ouled Azzouzi, Ouled Baya, Ouled Benalia, Ouled Larbi, Ouled Khaled, Ouled Chali, Ouled Mostefa, Ouled Ziane	Operational
Chali	Ouled Chali, Ouled Mouloud	Operational
Igherghar	Ouled Chikh, Ouled Abbas, Ouled Kaddour, Ouled Moussa, Ouled Mostefa	Operational
Madjen/Niberchane	Ouled Kaddour, Ouled Amor	Operational

The Kou-Moussa spring

The Kou-Moussa Spring is located just near Tafssast spring, which is only about 288 m to the south. The spring UTM geographic coordinates are 3624671.00 m N and 698596.00 m E, and the altitude is about 1233 m, and it irrigates an area of only 01 ha (Figure 4). It was once among the mainsprings of water for irrigation and consumption by bedouin farmers and herders of the region, but unfortunately, now it is neglected by its owners, and it requires adequate management. Currently, the plots irrigated by this source are abandoned, although the spring is still operational. The flow rate of this spring is inferior to 1.00 l / s.

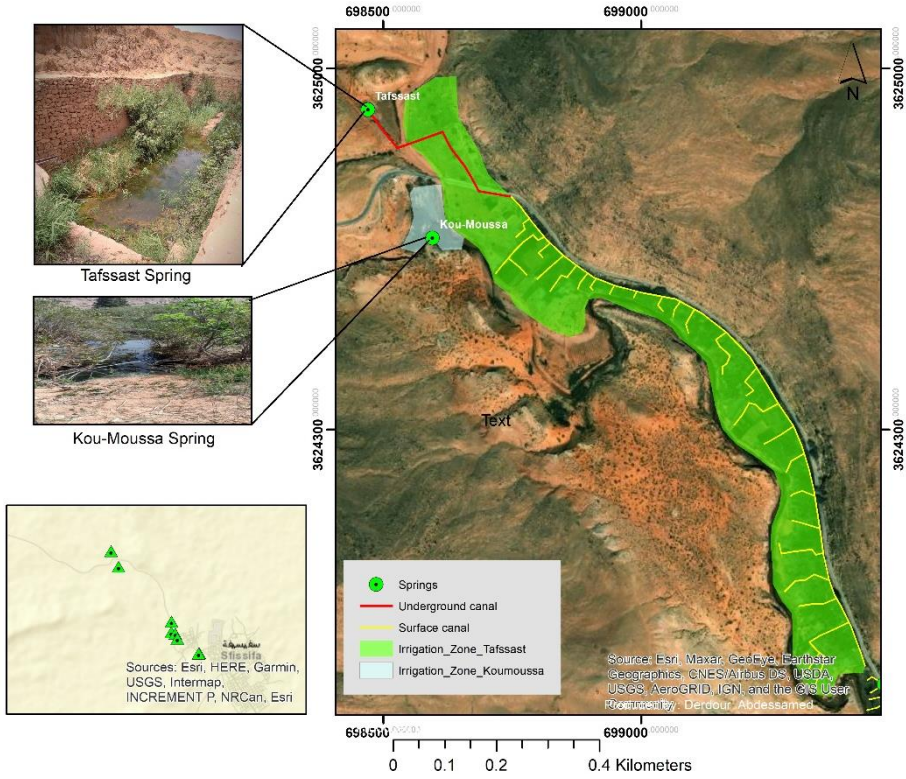


Figure 4: Tafssast and Kou-Moussa springs irrigation system (Derdour, 2021)

The Nat-Chali, Nat-Amar and Tiafine springs

The Nat-Chali is a spring coming from a cave ceiling which is located at 3623535.00 m N and 699571.00 m E near the Ksar of Sfissifa (Figure 5). From this spring, the water flows in a Seguia to the storage basin called "Madjen" which stores water, then from the Seguias (channel with a lower section than that of the Madjra), the water arrives in the Guemouns. (Gardens). The waters of this source irrigate an area of only 0.42 ha. The flow rate of this source is of the order of 02.5 l/s, the flow rate of the source varies according to the season and the rainfall. The Nat Amar spring is located at 3623806.00 m N and 699471.00 m E, downstream of a hill reservoir, and it is no longer operational after the drought that hit the region. Tiafine spring is located in the lower reaches of Wadi Sfissifa and irrigates an area of 6.26 ha. The spring UTM geographic coordinates are 3623612.00 m N and 699534.00 m E, with an altitude of 1222.72 m. It is characterized by a high flow rate compared to other sources which is around 3 l / s.

Igherghar spring

Igherghar spring is located at 3623632.00 mN and 699470.00 mE. It's a high flow source with a flow rate of 3 l/s, which is located on the bank of the wadi near the ksar, such as the Tafssast spring, the technique of transporting water from the "Igherghar" source from the so-called "Tijane" area to 'in the area called "Taourirt", it subdivides into two parts: an underground part "Tissfalet" with 490 m in length, then a surface part where the water is conveyed by Seguïas over several kilometers where it irrigates an area of 08.5 ha (Figure 5).

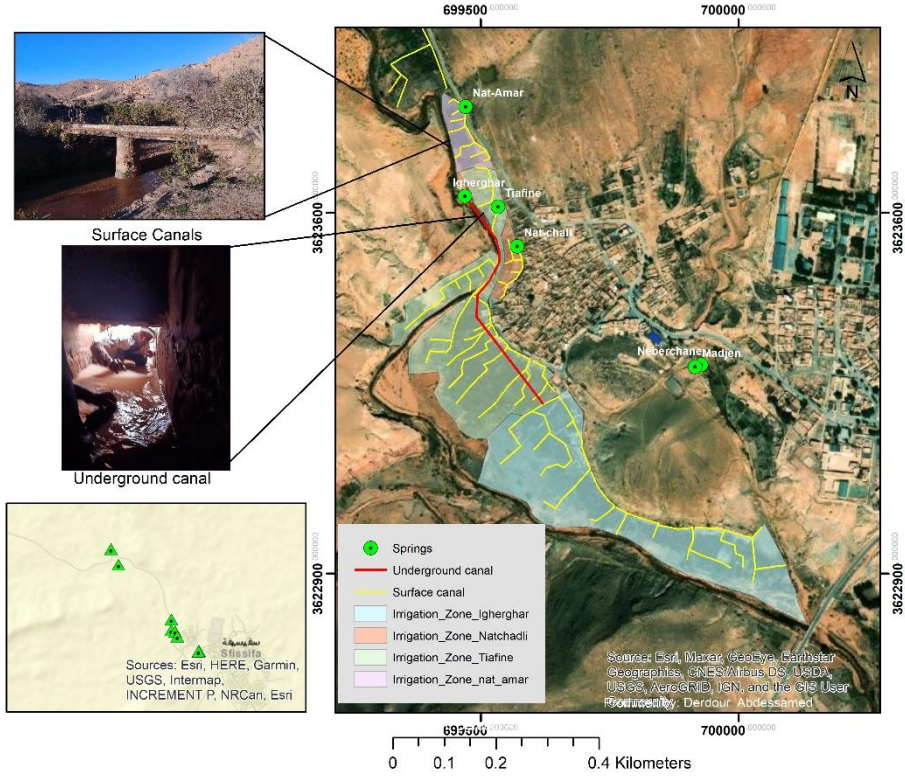


Figure 5. Igherghar, Natchadli, Tiafine, Natamar springs irrigation system (Derdour, 2021)

Madjen and Niberchane springs

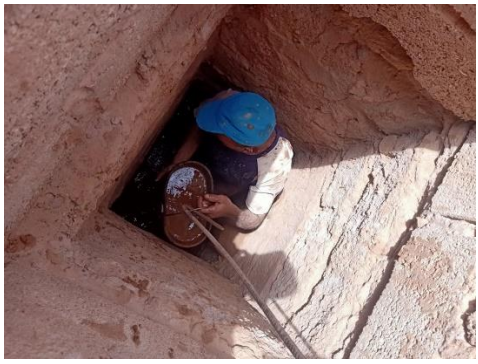
The two springs Madjen, and Niberchane called also « Ain Kahla », are neighboring springs, with flow rates inferior to 1.00 l/s, their UTM geographic coordinates are 3623301.00 mN and 699916.00 mE, 3623305.00 mN, and 699928.00 mE, respectively. They irrigate an area of 1.40 ha. When it comes out of the water on the ground, it is

channeled through a Seguia to the collective Madjen 7 m long and 4 m deep (storage basin). From there, the water is shared by the Nouba, on the two families who own the spring (Ouled Kaddour, Ouled Amar).

REHABILITATION WORKS OF WATER SPRINGS

As part of a Micro-financing Program from the Global Environment Fund - PMF FEM / UNDP Algeria, the oasis inhabitants' volunteers of the region in collaboration with the association Tnant turned their attention to rehabilitating the ancestral irrigation system of the oasis, to deliver a safe, reliable water supply. The rehabilitation works was a challenge (Figure 6). The water resources department of the Wilaya of Naâma, also contributed to rehabilitation works in the spring of Tafssast in September 2021 (Figure 7, Figure 8), the cost of the operation was around 6 million DZD (Algerian Dinar).

a) Rehabilitation of the source "Tafssast"



b) Cleaning of vertical shafts

c) Cleaning of underground canal (Tissfalt)

Figure 6. Rehabilitation works in oasis Sfissifa (Derdour, 2021)

Figure 7. Tafssast Spring before rehabilitation works (Derdour, 2021)

Figure 8. Tafssast Spring after rehabilitation works (Derdour, 2021)

OASIS WATER QUALITY

From the oasis of Sfissifa, four (04) groundwater samples were gathered from the main springs (Tafssast, Kou-Moussa, Tiafine, Igherghar) and analyzed.

Physicochemical assessment

The results of the physicochemical parameters of the groundwater quality of the oasis of Sfissifa are summarized in Table 2. The table also provides the average and standard deviation for each parameter. The pH of the study area fell within 7.47 and 7.80 and had a mean of 7.56. Therefore, the groundwater in this study region is alkaline (pH >7.0). The electrical conductivity in this study varied from 443 to 685 µS/cm, with a mean value of 544.77 µS/cm. Therefore, the water is classed as "good water" in terms of conductivity (250 < EC <750). TDS consists of calcium, bicarbonates, chlorides, magnesium, sulfates, and potassium, which are inorganic salts dissolved in groundwater. The values of TDS of the oasis of Sfissifa range from 2.9 to 334 mg/L in groundwater samples, with a mean value of 212.72 mg/l. Based on TDS classification, all samples are appropriate for drinking (TDS<500). Turbidity values vary from 0.551 to 3.09 NTU, all the sampling springs had their turbidity levels lower than the Algerian guidelines (T<5 NTU). The values of calcium in groundwater in the study area range from 52.9 to 83.36 mg/l, with a mean value of 62.72 mg/l. We remark that all calcium concentrations of samples are within the range allowed by the Algeria standards, which set a maximum value of 200 mg/l. All magnesium results are within standard limits (150 mg/l), where the mean value is 26.05 mg/l, and groundwater samples spread from 15.79 to 34.02 mg/l. The amount of sodium concentration in the present study was 10 to 26 mg/l, noting that the maximum concentration allowed in drinking water is 200 mg/l. The mean concentration of Ammonium in our study area ranges from 0.001 mg/l to 0.022 mg/l. Sulfates in our study area varied from 62 mg/l to 95 mg/l, with a mean value of 79.5 mg/l. We note that the guideline value of 400 mg/l prescribed by Algerian Standards is respected by all samples. Chloride is one of the major inorganic anions in water and is generally associated with sodium. The chloride concentration was within the guideline range established by Algerian Standards, where chloride concentrations in the present study ranged from 21.98 to 32.19 mg/L. Nitrate concentration is also one of the important criteria as far as groundwater quality standards for drinking water are concerned. The results showed that the study area's nitrate concentration was in the range of 3.9 mg/l to 9.1 mg/l, with a mean value of 7.0 mg/l. The content of phosphates in groundwater samples spread from 0.041 to 0.103 mg/l. From the short review above, key findings emerge that all water samples analyzed fell within Algerian Standards' guidelines limit. The result of following the abundance of ions indicated the cations were in the order Mg^{+2}> Ca^{+2}>Na^{+}> NH_4^{+} and the abundance of anions was in the order SO_4^{-2}> Cl^{-}> NO_3^{-} > PO_4^{-3}. The results showed that the chemical compositions of water highly depend on the geology where the groundwater is located. Thus, the concentration of magnesium and calcium in the water is related to

the dolomite rocks of the Jurassic. We conducted that all water springs are from the same aquifer of Jurassic.

Table 2. Analysis result of each parameter for the study area

Algerian Standards	Parameter	Tafssast	Kou-Moussa	Tiafine	Igherghar	Mean
25 °C	T°	16.6	20.5	21.3	20	19.6
5 NTU	Turb	0.551	3.09	1.53	2.68	1.96
6.5-9	PH	7.8	7.47	7.48	7.49	7.56
2800 µS/cm	Cond	433	488	573	685	544.75
/	TDS	2.9	236	278	334	212.72
200 mg/L	Ca^{+2}	58.51	56.11	52.9	83.36	62.72
50 mg/L	Mg^{+2}	15.79	24.78	34.02	29.64	26.05
27.1 mg/L	Na^{+}	10	12	19	26	16.75
0.5 mg/L	NH_4^{+}	0.001	0.004	0.022	0.002	0.007
50 mg/L	NO_3^{-}	9.1	3.9	6.6	8.4	7.00
400 mg/L	SO_4^{-2}	78	95	62	83	79.5
5 mg/L	PO_4^{-3}	0.077	0.041	0.103	0.059	0.07
500 mg/L	Cl^{-}	26.32	21.98	32.19	24.81	26.32

Water quality for irrigation purposes

The quality of irrigation water is an important parameter to consider, not only in the study of the direct impact on crops but also in that of the indirect impact on soils. The assessment of water quality for agricultural purposes is based on evaluating the sodium content compared to the system's total cations. In the study area, the EC, SAR, and Wilcox scheme assessed the quality of water. This method is chosen according to the study's needs. The quality of water for irrigation may be categorized, based on their SAR, into four main types: "excellent" when SAR values are less than 10 meq/l, "Good" when SAR values are between 10 and 18 meq/l, "Doubtful" if SAR values are between 18 and 26 meq/l, and "Unsuitable" when SAR values are greater than 26 meq/l (Suarez *et al.*, 2006).

The SAR suggested by the US Department of Agriculture's salinity laboratory (Wilcox, 1955) is measured using Eq. (1):

$$SAR = \frac{rNa^{+}}{\sqrt{rCa^{2+} + rMg^{2+}/2}} \quad (1)$$

where Na^{+}, Ca^{2+}, Mg^{2+}, are the concentrations of ions in milliequivalents per liter.

The values of SAR were calculated for each spring as described in equation (1), and the results are listed in Table 3. The results demonstrate that SAR values ranged between

0.30 and 0.62. From these results, it is clear that groundwater is rated as “excellent” and would be ideal for irrigation.

Table 3. Values of SAR of the study area

Springs	SAR	Conductivity
Tafssast	0.30	433
Kou-Moussa	0.62	488
Tiafine	0.34	573
Igherghar	0.50	685

Percentage sodium (%Na)

Percentage sodium (%Na) is an indication of the soluble sodium content of the groundwater and is also used to evaluate Na hazard. In all-natural waters, %Na is a common parameter to assess its suitability for irrigation purposes since sodium reacts with the soil to reduce permeability. The %Na of the groundwaters in the study area ranges from 10.11 to 26.02 %. The Wilcox (1955) diagram (Figure 9) relating sodium percent and EC shows that 100.00 % of the groundwater falls in the ‘‘Excellent’’ range. This makes the groundwater in the study area suitable for irrigation purposes

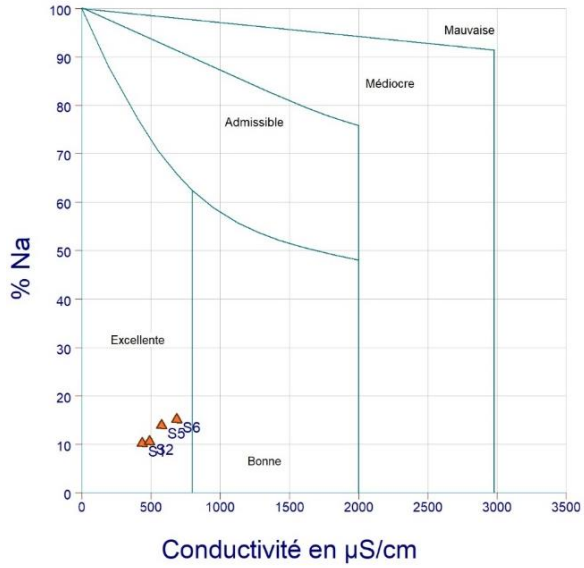


Figure 9. Wilcox diagram showing the suitability of groundwater for irrigation

CONCLUSION

For centuries, human societies in drylands have overcome the challenge of water scarcity through traditional methods of water harvesting. Ksar Sfissifa is located in the center of the municipality of Sfissifa; characterized by its high agricultural activity. The agricultural area of Sfissifa represents an important agricultural field in the region that feeds locals with vegetables, tree crops, and cereals. The Oasis of Sfissifa is irrigated by natural springs, and it covers an area of 59 ha. This zone represents practically the only green zone in the region. For centuries, agriculture was practiced on alluvial deposits on the banks of the wadi. The traditional irrigation system in the oasis is called "Tissfalt". The essential idea of Tissfalt is that of a gently sloping tunnel, often along the radius of an alluvial fan, which extends upslope until the water table is tapped and emerges at the downslope end to supply the oasis. Ancestral rules and laws have been established in the oasis to share water between the co-owners with rigor and justice. The principle adopted is that the water share depends on the contribution of each owner. These amazing structures allowed the inhabitants of Ksar Sfissifa to succeed despite long dry periods when there was no surface water to be had.

Like many oases in foggaras, the unit of sharing adopted in the oasis of Sfissifa is the time called "Kherrouba" of 45 minutes. For the study area, the assessment of water potential for drinking uses was evaluated using physicochemical parameters, and the results show that all water samples analyzed fell within Algerian Standards' guidelines limit and the World Health Organization. The assessment of water quality for irrigation by using the sodium adsorption ratio (SAR), demonstrates that SAR values ranged between 0.30 and 0.62. From these results, we confirm that groundwater is rated as "excellent" and would be ideal for irrigation and that the Tafssast spring is the best compared to other springs. The inhabitants of the region and local communities have made significant progress in restoring this traditional irrigation system, but there is still a long way to go. The mean average age of the farmers is 55.5 years, which poses a risk to the sustainability of this oasis. The dynamic monitoring of spring water, the management of pollution sources, and the restriction of groundwater overexploitation should all be improved to recover and protect this system in the oasis of Sfissifa.

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