Larhyss Journal, ISSN 1112-3680, n°58, June 2024, pp. 105-145

THE ALGERIAN FOGGARA
PART 1: ORIGINALITY OF A HYDRAULIC SYSTEM

REMINI B.

Department of Water Science and Environmental, Faculty of Technology, Blida 1
University of Blida, PO Box 9000, Algeria.

reminib@yahoo.fr

Research Article – Available at http://larhyss.net/ojs/index.php/larhyss/index
Received February 2, 2024, Received in revised form May 21, 2024, Accepted May 23, 2024

ABSTRACT

This article has two parts. It reveals some secrets hidden behind this ancestral hydro-agricultural development which has been operating for more than 30 centuries. During the period 1992-2024, several missions were carried out in the foggaras oases. Investigations and surveys were carried out among the owners of the foggaras and the Ksourian population. The first results obtained show that the know-how acquired on foggaras is immense. For the first time, new notions about foggaras have been introduced into the technical bibliography. In this first part, we established two types of foggaras: volumetric and hourly. The volumetric foggara is found only in Algeria and was dug in the oases of Gourara, Touat and Tidikelt which take the shape of a crescent. Approximately 80% of the total number, the volumetric foggara of exceptional ingenuity allows the gardens to be irrigated in parallel, it is equipped with a network of triangular seguias. As for the hourly foggara, it is less present on Algerian soil, the hourly foggara contains a network of branched seguias and makes it possible to irrigate the gardens in series, i.e. in turn. The majority of these foggaras are located in the Saoura valley. Part 1 of this paper demonstrates the originality of the Algerian foggara which is different from other foggaras in the 52 countries of the planet.

Keywords: Foggara, Volumetric distribution, Hourly distribution, Triangular network, Branched network.

NOMENCLATURE

Ahbas: dam
Ain: water source
Tissanbath: gallery
Foggara: draining gallery
Kial El Ma: the water measurer

Kialine el Ma : plurals of Kial El Ma
Khettara: Moroccan Foggara
Khottara de la Saoura: pendulum well
Khottara of Mzab: Animal traction well
Guemoun: garden
Ksar: cty of farmers
Ksour: plural of Ksar
Kasria: triangular basin narrowed at the base by openings
Kasriates: plural of Kasria
Madjen: Water storage basin
Sebkha: a saltwater lake
Seguia: open-air canal
Souaguis: plural of seguia
Chaabat: tributary (or ravine)
Tahtania: below
Terdja: Seguia: open-air canal
Foukania: above

INTRODUCTION

Difficult to live in arid regions and yet for several centuries, man has settled in these places hostile to life. The man even arranged his place of refuge; the oasis, a humid area in an arid region. But without water the oasis will not see the light of day. After the drying up of water sources, man was obliged to invent water collection techniques. This is how various techniques for capturing groundwater have been carried out. The only hydro-agricultural development that has had success on a global scale is without a doubt foggara. A slightly inclined underground gallery which captures groundwater under the effect of gravity and without any energy (Remini, 2017). These foggaras are located in more than 52 countries around the world (Remini et al, 2014a). The capital of this territory of draining galleries is ancient Iran (Persia), since it holds approximately 22,000 qanats (the foggara of Iran) (Ghayour 2000; Pouraghniaei and Malekian 2001; Ghorbani 2007). This number of qanats provides approximately 7.6 billion m^3, or 15% of the country's total water needs, and play a major role in advanced water harvesting (Ahmadi et al, 2010). This figure of 22,000 qanats was much higher, since it was estimated in 1958 at between 40,000 and 50,000 qanats according to various authors (Boccuti et al, 2022). Some authors claim that the total number of Qanats in service in Iran is currently 41,169 with a total length of 21,700 km and around 4 billion m^3 of water withdrawal (Beaumont 1971; Wulff 1968 ; Maghrebi et al, 2022). If today, Iran has this large number of foggaras, it is thanks to the incessant maintenance work provided by the villagers, which allowed the population to survive for several centuries. Without this labor and management provided by the local population, this would not be possible. The foggaras would have fallen into ruin with the villages and even their gardens (Sarga, 2023). Other countries such as the Sultanate of Oman have 4112 falaj of which 3108 falaj are in operation and provide a water flow of 680 million m^3/year to irrigate approximately 26,500 hectares (Al-Hatmi and Al-Amri, 2000; Zaher bin khaled et al, 2008). According to Zaher bin khaled et al (2008), more than 33% of Oman's agricultural land is irrigated by aflaj. The flow rates of the aflaj vary between 15 and 60 l/s and the flow of some large aflaj can reach up to 1,500 l/s in wet periods (Zaher bin khaled et al, 2008). Other authors estimate that there are approximately 3,000 falaj systems still in use today, representing approximately 30% of Oman's groundwater (Al-Marshudi, 2001; Al-Marshudi, 2007; Al-Kindi et al, 2023). A study revealed in 1996 that more than 1,000 out of 4,112 falajs had dried up (Zekri and Al Marshudi, 2008). In the Sultanate of Oman, the supply of drinking and irrigation water from the Aflaj is estimated at 410 million m^3/year, which represents 38% of the fresh water in the entire Sultanate of Oman. Such a volume fully satisfies the demand for drinking water and irrigation of part of the rural population (Norman et al., 1998; Zekri and Al-Marshudi, 2008). It should be remembered that agricultural production in the Sultanate of Oman almost depends on irrigation through the aflaj system (Norman et al, 1998). Large cities are supplied with drinking water through desalination plants (Al-Ghafri, 2018). In Afghanistan, the neighboring country of Iran holds around 7000 Karez which irrigate around 170,000 ha of land (Khan et al., 2015). Other authors argue that the Karez systems irrigate approximately 163,000 ha of land with 6,000 to 7,000 individual Karez across Afghanistan (Azimi, and Mccauley, 2002; Hussain et al, 2008; Himat and Dogan, 2019). Karez systems irrigate 15% of Afghanistan's total agricultural area (Qureshi, 2002; Himat and Dogan, 2019). In Morocco, in the province of Tafilalet, a recent inventory of khettaras revealed the existence of 500 khettaras (El Faiz and Ruf, 2010). The total number of khettaras in the Tafilalet region (Morocco) is 570, of which 304 are currently active. The area covered by the khettaras is approximately 16,000 h, with a total network length of 855 km. The average flow rate is around 700 L/s across all the khettaras (Berraouz et al, 2022). However, an inventory was carried out in 2005 by the Japanese International Cooperation Agency and the Regional Agricultural Development Office of Tafilalet, the municipality of Ferkla-Essoufla has 29 khettaras with a total length of approximately 74 km. Ten khettaras are currently dried up and the average outflows from flowing khettaras vary between less than 1 and 19 l/s (Khardi et al, 2023). In the Xinjiang Uyghur Autonomous Region (China), in 2004 there were a total of 926 karez in the 31 communes of the Turpan basin. Of these, 322 karez were active, 430 were inactive and 174 were recoverable. On the other hand, the inventory carried out in 2011 gave a total of 1,108 karez in the Xinjiang Uyghur Autonomous Region made up of 31 communes in the Turpan basin. Among them, 278 karezes were active, and 830 were inactive (Li et al, 2023). In Algeria, more than 2,200 foggaras were recorded in 2022 (Remini, 2023; Remini, 2022), of which more than 1,000 foggaras are located in the wilaya of Adrar. Today, however, there are still around 800 foggaras in operation. The objective of this article is to bring out the similarities between the different foggaras on the planet and to highlight the originality of the Algerian foggara compared to other foggaras.

METHODOLOGY OF WORK

This paper on the Algerian foggara has never been programmed, nor even planned for possible publication. It should be remembered that my first line of research on the siltation of dams was crowned by the defense of the first state doctoral thesis under the direction of Professors Kettab Ahmed and Jean Michel Avenard in 1997. At the same time we began a completely different line of research from siltation since it is interested in the effect of mega obstacles on wind dynamics and the silting of oasis spaces. This research journey was crowned by the defense in 2001 of a second doctoral thesis from the University of Champagne Ardenne in Reims under the direction of Professor Monique Mainguet. It was this research on the sand of the Algerian Sahara that opened the way for me towards a new, much more attractive line of research. These are indeed foggara systems. Moving periodically to the oases of Touat and Gourara, we were fascinated by the foggara system. My first scientific trip was made in 1998 to the oases of Timimoun. It was the beginning of an adventure to discover volumetric foggaras. And there you have it, once you enter the Sahara, it attracts you and it becomes impossible to separate. Each year, one or two missions are organized in the oases of Touat, Gourara and Tidikelt. We got used to meeting the Kial El Ma, the owners of the foggaras and the Ksourian population. While traveling in the oases of the Saoura at the beginning of the 2000s, we discovered another type of foggaras devoid of kasriates. These are the foggaras of Beni Abbes, Taghit, Kenadsa, Ouakda where the water at the exit of the gallery flows directly into a collective Madjen. Other foggaras that we have the chance to visit several times have the same distribution network as that of the Saoura foggaras. These are the oases of Moghrar, Laghouat, Tindouf, Tabelbala. For us, it's a discovery to see foggaras of foggaras in our country. All this diversity of foggaras pushed me to prepare a third PhD thesis on foggaras, which was defended in 2011. Such recognition helped us a lot to continue the adventure. During this stage, we focused our work on sharing the foggara water between the co-owners. Two modes of water destruction have been highlighted and which we have preferred, called hourly and volumetric modes. Thanks to these new concepts, only the foggara systems of Touat, Gourara, Tidikelt and Tamanrasset have a water distribution network per unit volume. During the month of February 2024, we carried out a mission to the Saoura oases and more precisely to visit the foggaras. During the month of March 2024, we visited some foggaras of Adrar and Timimoun. During 32 years (1992-2024) of field work we carried out investigations and surveys with the Ksourian population, the Kialines El Ma and the owners of the foggaras. It emerges from this long journey that the Foggara heritage is very rich and diverse, whether in terms of water capture (upstream part) or in terms of water sharing. It is this richness of the foggara system and the importance of the know-how acquired over centuries that pushed us to prepare this article on the Algerian foggara.

RESULTS AND DISCUSSIONS

Definition of foggara

The word foggara comes from the Arabic word "Fedjara" which means gushing of water. We define the foggara as being a slightly inclined horizontal well which consists of draining water from the aquifer to the surface of the ground (Fig. 1) (Remini, 2023; Remini, 2022). When digging the gallery, the vertical shafts are used for the penetration of air and light. The embankment is evacuated via vertical shafts. The digging of a foggara will take place if the static level is higher than that of the gardens to create gravity.

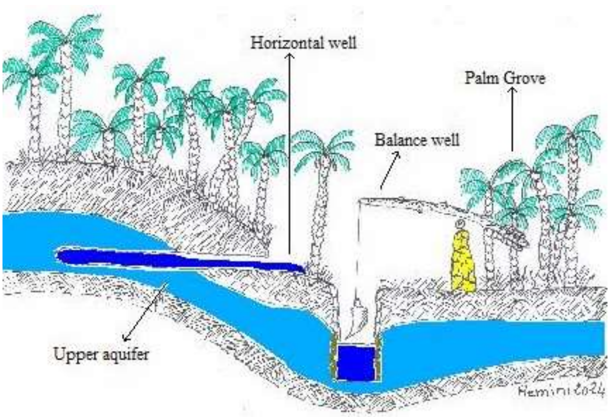


Figure 1: Diagram of possible wells (vertical and horizontal) to dig to draw groundwater (Diagram, Remini, 2024)

But from a practical point of view, we cannot excavate with rudimentary means only a section of gallery of around twenty meters. The worker who digs the gallery needs oxygen and light to move forward. Digging vertical wells along the gallery will facilitate the evacuation of debris and allow the penetration of light and air (Fig. 2).

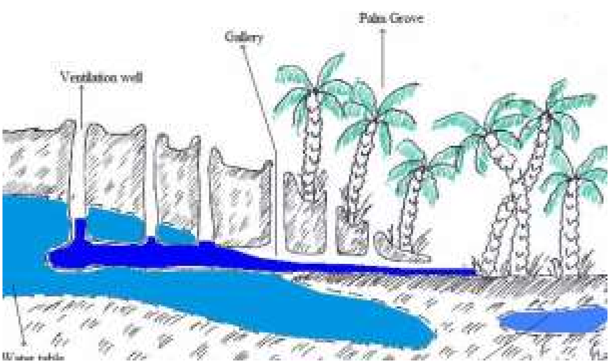


Figure 2: Actual diagram of a foggara; a horizontal well with vertical wells (Diagram Remini, 2024)

The Q² of the foggara (Quantity and Quality of the foggara water)

The foggara is made up of two parts; upstream and downstream. The upstream section represented by the underground gallery. The downstream part concerns the distribution network. For the upstream part, it is common between foggara, qanat, khettara, falaj and karez. On the other hand, for the downstream part, there are two different water distribution networks; the triangular network and the branched network. The underground gallery is divided into water sections: collection and transport. The collection part is intended for drainage of water from the aquifer. The transport part is intended for transporting groundwater to the ground surface. However, the roles that the two sections play are much more important. This involves the quantification of water (Q) which is carried out at the catchment section. Water quality (Q) is determined at the "transport" section (Fig. 3).

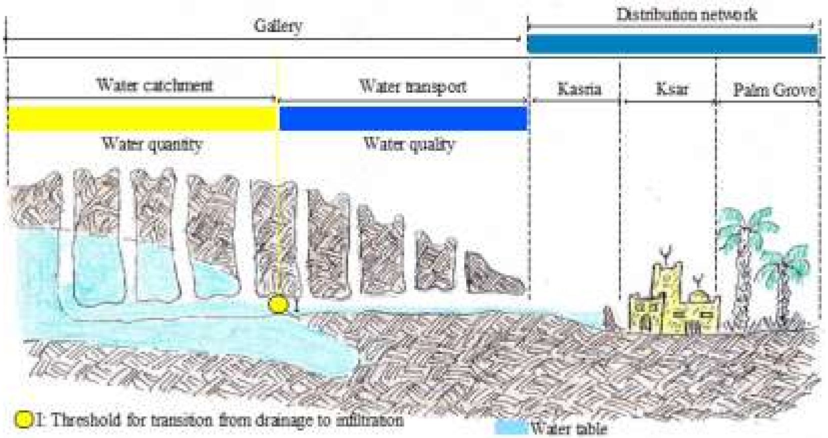
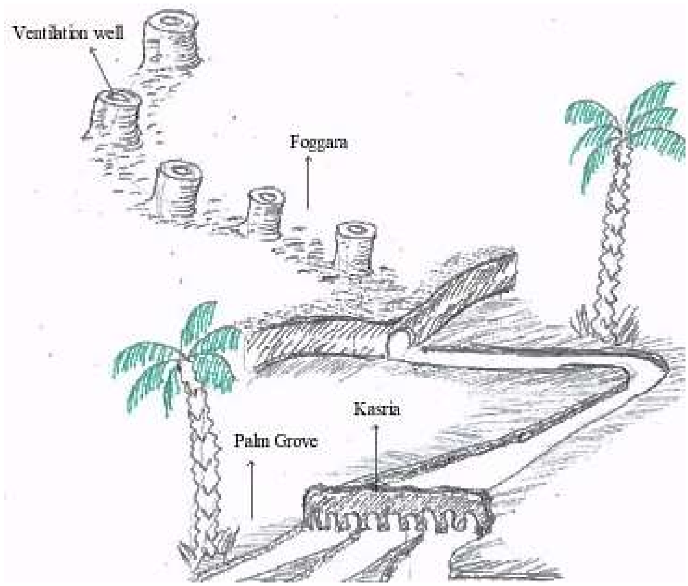


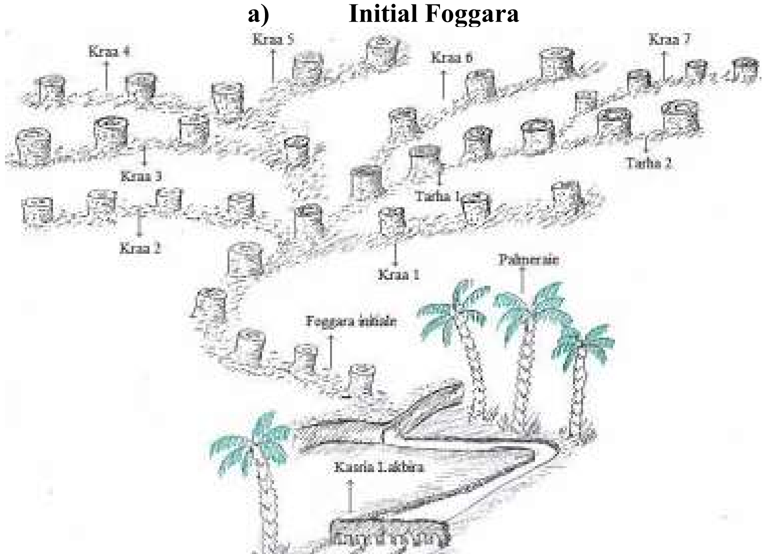
Figure 3: Diagram of the upstream part of the foggara system. The quantity and quality of water is determined in this part. (Diagram Remini, 2024)

Quantity of water in a foggara

The quantity of water in a foggara is expected to change over time for socio-economic reasons of the oasis. The ksar is expected to expand because of the increase in population. Obviously, this will lead to an increasing demand for drinking water to meet the water needs of the population of Ksar. Obviously, this will lead to an increase in the number of gardens and therefore the need for irrigation water will also increase. This is how the farmers put into practice two original techniques called "Tarha" and "Kraa". The first means extension and consists of extending the gallery by a few wells towards the upstream of the foggara. This means increasing the section of the groundwater collection gallery. On the other hand, the second technique called "Kraa", which means the foot, consists of adding a section of auxiliary gallery to the main gallery (Remini, 2016). The multiplication over time of Tarha and kraa will lead to the transition from a foggara with a single gallery to a foggara with a network of galleries (Remini, 2016). It is quite simply an evolution from a young foggara to an old foggara (Fig. 4(a and b)).



a) Initial Foggara



b) Foggara with several Kraa and Tarha

Figure 4: Evolution over time with several Kraa and Tarha of the flow of the *n* foggara (Diagram, Remini, 2024)

Water quality in a foggara

The quality of the water in the foggara is determined in the part of the "transport" section of the foggara gallery. Groundwater, thanks to infiltration, reaches the aquifer with water doped with mineral salts from several types of rock. In the "transport" part consisting of a section of gallery of around ten kilometers on a very gentle slope, the water flows slowly and will have time to adapt to the different types of rock. When leaving the gallery, the quality of this water is exceptional; it is a spring water par excellence or even a mineral water. In addition, the foggara provides continuous water without interruption. Foggara water is not stored, even water intended for irrigation; its lifespan in the madjen does not exceed 24 hours. There is even water from certain foggaras which is used by Hammams as thermal water. The example of the foggara of the oasis of Bouda in the wilaya of Adrar since it supplied a Thermal hammam in Bouda for around ten years, but unfortunately the Hammam closed its doors due to the deterioration of the foggara.

Origin of foggara

The foggara is considered one of the greatest inventions in the history of hydraulics. Moreover, it is classified among the 7 wonders of the world. Thanks to its success, foggara has spread to the 4 corners of the planet. So, in this case, how did foggara end up in 52 countries across the planet? According to Goblot (1973), foggara is of Iranian origin. Developed from mining techniques, foggara originated in ancient Persia, more than 3000 years ago (Goblot, 1963; Goblot, 1979; Hussain et al, 2008; Kazemi, 2004). From this region, it spread to the majority of arid and semi-arid countries on the planet. It is the oases that have attracted foggaras techniques. This is how the development of intra-desert type oases which manifest themselves in the Sahara, the commercial axis of silk and the axis of the diffusion of Islam is directly linked to the expansion of the foggara (in regions where hydrogeological conditions are favorable). Intra-desert type oases where the date palm constitutes the main vegetation around which arboreal, vegetable and forage species gravitate. The palm tree is the sacred tree of Muslims. This type of oasis is located in the countries of Arab Islam (Maghreb and Mashreq), Turco-Mangol Islam (from Anatolia to Central Asia), Nano-Indian Islam (Remini, 2011). The spread of foggara is directly linked to the axis of development of date palm oases (Remini, 2011). Unlike the gold trade axis crossing the Sahara towards the African Sahel, the development of trans-Saharan oases was carried out using other water capture techniques; the foggaras did not follow the spread of oases in these "black" Islamic countries. But with the Spanish, draining foggaras developed in the new world (Remini et al, 2014a, Remini, 2011) (Fig. 5).

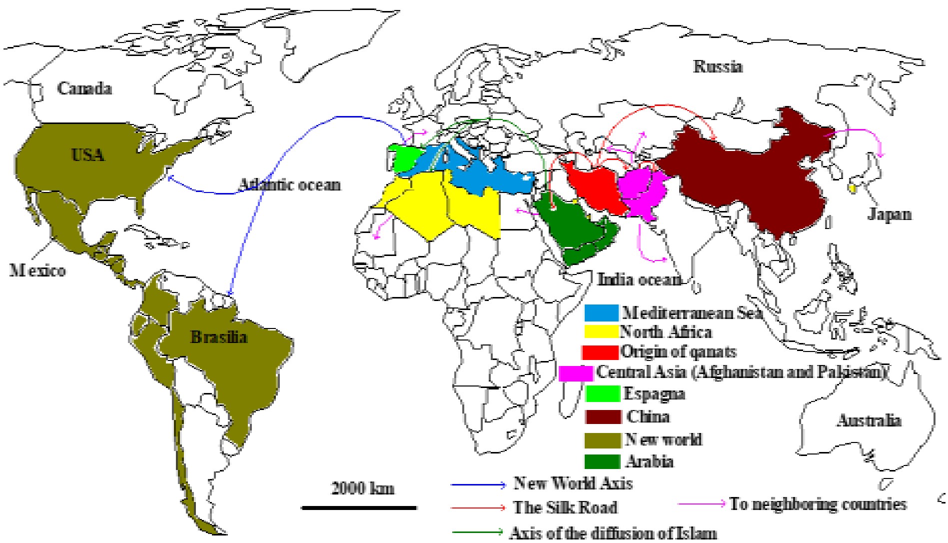
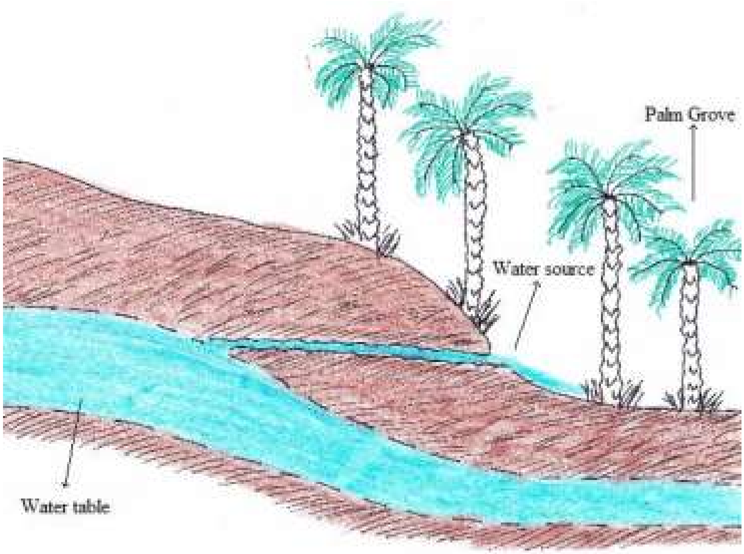
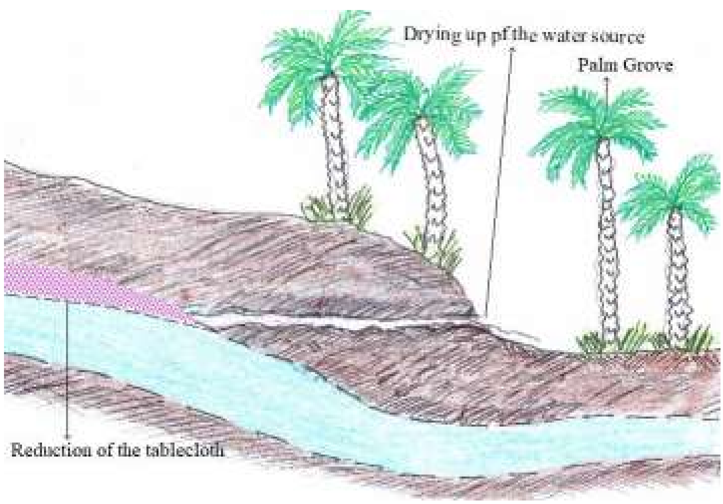


Figure 5: Diffusion of draining galleries (source Goblot, 1979, modified by the author in 2024)

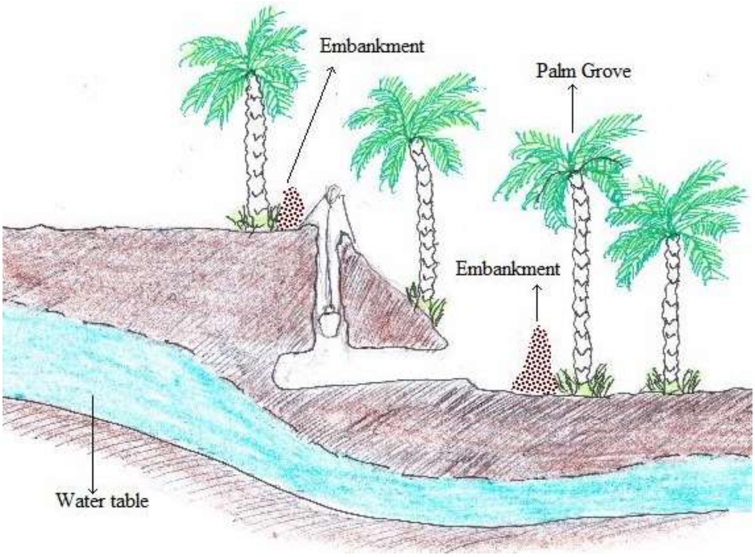
If today, the origin of the qanât is well known and that it developed from mining techniques, on the other hand, the origin of the foggara of the Algerian Sahara is surrounded by doubts. Some authors confidently assert that it is a local invention and that it has no relation to the qanât of Iran. Others say it is more of a technique transferred from ancient Iran via Arabia via the Silk Road. From Arabia to North Africa via the axis of the diffusion of Islam as we have just discussed previously. The surveys that we carried out with the old owners of the foggaras and the Ksourian population of the oases of Touat, Gourara and Tidikelt, the foggara is of local origin. The most repeated version in these regions is that the birth of foggaras is due to the drying up of water sources. The drawdown of the water table caused by repeated droughts has led to the drying up of water sources. Farmers dig in the opposite direction of the flow in search of this precious liquid until they reach the starting point of this water (aquifer) (Fig. 6(a, b and c)). Moreover, this foggara digging technique has become widespread across all foggaras made in the Algerian Sahara.



a) Source of living water



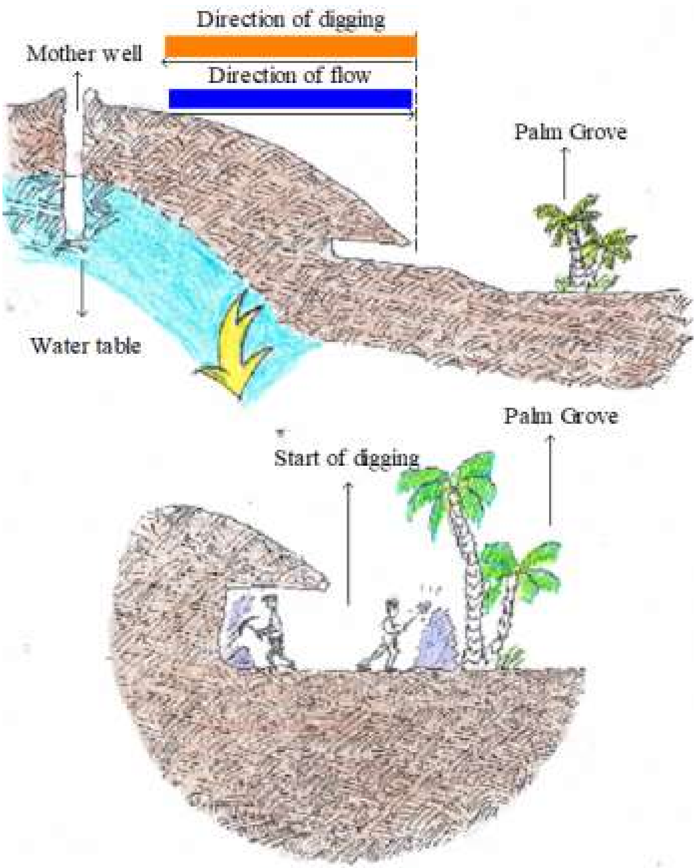
b) Drying up of the water source



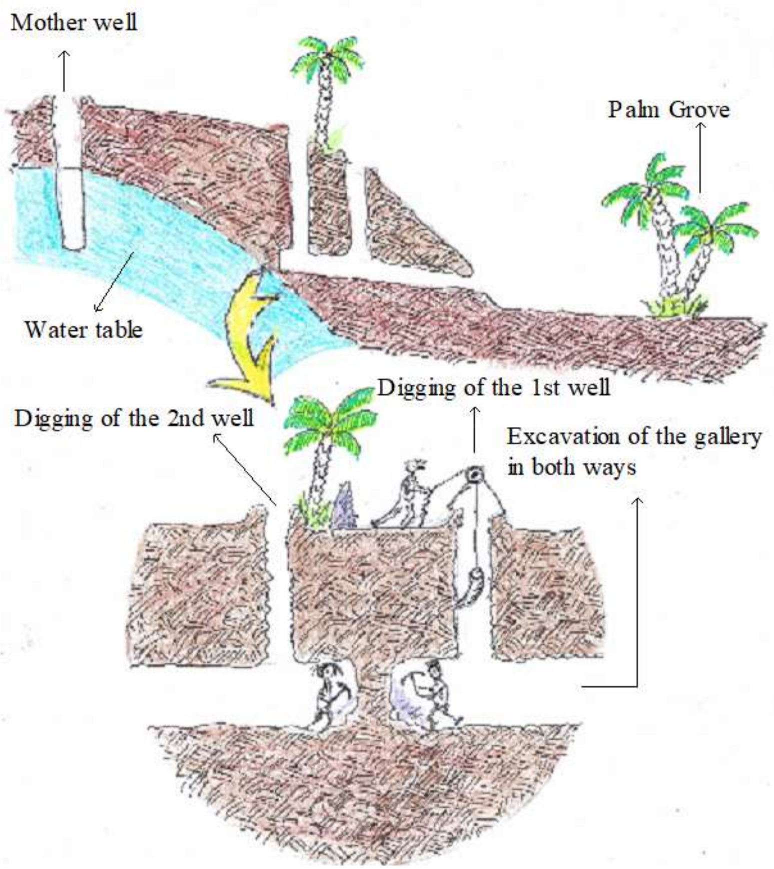
c)Digging for spring water

Figure 6 : Approximate diagram of the invention of the foggara (according to the old owners of the foggaras in the region) (Diagram Remini, 2024)

Paradoxically, once the mother well has been located and dug, we begin digging the foggara from downstream to upstream. In a first step, we begin digging a section of the gallery with a length of 15 m on average from the garden (Fig. 7a). In a second step, the first vertical well is dug which will be used to evacuate the backfill and allow the penetration of light as well as the oxygenation of the gallery. In a third step, the second vertical well is dug (Fig. 7b). In a fourth step, we dig the second section of the gallery from the first and second wells and so on until reaching the mother well (Fig. 7b).



a) First stage: digging of the first section



b) Digging of the second shaft and the gallery

Figure 7 : Diagram of the stages of digging a foggara in the oases of Touat, Gourara and Tidikelt (Diagram executed on the basis of information collected from the owners of the foggaras) (Remini, 2024)

The countries of the foggaras

When we started working on foggaras in the 1990s, we believed that foggaras existed only in Algeria. But over time we learned that the foggara is a world heritage. A bibliographic search reveals that the foggara was discovered in Iran more than 3000 years ago (Goblot, 1973). Around 60,000 foggaras dug in this country. It is currently estimated that 30,000 foggaras are in operation, or 50% of the total. Foggara has spread to arid and semi-arid countries around the world. It is very difficult to know exactly how many countries have adopted this ancestral technique. Few authors have cited the countries with draining galleries. In 1995, Karim Khan and Nawaz reported that 22 countries had adopted traditional hydraulic engineering. According to Adin (2006), drainage galleries exist in 34 countries around the world. Hofman (2007) highlights the existence of drainage galleries in 35 countries. Boustani in 2008 also reported the number of 35 countries with drainage galleries. In 2014, Remini et al put forward the number of 52 countries that adopted foggara (Fig. 8 and table 1). Out of approximately 60,000 foggaras dug in these countries, there are currently an estimated 30,000 draining galleries in operation, or 50% of the total. It is thanks to its success that foggara has spread to the 4 corners of the planet. The know-how is exported from one country to another to reach the number of 52. The foggara has been dug in all the continents of the planet except that of Australia.

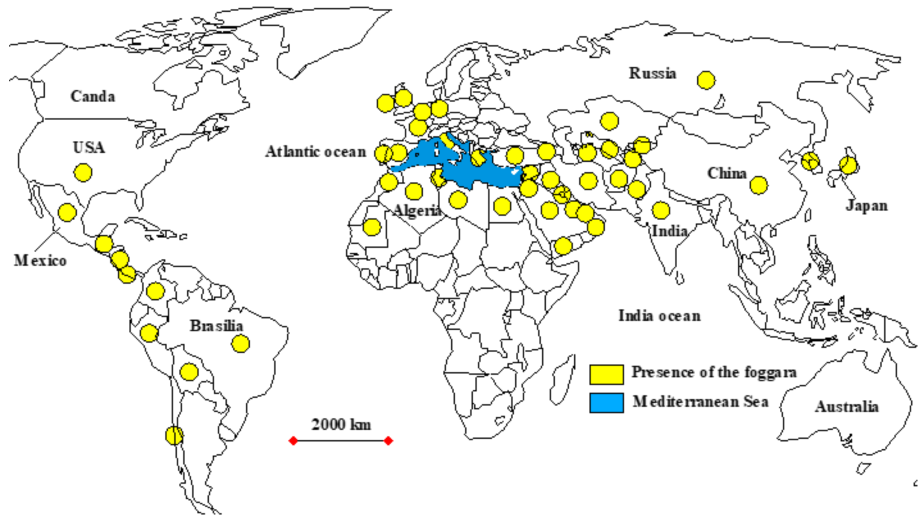


Figure 8: Situation of foggaras in the world (Remini et al, 2014a)

Table 1: Draining galleries around the world (Remini, 2011; Remini et al, 2014a)

N°	Country	Appellation	N°	Country	Appellation
1	Algeria	Foggara	29	Russia	
02	Morocco	Khettara, Rhettara	30	Armenia	
03	Tunisia	Kriga, Foggara	31	Türkiye	Felledj
04	Libya	Foggara	32	Cyprus	
05	Egypt	Ain, Auyounes (pluriel)	33	Greece	
06	Mauritania		34	Italia	Ingruttato
07	Saudi Arabia	Falaj	35	France	
08	Oman	Falaj, Aflajs (pluriel)	36	Germany	
09	Bahraïn	Qanat	37	Belgium	
10	Qatar		38	Spain	Gallarias, Mina
11	Arab Emirates	Falaj	39	Holland	
12	Yémen	Falaj, Ghayl, Miyan	40	Portugal	
13	Syria	Qanat Romani	41	Luxembourg	
14	Jordan	Qanat Romani	42	Peru	Pukios

15	Libanon		43	Brazil	
16	Iraq	Khariz, Qanat	44	Bolivia	Galarias
17	Iran	Qanat	45	Mexico	
18	Pakistan	Karez, Kariz	46	Argentina	Galarias
19	Afghanistan	Karez	47	Chile	
20	India	Surangam	48	USA	
21	China	Kanerjing	49	Ex Czechoslovakia	
22	Japan	Mambo-mappo	50	Island	
23	Corée	Man-nan-Po	51	Cambodia	Kanerjing
24	Turkmenistan	Felledj	52	England	
25	Azerbaijan				
26	Uzbekistan				
27	Kazakhstan				
28	Tajikistan				

(Références: Daanish and Muhamed, 2007 ; Cristini and Langlais, 2004 ; Guillermou, 1993 ; Wessels and Hooggeveen, 2002 ; Ben Brahim, 2003 ; Boustani, 2008 ; Abdin, 2006 ; L'Hote, 1990 ; Goblot, 1963 ; Digard and Briant, 2001 ; Abdin, 2006 ; Cristini and Langlais, 2004 ; Wulf., 1968 ; Lynn Teo Simarski, 1992 ; Goblot, 1979 ; Wulf, 1968 ; Cnesta, 2003 ; Azzi, 1992 ; Ben Brahim, 2003 ; Al sulmani et al, 2007 ; Digard and Briant, 2001 ; Ben Brahim, 2003 ; Viqueira, and Rodriguez, 2001 ; Bezza 2006, Hofman, 2007 ; Karimi, 2003 ; Pierre, 2001 ; Banks and Soldal, 2002 ; Gonzalez Andricani and Bazurco, 2004 ; Wattmann, Gonon and Thiers, 2000 ; Kobori,, 1980 ; Kobori, 1982 ; Kobori,, 1990 ; Kobori et al, 1980 ; Arrus, 1985 ; Al Gharfi et al., 2000 ; Simarski, 1992 ; Rizk and Al Sharhan, 2003)

The drainage gallery technique has proven its effectiveness in arid and semi-arid regions over 3000 years of service. For more than half a century, the technique of draining galleries has been abandoned to the detriment of modern techniques such as drilling and motor pumps. If only vestiges of this technique remain in 40 countries, it continues to function in ancient oases with modern techniques in 10 countries : Algeria, Iran, Syria, Morocco, Sultanate of Oman, China, Afghanistan, Jordan, Yemen and Tunisia (Fig. 9).

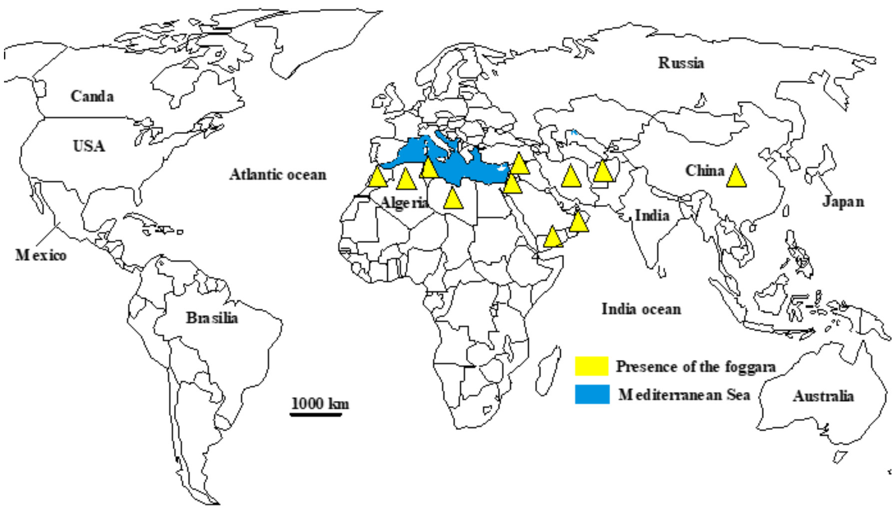


Figure 9: Drainage galleries in service around the world in 2009 (Remini et al, 2014a)

If digging a drainage gallery is practically impossible today, maintaining the number and flow of functional galleries remains an increasingly difficult operation. Table 2 gives an idea of the decline of this technique throughout the world.

Table 2: Characteristics of drainage galleries in some countries around the world (Remini et al, 2014a)

Country	Number of initial galleries	Number of galleries in service	Debit (l/s)	Length of the gallery (km)
Iran	50000	22000	274000	**250000**
Afghanistan	20000	6000	100000	
Pakistan	1000	730		
Oman	4112	3012	680	**2900**
Syria	239	29		
Algéria	1400	903	2781	
Yemen	94	02		
United Arab Emirates		07	315	
Saudia Arabia	4000 à 5000			
Jordan		05		
Iraq	100			
Mexico	150			
Bolivie	64			
Morocco	570	150		**450**
China	1400	400	11360	**5000**
Tunisia	09	02		

(Références: Boustani, 2008; Wulf, 1968; Stiros, 2006; Balland, 1992; Al Marshudi, 2007; Al Gharfi et al., 2003; Lighhtfoot, 1996; Bezza, 2006; Gonzalez Andriami, 2004; Karimi, 2003; Viqueira et al., 2001; Hofman, 2007; Adin, 2006; Ghorbanai, 2007; Goldsmith. and Hildyard,1984; Ben Brahim, 2003; Ben Brahim, 2004; Gonzalez Andricani and Bazurco, 2004, Rizk and Al Sharhan, 2003; Hussain et al., 2008; Walther, 2009)

On the national territory, the foggara after its success in the oases of Touat, Gourara and Tidikelt, it spread towards Tamanrasset in the south, towards Biskra in the north and towards Tindouf in the west. Numbering 2,400, foggaras were dug in 14 wilayas out of the 58 in total (Remini, 2024) (Fig. 10). More than 1400 foggaras are found in Touat, Gourara and Tidikelt followed by the Saoura valley with more than 90 foggaras.

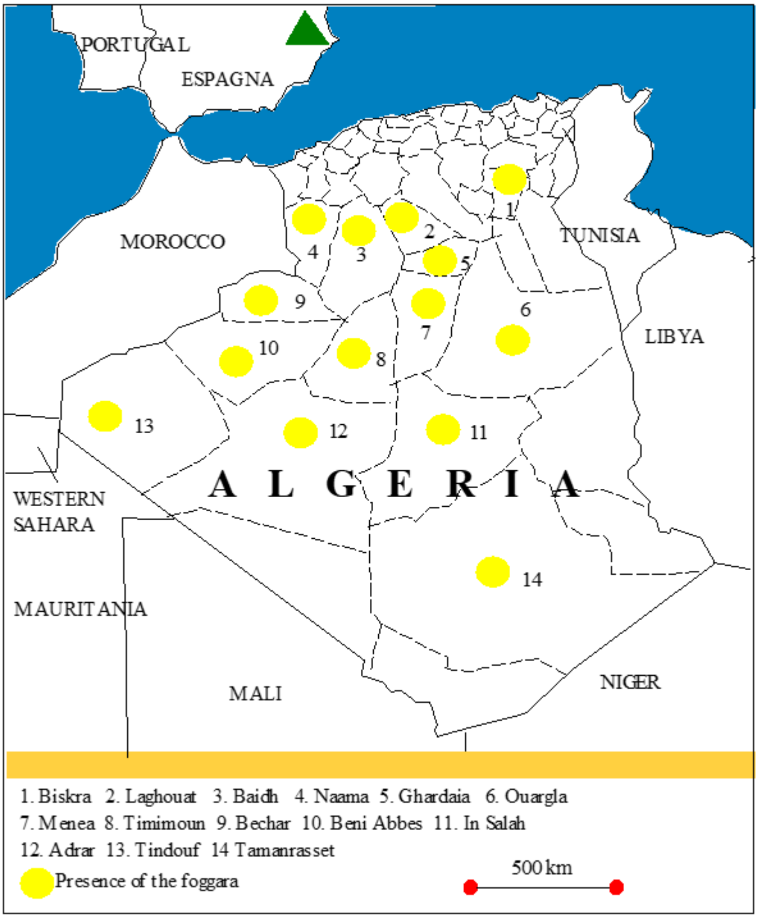


Figure 10: Presence of foggaras across the wilayas of Algeria (Remini, 2024)

In the early nineties when we started studying foggaras, we learned that foggaras only exist in the oases of Touat, Gourara and Tidikelt. But the reality is quite the opposite, since at the beginning of 2001 we carried out work missions in the oases of the valley. To our surprise we observed foggaras of short length equipped with a distribution network different from that used in Adrar, Timimoun or Tidikelt. No kasria has been found in the palm groves of the Saoura valley, but rather, the water from the foggara once on the ground flows directly into a large Madjen. We found this type of foggara in several oases in the southwest of the Sahara. Hourly foggaras have been highlighted in the oases of Tindouf, Tabelbala, Ouakda, Lahmar, Beni Ounif, Stitten, Mechria Essaghira, Moghrar, Taghit, Beni Abbes, Boukais, Kenadsa, Ain Madi, Boussemghoun. Volumetric foggaras are located only in the oases of Touat, Gourara and Tidikelt, with the exception of the foggara of Hennou; an hourly foggara in the middle of the volumetric foggaras of the Tamentit oasis. We have established the first map of Algerian foggaras (Fig. 11 and table.3).

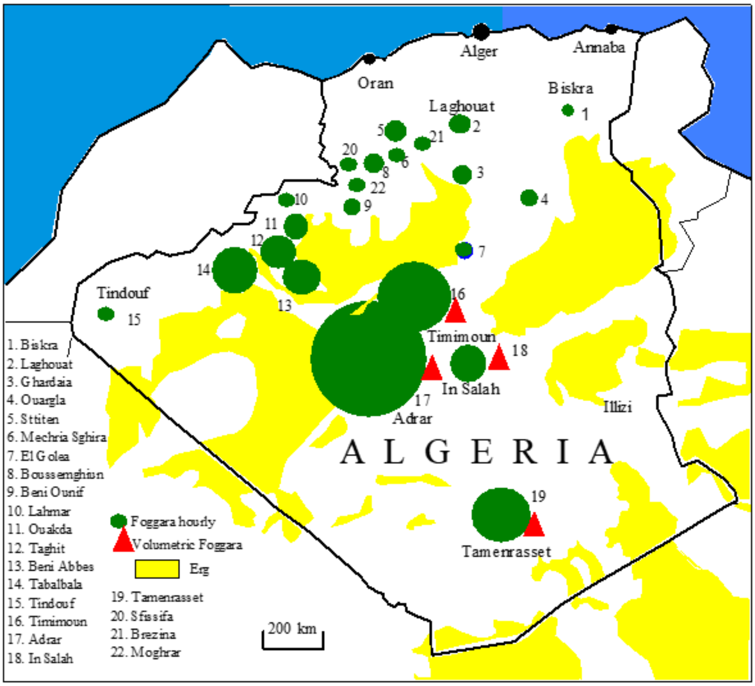


Figure 11: Distribution of volumetric and hourly foggaras in Algeria (Remini, 2023 ; Remini, 2022)

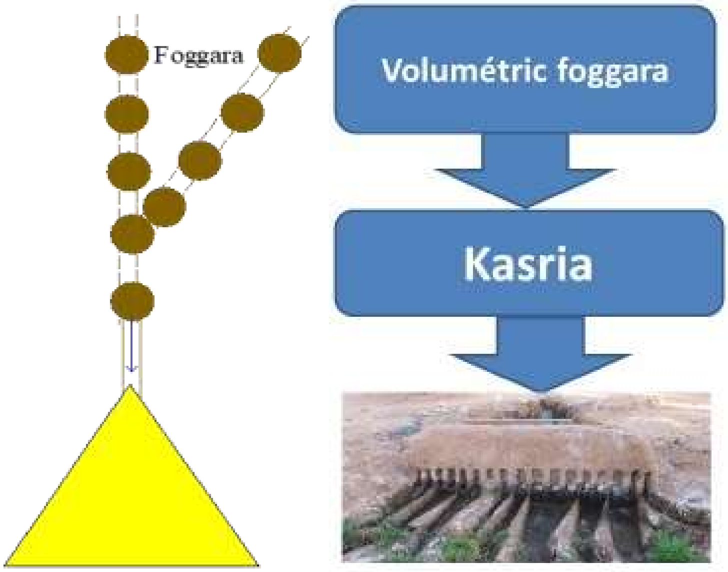
Table 3: Characteristics of Sahara foggaras (Remini, 2023; Remini, 2022)

Type of foggara	Name of the oasis	Number of foggara	Water source
Albian Foggara	Adrar	1215	Intercalary Continental
	Timimoun	550	Intercalary Continental
	In Salah	50	Intercalary Continental
Foggara of Erg	Timimoun	64	Grand Erg Occidental
	In Ghar	10	Miliana Erg
	Ezzaouia	05	Ezzaouia Erg
	Tabalbala	101	Erraoui Erg
Kenadsa Foggara	Kenadsa	12	Berga Cliff
Garden Foggara	Timimoun	07	Infiltrations
Ouakda Foggara	Bechar	22	Water table
River Foggara	Tamenrasset	184	Inferoflux tablecloth
	Tindouf	01	Inferoflux tablecloth
	Sfissifa	02	Inferoflux tablecloth
	Brezina	01	Inferoflux tablecloth
	Moghrar	02	Water source
	Hannou (Adrar)	01	Water source
	Beni Ounif	02	Water source
	Lahmar	04	Water source
Ain Foggara	Beni Abbes	65	Water source
	Taghit	45	Water source

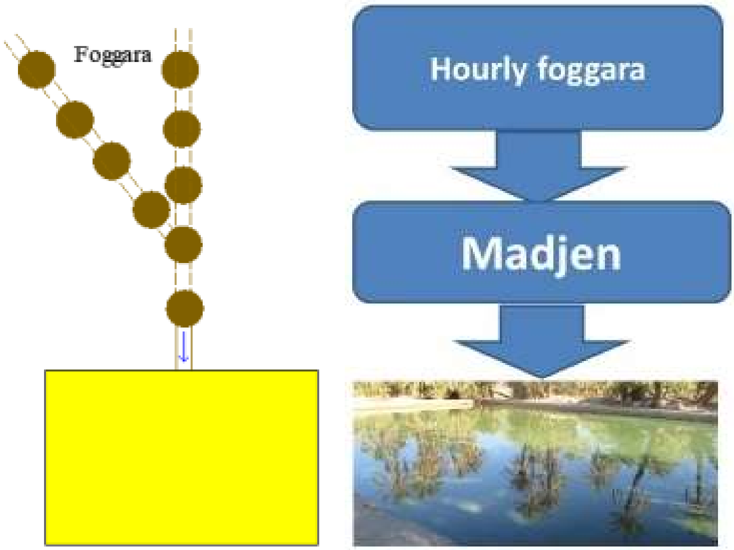
	Mechria Esseghira	2	Water source
	Stiten	11	Water source
	Boussemghoun	09	Water source
	Ain Madhi	01	Water source
	Laghouat	09	Water source
Mzab Foggara	Ghardaia	02	Wadi Mzab floods
Total		2374	

Types of foggaras in Algeria

The first scientific trip on the silting of oasis areas was organized in the region of Adrar, a city located 1,400 km southwest of Algiers. The first foggaras we discovered were the foggaras of Tamentit. After a short stay in the ksours of Tamentit, we joined the beautiful oases of Timimoun, we visited the foggaras of the city center of Timimoun such as the famous foggara of El Megfhier, the foggara of Ifli as well as the beautiful foggaras of 'Ouled Said. This trip to the countries of the foggaras has remained engraved in our memory. We were impressed by the kasria, the chegfa and more particularly the Kial El Ma with these manipulations with its copper plate with holes using clay (Remini, 2019; Remini and Ghachi, 2019). For us, we were convinced that the foggara originated in the regions of Touat, Gourara and Tidikelt. But after our mission to the Saoura, we encountered another type of foggara without the kasria, nor even the Kail El Ma with his Chegfa. They are foggaras of short length. At the exit of the gallery; the water flows in a seguia towards the collective madjen. After visiting all these foggaras, we have highlighted two types of foggaras which have the same upstream part (gallery equipped with ventilation shafts) but the downstream part (distribution network) is completely different. A foggara which discharges its water directly into the kasria (Fig. 12a and 13a). These are the foggaras of Tidikelt, Gourara and Touat. A foggara which directly diverts its water into a large basin (collective Madjen). We speak of the foggaras of the Saoura valley (Fig. 12b and 13b).

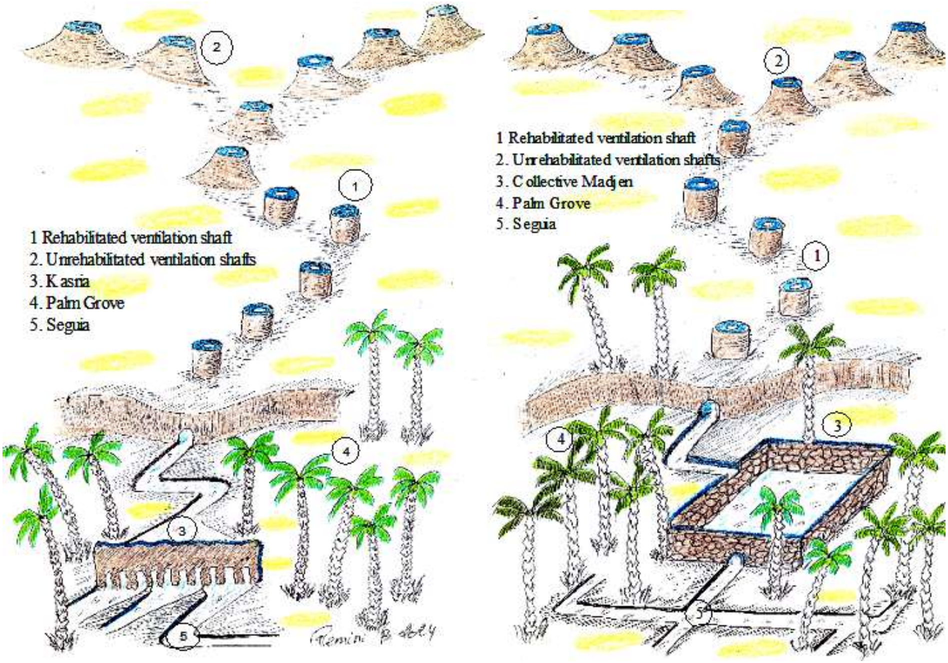


a) Volumetric Foggara



b) Hourly Foggara

Figure 12: The two types of foggaras existing in Algeria (Diagram Remini, 2024)



a) Volumetric Foggara **b) Hourly Foggara**

Figure 13: The madjen and the kasria, two essential elements The two types of foggaras existing in Algeria (Diagram Remini, 2024)

After a series of investigations and surveys carried out with the local population of the regions of Touat, Gourara, Tidikelt and the Saoura valley, two types of foggaras were highlighted. These are the Hourly foggara and the volumetric foggara. We define the volumetric foggara as being a foggara whose water distribution network is carried out per unit of volume (Remini, 2019). This type of foggara is located in the oases of Touat Gourara and Tidikelt which take the form of a crescent (Fig. 14). The majority of volumetric foggaras are fed by water from the Continental Intercalaire aquifer (Fig. 15). The volumetric foggaras arise on the outskirts of the Tademaït plateau which plays the role of the foggara water tower.

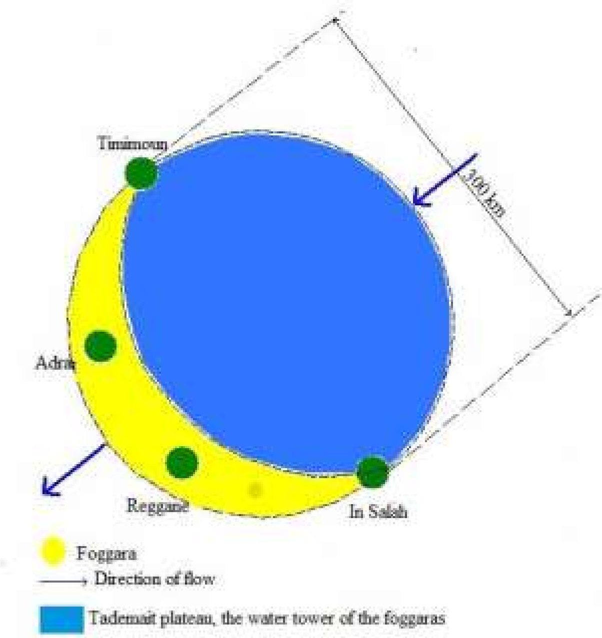
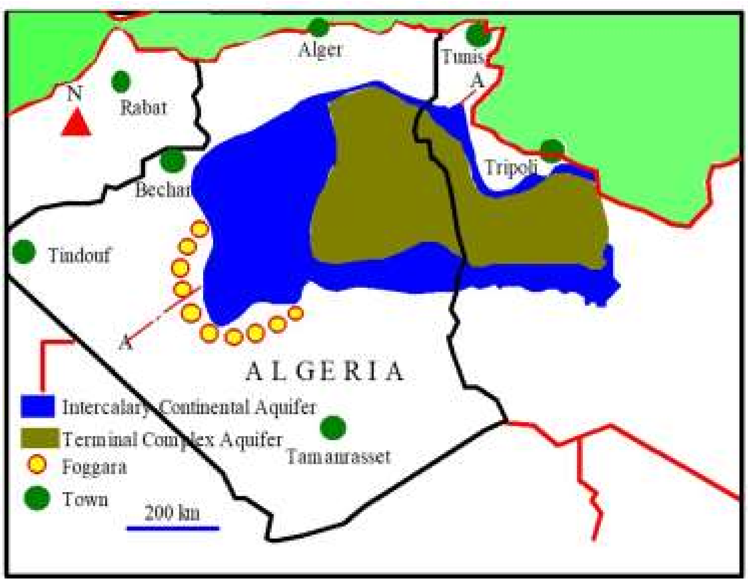


Figure 14: The crescent of the oases of Gourara, Touat and Tidikelt (GTT), the cradle of the volumetric foggara (Remini, 2024)



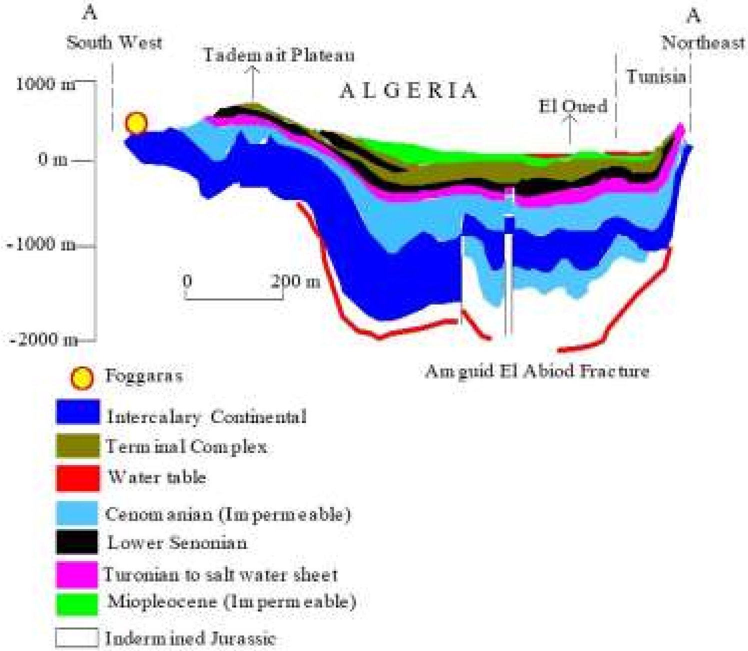


Figure 15: Intercalary Continental aquifer: the source of Albian foggaras (source UNESCO in 1972 Castany, 1985 as amended by the author)

We define the Schedule foggara as being a foggara whose water distribution network is carried out per unit of time. This type of foggara is located in the oases of the Saoura such as Taghit, Beni Abbes, Boukais, Beni Ounif, Ouakda; We also find these foggaras in the oases of Tindouf, Moughrar and Sfissifa. The network of a volumetric foggara is much more complex since it is made up of kasriates, seguias and madjens of different dimensions (Fig. 16). On the other hand, the water distribution network is very simplified since it is made up only of structures such as a large basin (Madjen) and seguias of constant dimensions (Fig. 17).

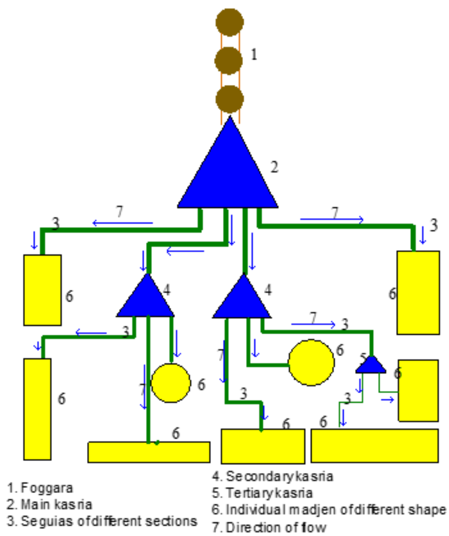


Figure 16: Diagram of the hydraulic water distribution network of a volumetric foggara (Diagram Remini, 2024)

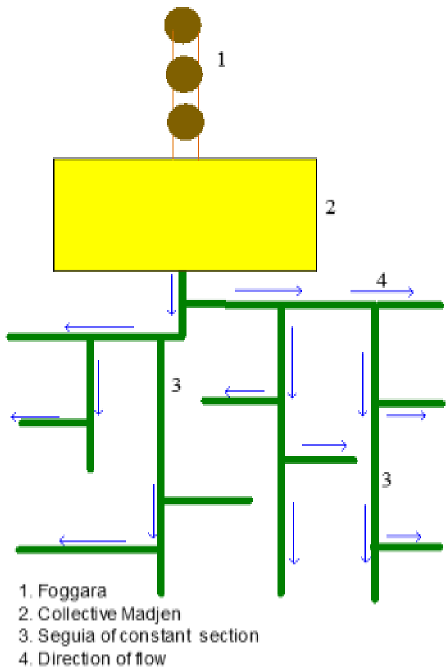


Figure 17: Hydraulic water distribution network of a foggara Schedule (Diagram Remini, 2024)

For the volumetric foggara, the irrigation of the gardens is carried out in parallel. That is to say, all the gardens receive their share of water at the same time (Fig. 18).

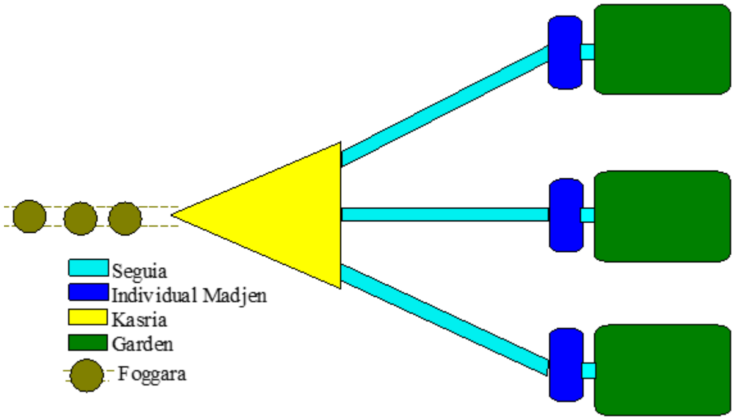


Figure 18: Diagram of parallel irrigation (Diagram Remini, 2024)

On the other hand, for the foggara Schedule, the irrigation of the gardens is carried out in series. That is to say, the irrigation of gardens is carried out in series. That is to say, the gardens receive their shares of water in turn or quite simply garden after garden (Fig. 19).

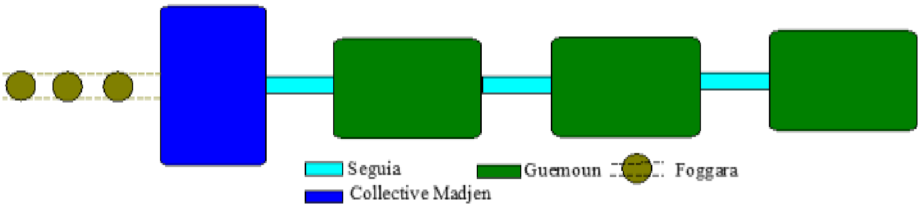


Figure 19: Diagram of serial irrigation (Diagram Remini, 2024)

In hydraulics books, whether in drinking water supply or in sanitation, there are two types of water distribution networks. These are the branched network and the mesh network (Fig.20 and 21). However, there is a third network which has never been cited in the bibliography. This is the water distribution network of the Volumetric foggara (Algerian foggara). We have named this network a triangular network or pyramid network (Remini, 2011; Remini, 2019; Remini, 2023) (Fig. 22).

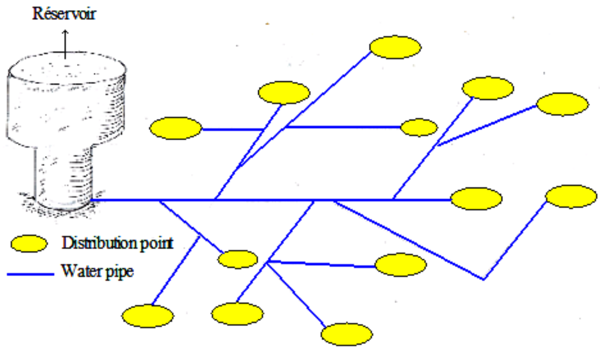


Figure 20: Branched water network (Diagram Remini, 2024)

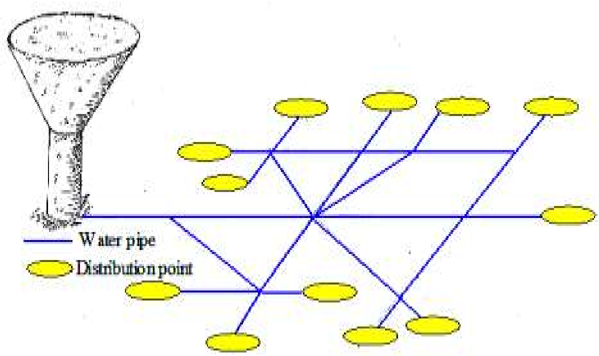


Figure 21: Mesh water network (Diagram Remini, 2024)

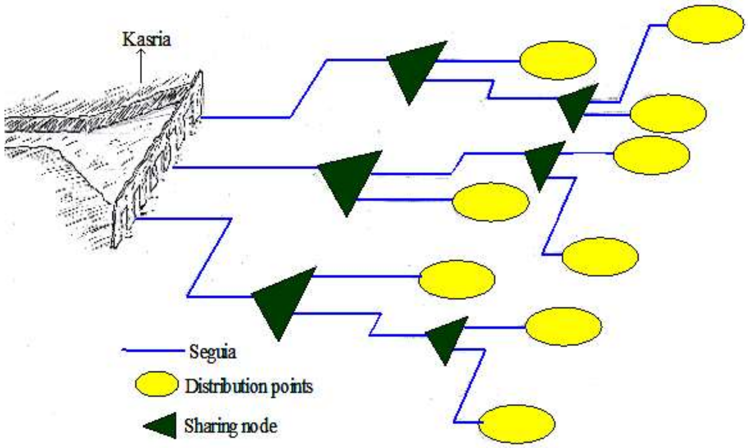


Figure 22: Triangular or Pyramidal water network (Diagram Remini, 2024)

Original from the oases of Touat, Gourara and Tidikelt, the triangular network is a local invention (Fig. 23). On the other hand, the hourly foggara, the distribution network is rather a branched network (Fig. 24). This type of network is mainly located in the oases of the Saoura valley. So, two networks: branched and triangular exist in the palm grove gardens irrigated by foggaras. For gardens irrigated by a volumetric foggara, each garden is equipped by an individual madjen which is located on the high point of the garden. The individual madjen is sized to fill for 24 hours. For gardens irrigated by a foggara Schedule, the water is stored first in a collective madjen which is located on the highest point of the palm grove. This pool is sized so that it fills for 24 hours. In turn, each garden will be irrigated one after the other, each will have its share of water in unit of time. Regarding the water distribution network of a foggara, each owner's share of water depends on their contribution to the construction and maintenance of the foggara. However, the volumetric foggara is much more advantageous compared to the Hourly foggara. Garden irrigation can be done throughout the day for volumetric foggara oases. It is an irrigation of choice. On the other hand, for gardens irrigated by a foggara Schedule, each garden waits its turn as it was fixed by the Djamaa. In this case, we are talking about imposed irrigation. Regarding the sizing of networks, that of the volumetric foggara requires rigorous sizing of hydraulic structures such as kasriates, seguias and madjens. On the other hand, the distribution network of an hourly foggara is simply satisfied with a dimensioning of the collective madjen. The seguias have constant dimensions.

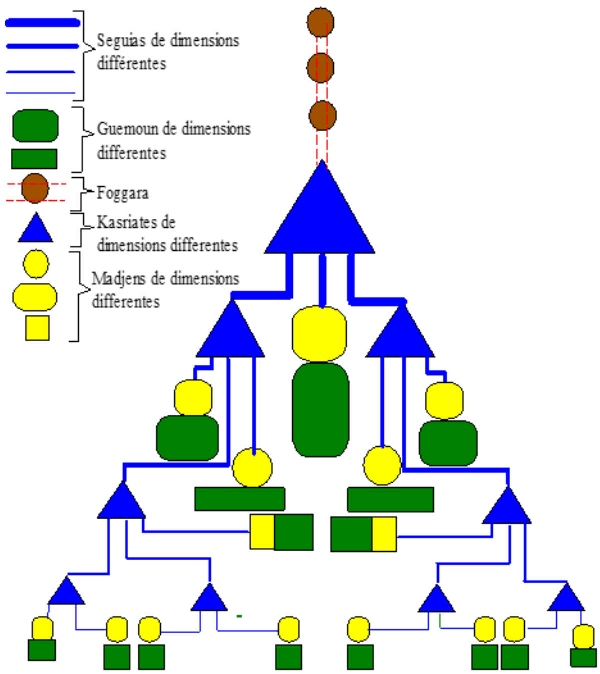


Figure 23: Water distribution network of a volumetric foggara (Diagram Remini, 2024)

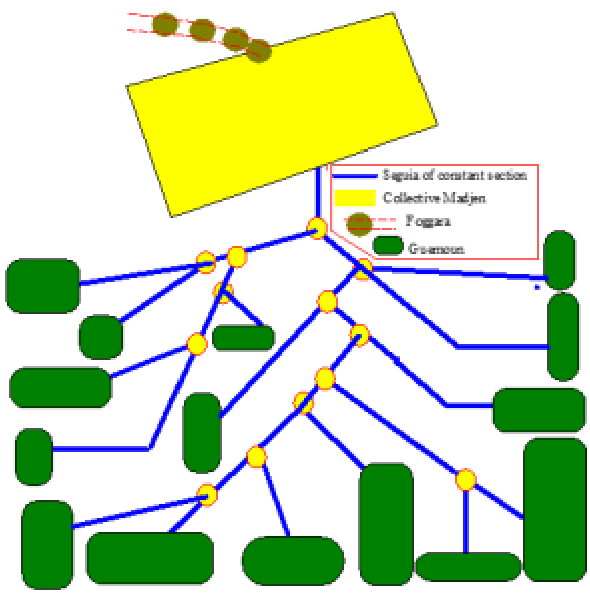


Figure 24: Water distribution network of a foggara Schedule (Diagram Remini, 2024)

Quantification of water shares

As we mentioned at the start of this study, the foggara is a collective good. Digging a foggara in an arid environment remains a very difficult mission. It is a group of farmers who participated in carrying out a mega project with rudimentary means and could take several years. Once the water has passed from the aquifer to the ground surface after flowing several kilometers into the subsoil, the water becomes a collective good which belongs to the participants of this project. In this case, the water from the foggara is shared equitably between the co-owners. That is to say, the parts of water are not equal, but they are different. This is how water management is governed by customary water sharing laws. Each co-owner's share of water is determined based on the volume of work provided during the construction or maintenance of the foggara. In this case, the share of water must be quantified and evaluated. So, for equitable distribution between the rights holders in the creation and maintenance of the foggara. Therefore, for equitable distribution between co-owners, quantification of water shares becomes essential. To resolve this problem, farmers implemented a process for measuring water shares. Unlike the foggara countries, Algeria is among the rare countries, if not the only country, with both types of foggaras: volumetric and hourly. Thanks to oasis engineering and invaluable know-how in the field of foggaras, two methods of measuring water volume were implemented based on flow through orifices. Whether for the volumetric foggara or for the hourly foggara, the process is based on the theory of orifice flows. For the volumetric foggara, the sharing of water between the co-owners is carried out by unit of volume. The triangular network requires a process that quantifies the throughput (Q) of each co-owner (Fig. 25). In this case, the method based on orifice flows requires permanent flow through the orifices. On the other hand, for the branched network requires a method which quantifies the time (T); the irrigation duration of each co-owner (Fig. 25). In this case, the method used on orifice flows requires non-permanent flow through the orifices.

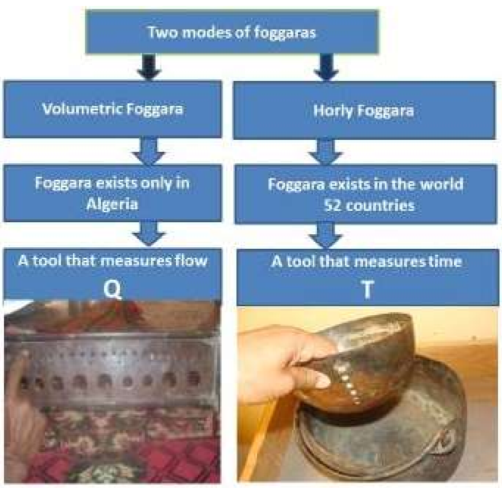


Figure 25: Two tools for quantifying the water share of the Algerian foggara (Volumetric and Hourly) (Remini, 2024)

For the volumetric foggara, the method of quantifying the flow rate Q is a copper plate pierced by openings of different dimensions. This plate is called Louh in the Gourara oases and Chegfa in the Touat and Tidikelt oases. It should be noted that each region has its own gauging tool with its own characteristics. For example, the Louh of the Gourara oases is a copper plate which contains two rows of holes (Fig. 26(a and b)). The Chegfa from the Tidikelt region is a cylindrical plate and has two rows of holes of different diameters. For example, in the Timimoun oasis, a rectangular copper plate measuring 57 cm × 18 cm is used (Remini, 2023). The plate is pierced with holes of several openings of different diameters whose unit of measurement varies from one oasis to another. In the oases of central Timimoun, we use the Tmen instead of Habba equal to approximately 0.0416 l/s (Remini et al, 2014b. Remini, 2023). In the oases of Ouled Said (Timimoun), the unit of measurement used is the Habba which is equal to 2.5 l/min (Remini et al, 2014b; Remini, 2023).

a) Louh (photo. Remini, 2007) **b) Chegfa (photo. Remini, 2024)**

Figure 26: Gauging operation of the foggara of an oasis of Touat, Gourara and Tidikelt

Once this process is installed perpendicular to the flow in a seguia made of clay, the water flows through the orifices of the Chegfa or the Louh. After a series of closings and openings of the orifices by the clay, the water level stabilizes at the level of a threshold fixed by the Kial El Ma. In this case, the level of the free surface of the water is flush with the mark fixed on the copper plate (Remini, 2019; Remini et al, 2014b; Remini and Gahchi, 2019). This explains that the height between the orifice and the mark is constant and equal to Ho. In this specific case, we obtained a permanent flow, that is to say the flow rates upstream and downstream of Chegfa (or Louh) are equal. In this case, you only need to count the number of open holes (with flow) to get the value of the flow. By using the laws of flow through an orifice for permanent flow (Carlier, 1980).

$$q = C_d \, x \, S_0 \sqrt{2gh}$$

Equation deduced from Bernoulli's theorem.

q: flow (m^3/s)

S_0: Orifice section (m^2)

C_d: Flow coefficient

g: acceleration of gravity (m/s^2)

For oases, (h) is fixed. Each gauging plate has its own (h). Ho

For our case, we have h= H_O.

We set A= C_d √2gHo: Characteristic coefficient of the gauging plate. Each plate must have its own plate coefficient.

In this case, the flow rate through an orifice is equal to: q=AxS0, so it is S0 which defines the flow rate of each part of water. For each part of water, we must count the number of open orifices. In this case, the flow through a number of orifices (n) is:

$$Q = n.q = n.S_{o}.. \, C_d \sqrt{2gHo} = n. \, S_o \, A$$

Each orifice section corresponds to 1 habba. The diameter of the hole and the height (h) of the Hallafa (gauging plate) vary from one oasis to another. It is for this reason that the Habba volume unit depends on the choice of diameter and height. Each co-owner receives their share of water in unit volume (Remini, 2019). The unit of measurement used is the Habba which corresponds to the section of the ring of a date pit. To quantify the water shares of the rights holders of an hourly foggara, different techniques are used to quantify the water shares, but the most used is the water watch. This water watch is based on the principle of flow through orifices, but in this case, it is a non-permanent flow unlike the volumetric foggara where the flow is assumed to be permanent. The measuring system is made up of two copper containers (Fig. 27). The largest is placed on the ground and filled with water. The second smallest graduated and holed at the bottom (Remini, 2019). The latter is placed on the free water surface of the large container. The water flows through the opening and once the small container fills with water it drops to the bottom of the large container. In this case, it is a question of determining the time of filling of the capsule (half-spherical container), that is to say when it is emerged by the water, a part of irrigation water is counted.

Figure 27: Diagram of the steps for measuring the water shares of a foggara Time by the water watch (Remini diagram, 2024)

This measurement system is widely used in the oases of Saoura, Tamanrasset, Tindouf and Moghrar. The principle of this measurement tool is based on determining the filling time of the half-spherical container through an orifice located in the bottom of the capsule (Remini, 2019).

Starting from the equation: $Q=C_d \times S_0 \sqrt{2gh}$

After a filling time (dt), there is a filling flow: $Q=dw/dt\ H_O$

The equality of the two equations gives us: $T=\frac{1}{Cd.So\sqrt{2g}}\int_0^H S(h)\frac{dh}{\sqrt{h}}$

For the foggara, we determine the unit of filling time:

$$T= K\int_0^H S(h)\frac{dh}{\sqrt{h}}$$

For the volumetric foggara, we determine the irrigation flow : $Q=C_d \times S_0 \sqrt{2gh}$

For the foggara Schedule, we determine the irrigation time:

$$T= K\int_0^H S(h)\frac{dh}{\sqrt{h}}$$

It is interesting to note that $T=f(C_d, S_0)$, which means that each oasis has its own Tassa (water watch). The filling time of the Tassa, which corresponds to the share of water in irrigation, varies from one oasis to another.

During our field missions, we noted that this method was used in oases which have hourly foggaras such as Oaukda, Lahmar, Taghit, Beni Abbes, Boukais, Boussemghoun, Moghrar, Tindouf, Sifissifa, and the foggara of Hennou which is located in the foggara of Tametit.

DISCUSSION

Evoking the word “Foggara” is evoking the history of water in Algeria. It is in this sense that we began this work on the foggara in the early 1990s. Based on missions in the oases of the Sahara, our first mission was set for the oases of Adrar; capital of the foggaras in 1998. Once on the site of the foggaras, I was dazzled by this system of draining galleries. For us outside the oases of Touat, Gourara and Tidikelt, there are no foggaras, but in reality given its success; foggara was exported to Saoura, to Tindouf, to Tamanrasset and even outside Algerian borders. A very in-depth bibliographic study on foggaras around the world revealed to us that the foggara was dug in 52 countries from the four corners of the planet. In addition, the upstream part of the foggara which consists of a gallery is the same for all the foggaras in the 52 countries of the world. However, even the downstream part which concerns the sharing of water represented by the water distribution network is the same for all foggaras. Except that the Algerian foggara has a second unique and original network. It is in this sense that we have adopted two types of foggaras: volumetric and hourly. Originating from the oasis crescent formed by the oases of Touat, Gourara and Tidikelt, the volumetric foggara is more ingenious than the hourly one which has a very simplified branched distribution network. A new distribution network different from the meshed and branched networks that we have called the triangular or pyramidal network was invented in the oases of Touat, Gourara and Tidikelt. This type of network ensures water sharing per unit of volume between rights holders. That is to say, the irrigation of the gardens took place in parallel. This means that all gardens receive their quantities of water at the same time. Unlike the hourly foggara which adopted a division per unit of time. In this case, each farmer's share of water depends on his contribution to the work of the foggara. For hourly foggara, the water share is evaluated in “time” which translates into an irrigation duration. Except in this case, the problem that arises is that irrigation cannot be done at the choice of the garden owner. The start time of consumption of the irrigation duration of each owner is imposed and the owner must wait his turn. It is this type of water sharing that has been adopted in all the foggaras of the 52 countries on the planet. Back to the volumetric foggara, the sharing of water is much more equitable, since the share of water is evaluated in “water volume” and not in “irrigation time”. The most interesting thing for this type of foggara is that the owners' shares of water arrive at their destinations at the same time; the madjens of the gardens fill up at the same time and not in turns like the hourly foggara. The originality of the Algerian foggara lies in the existence of the “Kasria” structure which ensures sharing by a unit of volume between the co-owners of the foggara (fig. 28).

Figure 28: Secondary Kasria of the foggara of El Meghier of the Timimoun oasis (Photo. Remini, 2015)

CONCLUSION

As we mentioned at the beginning of this study that the Algerian foggara is different from the Iranian qanat, the Moroccan khettara, the Omani falaj and the Afghan Karez. The original results obtained in this study (not completed) indicate new names have been introduced into the technical bibliography. This is how we established two types of foggaras: volumetric and hourly, each of them is equipped with its own water distribution network. If today, we have confirmed through very in-depth bibliographic research that the hourly foggara equipped by a branched distribution network exists in the 52 countries on the planet that have foggaras. However, we have demonstrated that the volumetric foggara exists in the Algerian Sahara and is of origin from the oasis crescent formed by the oases of Touat, Gourara and Tidikelt. So, by a simple addition, Algeria is the only country which has both types of networks: volumetric and hourly. In addition, it should be noted that the volumetric foggara is much more ingenious and social than the hourly foggara. The originality of the volumetric foggara lies in its distribution network which is different from the existing networks in the bibliography, namely the branched and meshed networks. We called this new network the triangular or pyramidal network. Unlike the volumetric foggara, the hourly foggara exists in the Saoura valley, in the oases of Tabelbala and Tindouf. The technical bibliography that we consulted showed that the upstream part of the foggara (i.e. the gallery and the ventilation shafts) is common to all the foggaras on the planet. This upstream part is the most studied. However, the downstream part of the foggara which contains the water distribution network is unknown or very little studied. This study demonstrated that the upstream part of the foggara was modified and adapted according to the hydrogeology and hydrology of each region of the Algerian territory. This is how we proposed 8 models of foggaras which adapt to all types of water sources, namely the Continental Intercalaire aquifer, the Erg aquifer, the Inferoflux aquifer, the water table and the floods. All the models of foggaras existing in the world are gathered in the Algerian Sahara. So, if today the Kial El Ma has been recognized and registered as an intangible heritage by UNESCO since 2018. So, now is the time to register the Algerian foggara at UNESCO.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

How can we not thank this entire oasis population, since it is thanks to them that this paper has just seen the light of day. Thank you very much for the welcome, the accommodation, the catering and above all I learned a lot about the foggaras and all the water collection techniques. During 30 years of work in the Algerian Sahara and thanks to my guide the foggara, I discovered an immense and beautiful country which is Algeria. I also discovered a wonderful Ksourian population and a very rich material and intangible heritage of indefinite immensity. The work we have carried out on foggaras is part of free research and does not fall into any area of research. This is research funded by myself. Besides, this study on the foggaras will end once I am in the other world. I will never forget the foggara since it allowed me to discover the most beautiful country on the planet; Algeria. Thank God, we had the chance to visit the oases of Timimoun, Adrar, Ouled Saïd, Bou Saada, Biskra, Tindouf, Tabelbala, Bechar, Moughel, Kerzaz, Igli, Kenadsa, Boukais, Tiout, Ain Sefra, Oulad Sidi Cheikh, Moghrar, Boussemghoun, Tamanrasset, Djanet, In Salah, In Ghar, Zaouiet Kounta, Igosten, Bouda, Tamentit, Ghardaia, Beni Isguen, El Atteuf, Bounoura, Metlili, Touggourt, Ouargla, El Oued, El Guerara, Tolga, Laghrous , Foughala, Biskra, Mchounech, Ghassira, Chegga, Djamaa, Boussaada, Sidi Okba and others. We hope that UNESCO will recognize the Algerian foggara, a foggara which is different from the qanat, khettara, Karez and falaj.

REFERENCES

ABIDI SAAD N., REMINI B. (2011). The foggaras of Touat: the pride of the local population, Annals of Science and Technology, Vol. 3, No 2, pp.107-113.

ADIN S. (2006). Qanat a unique groundwater management tool in arid regions: the case of Bam region in Iran, International symposium on groundwater sustainability.

ABOUEI R. (2006). Conservation of badgires and qanats in Yazd central, Iran. The 23th conference en passive and low Energy Architecture, Geneva, Switzerland, pp. 6-8.

AL-MARSHUDI, A.S. (2001). Traditional Irrigated Agriculture in Oman, Water International, No 26, pp. 259–264.

AL MARSHUDI AS. (2007). The Falaj Irrigation System and water allocation markets in northern Oman, Agricultural water management, No 91, pp. 71-77.

ARRUS R. (1985). Water in Algeria from imperialism to development (1830 -1962), Office of University Publications Algiers, Presses Universitaires de Grenoble, 388 p.

AL SULAIMANI Z.B., HELMI T., NASH H. (2007). The social importance and continuity of falj use in northern Oman, International History, Seminar on Irrigation and drainage, Teheran, Iran, pp. 2-5.

AL-KINDI, K.M., ALQURASHI, A.F., AL-GHAFRI, A.; POWER, D. (2023). Assessing the Impact of Land Use and Land Cover Changes on Aflaj Systems over a 36-Year Period, Remote Sensing, Vol. 15, https://doi.org/10.3390/rs15071787

AHMADI H., SAMANI A.N., MALEKIAN A. (2010). The Qanat: A Living History in Iran. Book Water and Sustainability in Arid Regions (Springer Edition), Chapter 8, pp. 125-138.

AZIMI, A., MCCAULEY D. (2002). Afghanistan's Environment in Transition", 1st Edition, Asian Development Bank, Manila, Philippines, pp. 1–12.

AL-GHAFRI A. (2018). Overview about the Aflaj of Oman, Proceeding of the International Symposium of Khattaras and Aflaj, Erachidiya, Morocco, October 9.

AL GHARFI A., NORMAN WR., INAN T., NAGSAWA T. (2000). Traditional, Irrigation scheduling in Aflaj Irrigation systems of case study of Falaj Al Hageer, Proceeding of the first International symposium Qanat, Vol. VI, Yazd, Iran, pp. 37-42.

AL-HATMI H.K., AL-AMRI S.S. (2000). Aflaj Maintenance in the Sultanate of Oman, in the Proceeding of the First International Symposium on Qanat, Vol. IV, pp. 154-161.

BEN BRAHIM M. (2003). The khettaras of Tafilat: past, present and future, International communication Frontnus-symposium, October, Walferdange, Luxembourg.

BEN BRAHIM M. (2008). Traditional irrigation and socio-cultural constructs in the Tafilalt Oases (Moroccan South-East), 2nd International Congress on "Oases and sustainable tourism", Zaragoza, August 7-11, Spain.

BEAUMONT P. (1989). The qanat: a means of water provision from groundwater sources, In Beaumont P., Bonine M., McLachlan K., Eds, Qanat, Kariz and Khettara, Wisbech, Menas Press, pp. 13–31.

BERAAOUZ M., ABIOUI M., HSSAISOUNE M., MARTÍNEZ-FRÍAS J. (2022). Khettaras in the Taflalet Oasis (Morocco): contribution to the promotion of tourism and sustainable development, Built Heritage, Vol 6, No 24, pp. 2-16.

BAALI E., AZOUGGAGH M., AHL RCHID O. (2002). Water pumpumg for irrigation in southern Moroccan Oasis, International Research on food security, natural resource Management and rural development, Kassal-Witzenhausen, October 9-11.

BALLAND D. (1992). Hidden waters, publications of the Department of Geography From the University of Paris Sud, France.

BISON J. (1990). Permanence of a peasantry in the Algerian Sahara: the example of the confines of the Grand Erg Occidental, Options Méditerranéennes, Série A/No 11, Oasis agricultural systems, pp. 289-298. (In French)

BANKS D., SOLDAL (2002). Towards a policy for sustainable use of groundwater by non-governmental organisations in Afghanistan, Hydogeology Journal, No 10, pp. 377-392.

BEZZA M. (2006). Overviewof the history of water resources and irrigation management in the near east region. 1er IWA International symposium on inter and wasterwater technologies in ancient civilization, Iraklio, Greece, October 28-30.

BOUSTANI F. (2008). Sustainable water utilization in arid region of Iran by qanats, Proceeding of world academy of science engineering and technology, Vol. 33, pp. 213-216.

BRIANT P. (2001). Irrigation and drainage in antiquity, qanats and underground pipelines in Iran, Egypt and Greece, Editions Thotm, Paris, France,190 p.

BOCCUTI S., FERRARI A., PINGUE G., DI LUZIO E. (2022). Qanat, una tecnologiadel passato, una risorsa per il futuro: riferimenti storici, aspetti socio-economici e repertorio tipologico Archeologia Calcolatori Vol. 33, No 2, pp. 153-174, doi 10.19282/ac.33.2.2022.09.

CARLIER M. (1980). General hydraulics. Editions Eyrolles, Paris, France, 565 p.

CLOUET Y., DOLLE V. (1998). Aridity, Oases and small production, hydraulic requirements and social fragility: an approach by spatial and socio-economic analysis, Drought Review, No 2, Vol. 9, pp. 83-94.

CRISTINI A., LANGLAIS S. (2004). The qanat: an ancestral capture device, H2O, No 46, pp.10-11.

CENESTA (Centre for sustainable development) (2003). Qanat Irrigation systems: an ancient water distribution system allowing specialised and diverse cropping in descent regions of Iran, Report proposal for a candidate site of globally important ingenious agricultural system (GIAHS), 21p.

DIGARD J.P., BRIANT P. (2001). Irrigation and drainage in antiquity, qanats and underground pipelines in Iran, Egypt and Greece. Editions Thotm, Paris, France, 190p.

DOLLE V. (1998). Oasis agriculture, a long history, what future? « Secheresse » Review, No 2, Vol. 9, pp. 81-82.

EL FAIZ M., RUF T. (2010). An Introduction to the Khettara in Morocco: Two Contrasting Cases. doi: 10.1007/978-90-481-2776-4_10.

GHACHI M., REMINI B., HAMOUDI S. (2021). The foggaras of Ezzaouia oasis (Algeria): the water always flows under the sand, Technology Reports of Kansai University, Vol. 63, No 2, pp. 2113-7128.

GHACHI M., REMINI B. (2018). Irsan: the largest foggara of Tidikelt (Algeria) in decline, Journal of Water Sciences & Environment Technologies, Vol. 3, No 1, pp. 279-248.

GHAYOUR H. (2000). A new review on geographical distribution of qanats in different regions of Iran, in Proceedings of the First International Conference on Qanat, Yazd, Iran, pp. 23-34.

GOBLOT H. (1963). In ancient Iran, water techniques and great history, Annals, Vol. 18, No 3, pp. 499-520.

GOBLOT H. (1979). Qanats: a technique for acquiring water, Paris, Mouton, 231 p.

GOLDSMITH E., ILDYARD N. (1984). The Qanat of Iran, The social and Environmental-Effects of large dams, chapter 21, Vol.1, overview, wedebridge ecological centre worthyvale Manor camelford.

GONZALEZ ANDRICANI C., BAZURCO M. (2004). Local knowledge and water management systems in Audean communities, Filter galleries in souther potosi, Bolivia, La Paz, pp. 1-7.

GHORBANI B. (2007). A glance at historical Qanats in Iran with an emphasis on Vazvan Qanat in Isfahan, in Proceedings of International History Seminar on Irrigation and Drainage, Tehran, Iran, International Commission on Irrigation and Drainage (ICID), pp. 165-172.

GUILLERMOU Y. (1993). Survival and social order in the Sahara, The Oases of Touat-Gourara-Tidikelt in Algeria, Cahier des Sciences Humaines, Vol 29, No 1, pp. 121-138.

HAMDAOUI T.M., REMINI B. (2020). Evolution of traditional water collection techniques in the Algerian Sahara, GeoScience Engineering, DOI 10.35180/gse-2020-0045, Vol. 66, No 4, pp. 204–222.

HUSSAIN I., ABU-RIZAIZA O.S., HABIB M.A.A., ASHFAQ M. (2008). Revitalizing A Traditional Dryland Water Supply System, The Karezes in Afghanistan, Iran, Pakistan and the Kingdom of Saudi Arabia, Water International, Vol.33, No.3, pp. 333–349.

HIMAT A., DOGAN S. (2019). Ancient Karez System in Afghanistan: The Perspective of Construction and Maintenance, Academic Platform, Journal of Engineering and Science Vol 7, No 3, pp. 347-354,

HOFMAN (2007). Is traditional water management by qanat in Iran compatible with the concept of IWRM? Technical summary, Engref center of Montpellier, 17 p.

HUSSAIN I., SIRAJ ABU RIZAIZA O., HABIB MOHAMED AA., ASHFAQ M., (2008). Révitalizing a traditional dryland water supply system, The karezes in Afghanistan, Iran, Pakistan and the Knigdom of Saudi Arabia, Water International, Vol. 33, No 3, pp. 333-349.

KHARDI Y., LACOMBE G., KUPER M., TAKY A., BOUARFA S., HAMMANI A. (2023). Pump or disappear: the dilemma of strengthening khettaras by solar pumping in the oases of Morocco, Agriculture Notebooks, Vol 32, No 1, https://doi.org/10.1051/cagri/2022030, www.cahiersagricultures.fr

KARIMI S. (2003). Qanat as the symbol of the native Iranians in water harvesting from groundwater resources, 3rd IWHA conference, December 11-14, Alexandria, Egypt.

KOBORI, I. (1980). Qanawat Romani of Taibe Oasis, Tokyo, University of Tokyo, Department of Geography, 98 p.

KOBORI I. (1982). Case studies of foggara Oases in the Algerian Sahara and Syria, Tokyo, Tokyo University, Department of Geography, report No 2, 45 p.

KOBORI, I. (1990). The qanat in Syria", In Geyer B. (Ed.), Traditional Hydro-Agricultural Techniques and Practices in Irrigation, Vol. 2, Paris, Librairie Orientaliste Paul Geuthner, pp. 321–328.

KOBORI, I., TAKAHASI, Y., KAWANO S. (1980). The water system of Taibe Oasis", In Kobori, I. (Ed), Qanawat Romani of Taibe Oasis, Tokyo: University of Tokyo, Department of Geography, pp. 53–82.

KHAN M.J., PACHA G., KHATTAK M.S., OAD R, (2015.) Water Distribution of Traditional Karez Irrigation Systems in Afghanistan, Irrigation and Drainage, No 64, pp. 169–179.

L'HOTE Y. (1990). History of the concept of the water cycle and the first hydrological measurements in Europe, Continental Hydrology, Vol. 5, No. 1, pp. 13-27.

LIGHHTFOOT D.K. (1996). Moroccan Khettara: traditional Irrigation and progressive Desiccation, Geoforum, Vol 27, No :2, pp. 261-273.

LIGHTFOOT DR. (1997). Jordanian Qanat Romani: qanats in the Levant: hydraulic Technology at the periphery of early empires, Technology and culture, Vol 38, No 2, pp. 432-451.

LIGHTFOOT DR. (2001). Traditional Wells as phreatic barometers: a view from qanats and tabe wells in developing arid lands, Water security in the 21 th century.

LYNN TEO S., AZZI R. (1992). Oman's unforiling springs, Revue Saudi Aramieg world, Vol. 43, No 6, pp. 26-31.

LI Q., GUO H., LUO L., WANG X., YANG S. (2023). Impact Analysis of Land Use and Land Cover Change on Karez in Turpan Basin of China, Remote Sensing, Vol. 15, Paper ID 2146, https://doi.org/10.3390/rs15082146

MAGHREBI M., NOORI R., SADEGH M., SARVARZADEH F., ERFANIAN A., AKBARZADEH AE., KARANDISH F., BARATI R., TAHERPOUR H. (2022). Anthropogenic decline of ancient, sustainable water systems: qanats. Groundwater, doi: 10.1111/gwat.13248

NORMAN W., SHAYYA R., WALID H., AL-GHAFRI A. (1998) Irrigation Water Costs and Management Practices Among Farms in Northern Oman, Journal of Scientific Research, Agricultural Sciences, Vol.3, Sultan Qaboos University, Oman, pp 1-8.

OLIEL J. (1994). Foggaras: an original irrigation system. Jews in the Sahara; Touat in the Middle Ages, CNRS History, 188 p.

PAPY L. (1959). The decline of foggaras in the Sahara, according to recent work, Overseas notebooks, Flight, Vol. 12, No. 48, pp. 401-406.

POURAGHNIAEI M.J., MALEKIAN A. (2001) Qanat in mountainous and plateau regions, in International Colloquium on Origin and History of Hydrology, Dijon, Université de Bourgogne, France.

PIERRE J.L. (2001). The mountains and people in a semi-arid environment: the example of the economy of the Tineghir palm grove, Liaison bulletin of history – geography teachers of the Reims academy, No 25, 3p.

QURESHI AS. (2002). Water Resources Management in Afghanistan: The Issues and Options. International Water Management Institute, Working Paper 49, Pakistan Country, Series No. 14.

REMINI B., ACHOUR B., KECHAD R. (2010). Types of foggara in Algeria, Water Sciences Review (Canada-France). Vol. 23, No. 2, pp. 105-117.

REMINI B. (2011). The foggaras of the Sahara oasis belt: past, present and future. Doctorate in science. Mohamed Khider-Biskra University, 217 p.

REMINI B., ACHOUR B. (2013a). The foggaras of In Salah (Algeria): the forgotten heritage. Larhyss Journal, No 15, pp. 85-95.

REMINI B., ACHOUR B. (2013b). The qanat of the greatest western Erg, Journal American Water Works Association, Vol. 105, No 5, pp. 104-105.

REMINI B., ACHOUR B. (2013c). The foggaras of Ahaggar: Disappearance of a hydraulic heritage, Larhyss Journal, No. 14, pp. 149-159.

REMINI B., ACHOUR B., KECHAD R. (2014a). The collecting of groundwater by the qanats: a millennium technique decaying, Larhyss Journal, No 20, pp. 259-277.

REMINI B., ACHOUR B., KECHAD R. (2014b). The sharing of water in the oases of Timimoun heritage cultural declining, Larhyss Journal, No 18, pp. 7-17.

REMINI B., ACHOUR B., KECHAD R. (2014c). The Foggara: a traditional system of irrigation in arid regions, Geoscience Engineering Journal, Vol. LX, No 32, pp.32-39.

REMINI B., REZOUG C., ACHOUR B. (2014d). The foggara of Kenadsa (Algeria), Larhyss Journal, No 18, pp. 93-105.

REMINI B., ALBERGEL J., ACHOUR B. (2015). The Garden Foggara of Timimoun (Algeria): The Decline of Hydraulic Heritage, Asian Journal of Water, Environment and Pollution, Vol. 12, No 3, pp. 51–57.

REMINI B. (2016). The role of the gallery in the functioning of the Foggara, Journal of water and land development, No 29, pp.49–57.

REMINI B., ACHOUR B. (2016). The water supply of Oasis by Albian foggara: an irrigation system in degradation, Larhyss Journal, No 26, pp. 167-181.

REMINI B., ACHOUR B. (2017). The Foggara of Moghrar (Algeria): An irrigation system millennium, Journal of Water Sciences & Environment Technologies, Vol. 2, No 1, pp. 111-116.

REMINI B. (2017). The Foggara of Tademait: without energy from the water from the subsoil to the surface of the ground, Larhyss Journal, No 32, pp. 301-325.

REMINI B., GHACHI M. (2019). Sharing the waters of the Irsan foggara of In Ghar oasis (In Salah-Algeria), Larhyss Journal, No 37, pp. 93-114

REMINI B. (2019). The Foggaras of the Sahara: sharing the water, the work of oasis genius, Larhyss Journal, No 39, pp. 25-57.

REMINI B. (2022). In the footsteps of the foggaras, Larhyss Journal, No 52, pp. 117-162.

REMINI B. (2023). When the foggara ensures the water security of the Oases, Larhyss Journal, No 3, pp. 219-257.

RIZK Z.S., AL SHARHAN S.A. (2003). Water resources in the United Arab Emirates. Water Resources perspectives: evaluations, Mangement and policy, Vol. 50, pp. 245-264.

SARGA, F. (2023). Archaeology of a Rural Qanat: Water Management and Social Relations in 17th Century Isfahan, Iran. Sustainability, Vol. 15, No 12, pp. 2-10. https://doi.org/10.3390/su15129463

SALIH A. (2006). Qanats a unique Groundwater management too in arid regions: the case of Bam region in Iran International symposium on Groundwater sustainability (ISGWAS), Proceeding, pp. 79-87.

SIMARSKI L.T. (1992). Qanat's unfailing springs. Revue Aramco word, Vol. 43, No 6, pp. 26-31

SIMARSKI L.T. (1992). Oman's unforiling springs. Revue Saudi Arameo world, Vol. 43, No 6, pp. 26-31.

STIROS SC. (2006). Accurate measurements with primitive instruments: the "paradox" in the qanat design, Journal of archaeological science, No 33, pp. 1058-1064.

VIQUEIRA J.P., PIMENTEL EQUIHUA J.L., RODRIGUEZ M.S. (2001). Tecnicas hydraulics in Mexico paralelismas con el Viejo Mundo : II Galerias Filtrantes (Qanat), XIII Economic History congress, Huesca, Espana, October 24, 25 and 26.

WATTMANN M., GONON T., THIERS C. (2000). The qanats of Ayn Manan in Kharga Oasis, Egypt, Journal of Archaemenid and researches, No 1, 8 p.

WALTHER C. (2009). Qanat of Irak, Reviving traditional knowledge for sustainable management of naturalresources, Unesco–unep, Introduction training world heritage, Nomination process of the Iraqi, Marshlands, June 29.

WESSELS J., HOOGGEVEEN R.J.A. (2002). Renovatuion of Qanats in Syria. Proceeding of a joust, UNV-UNESCO-ICARDA, International workshop, Alexandria, Egypt, September 21-25.

WULF H.E. (1968). The Qanat of Iran, Scientific American, pp. 94-105.

ZEKRI S., AL-MARSHUDI A. (2008). A millenarian water rights system and water markets in Oman, Water International, No 33, pp. 350-360.

ZAHER BIN KHALED A., HAMAD BIN KHAMIS AH., SAIF BIN SULAIMAN A.L., TARIQ H. (2008). Maintenance works of water structures, aflaj challenges in the Sultanat of Oman. Conference: WSTA The 8th Gulf Water Conference, Water in the GCC, Towards an Optimal Planning and Economic Perspectives, March 3-6, Manama, Kingdom of Bahrain.