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THE ALGERIAN FOGGARA
PART 2: THE WEALTH OF KNOW-HOW

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ABSTRACT

This article 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 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. This is how in Algeria, there are two types of foggaras: volumetric and hourly. Part 2 of this article highlighted the diversity of the foggara. Eight (8) models of foggaras have been highlighted in the Algerian Sahara. These are the Tademaït foggara, the Erg foggara, the garden foggara, the wadi foggara, the Ouakda foggara, the Kenadsa foggara, the Ain foggara and the Mzab foggara. An acquisition of significant know-how has given rise to a diversity of foggaras, thus justifying the originality of the Algerian foggara. A proof which demonstrates the greatness of the Know-how and the oasis genius. So, should we let a heritage of this magnitude die out in the short term?

Keywords: Algerian Foggara, Erg foggara, Tademait foggara, Garden foggara, Ouakda foggara. River foggara.

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

As we mentioned at the beginning of the paper, there are two types of foggaras: Hourly and volumetric. This originality is specific to Algeria. During 32 years of research in the oases of the Algerian Sahara, we have highlighted 8 models of foggaras. A wealth of invaluable know-how that has been acquired over several centuries. Such know-how allowed the oasis to develop the foggara according to the hydrogeological conditions and the topography of each environment. The multiplication of water collection models is a direct consequence of the success of a water acquisition and irrigation system. This is

how foggara was exported throughout the Algerian Sahara. It is even exported across borders. In the oases of Touat, Gourara and Tidikelt, volumetric foggara predominates. The last census at the level of these oases gave that approximately 1890 foggaras (for the 3 models) were inventoried according to the foggara observatory in 2021 according to the foggara observatory. Only the foggara of Hennou in the oasis of Tamentit is the exception in the oases of Touat since it is the only foggara which has adopted the hourly water distribution network (Remini, 2011). This particularity means that the Hennou foggara is the first foggara that was dug in the Touat oasis. The other foggaras were dug after the Hennou foggara since they were equipped with a volumetric distribution network.

Albian foggara (or Tademaït foggara)

Three water catchment models have been highlighted in the regions of Touat, Gourara and Tidikelt, which we prefer to call the oasis crescent. The most widespread and most published in the technical bibliography is the foggara model which captures the waters of the Continental Intercalaire on the outskirts of the Tademaït plateau which is considered the water tower of the foggaras (Ghachi et al, 2021b, Remini, 2011; Remini, 2022) (Fig. 1 and 2). This particular foggara which draws ancient waters from the deep aquifer, we called it the Albian foggara or the foggara of Tademaït or the foggara of the oasis crescent (Remini, 2017; Abidi and Remini, 2011; Remini, 2011; Remini, 2016 Remini and Ghachi, 2021; Remini et al, 2013b).

However, no one can confirm that the Ksourian population was not aware of the magnitude of the Continental Intercalaire aquifer more than 20 centuries ago. The Tademaït plateau; an immense flat and stony region surrounded by the Grand Erg Oriental to the east, the Grand Erg Occidental to the north, the Erg Chech to the west and the Hoggar massif to the south. Located at an average altitude equal to 600 m, the Tademaït plateau with an area equal to 15,000 km^2 with dimensions equal to 500 km x 30 km which takes the shape of a crescent extending from In Salah from the southeast to in Timimoun in the northwest. With a diameter of approximately 300 km connecting Timimoun to In Salah as the crow flies, approximately 3000 km of galleries of 1815 foggaras are distributed over this surface (Remini and Achour, 2016; Remini et al, 2010). These foggaras have been drawing their water from this invisible sea for more than 20 centuries. The subsoil of the Tademaït plateau contains one of the largest aquifers on the planet called the Continental Intercalaire with a capacity estimated between 30,000 and 100,000 billion m^3 (Remini, 2021a; Remini, 2021b).

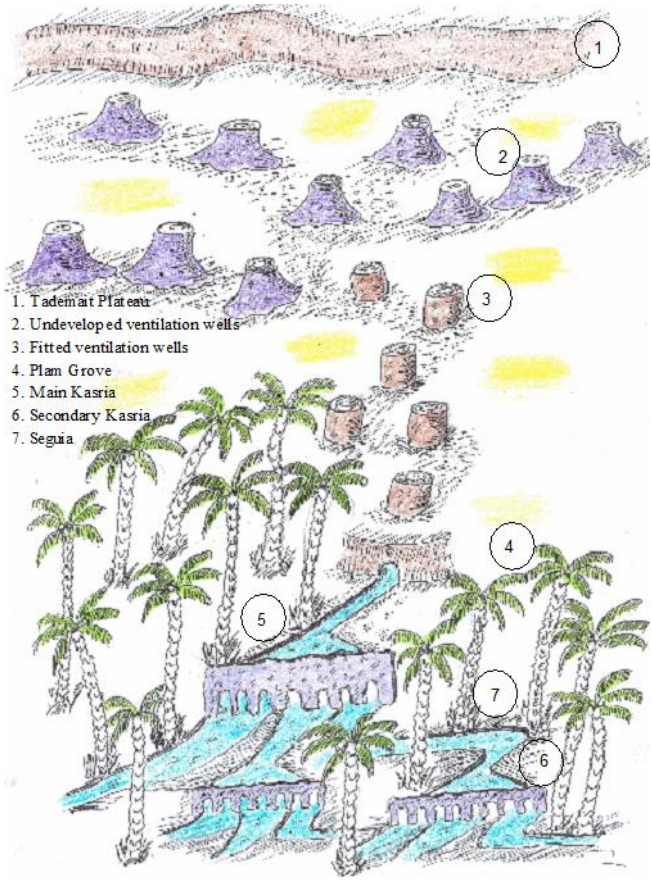


Figure 1: Synoptic diagram of the Albien foggara (Remini diagram, 2024)

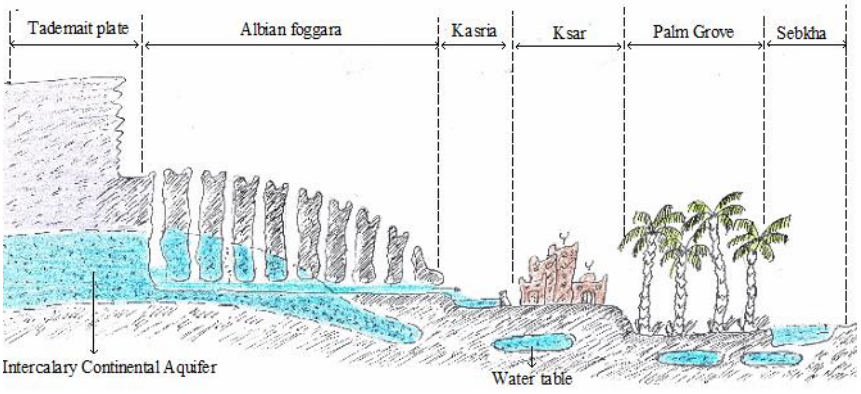


Figure 2: Diagram of a longitudinal section of an Albian foggara (Remini diagram, 2024)

The Foggara of the Erg

On the opposite side of the Tademaït plateau, it is the Grand Erg Occidental which feeds the foggaras through the water table which formed under the sand following the discharge of flood waters drained by the wadis. It is a body of water of exceptional quality since the sand itself plays the role of a natural filtration membrane. This second model of foggaras we called the Erg foggara which is located mainly in the oases of Gourara and more particularly in the oases of Ouled Said and Aghlad (Remini, 2011; Remini and Achour, 2013b) (Fig. 3 and 4).

The Erg foggara is characterized by a part of these wells which are lost in the Erg and no one can define the exact number of ventilation wells. The quality of the water is good since it has been treated naturally. In addition, these waters are warm in winter and cool in summer. The Erg foggara is characterized by 3 parts: the gallery, the supply seguia (Fhel) and the distribution network. With a slight slope and a length that can exceed 10 km, the Erg foggara gallery dug at the bottom of the Erg is equipped with a multitude of ventilation shafts. Unlike the foggara of Albien, the foggara of Erg is small with a seguia covered with flat stones to protect against silting. Called Fhel, this open-air canal with a length exceeding 150 m between the water outlet of the gallery and the main kasria. During the work missions that we have carried out in the oases of Gourara since the beginning of the nineties. In the oases of Ouled Said and Timimoun, farmers confirmed to us that the foggaras of Ouled Saïd exploit the water table of the Grand Erg Occidental. This model of foggaras is located as we mentioned in the oases of Ouled Said (Timimoun) and the oases of Tabelbala. There are 64 of them, the foggaras of the oases of Ouled Said, the oases of Kali, the oases of Hadj Guelmane, the oases of Aghled, the oases of Soumatra, the oases of Lazora and the oases of Badiede are classified as foggaras of Erg. Table 1 gives an overview of the number and mileage of the gallery.

We classified the foggaras of Tabelbala as foggaras of the Erg, since they draw water from the Erg Erraoui. Equipped with more than 1000 ventilation shafts, these foggaras, numbering 101, have a gallery with a total length exceeding 100 km. These foggaras which functioned for more than 9 centuries made it possible to irrigate the palm grove and supply the ksar of the Tabelbala oasis without interruption. Unfortunately, today, no foggara is in service, all this hydraulic heritage has disappeared, only vestiges and traces of galleries as well as traces of the collapse of the wells remain.

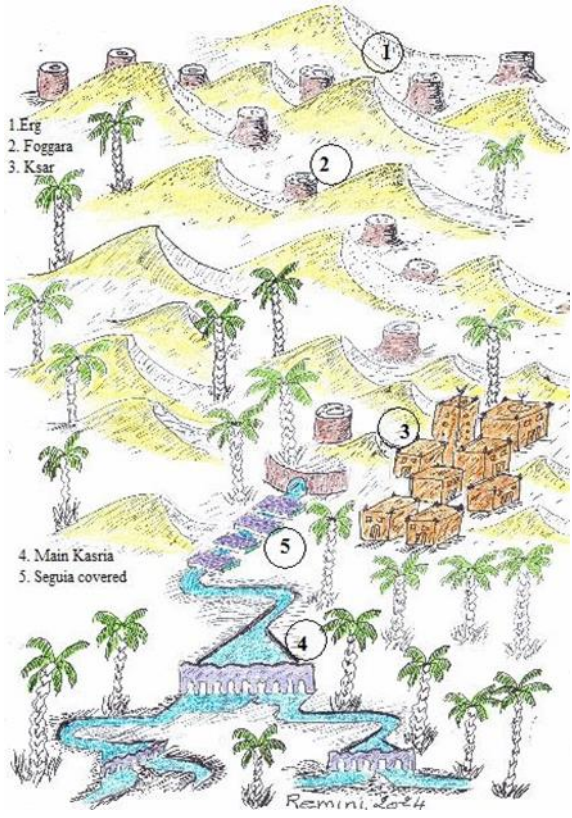


Figure 3: Synoptic diagram of the Erg foggara (Diagram Remini, 2024)

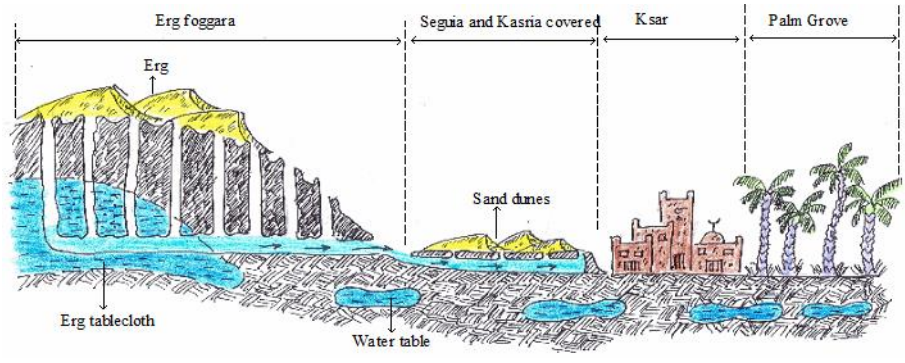


Figure 4: Diagram of a longitudinal section of an Erg foggara (Diagram Remini, 2024)

Table 1: The foggaras of Erg in the oases of Gourara (Remini, 2022)

Foggara	Number
Ouled Said	25
Kali	18
Aghled	04
Hadj Guelmane	10
Larosa	-
Badeide	2
Samouta	05
Total	**64**

The Garden Foggara

In the oases of Touat, Gourara and Tidikelt, the third model of the foggara has never been mentioned in the technical bibliography. It's a foggara that we are lucky to discover. We nicknamed it the garden foggara. By the way, it was in the middle of a garden in the central Timimoun oasis that we discovered this pretty foggara by chance. It is a small foggara with a gallery not exceeding 200 m in length, equipped with around ten ventilation shafts (Remini et al, 2015) (Fig. 5 and 6). Equipped with a kasria with a single opening and a small madjen, the garden foggara as its name indicates is located in a garden in the middle of the distribution network of the volumetric foggara which is supposed to irrigate one or two gardens of the palm grove. Its role is to draw groundwater from infiltration caused by irrigation water from the classic foggara.

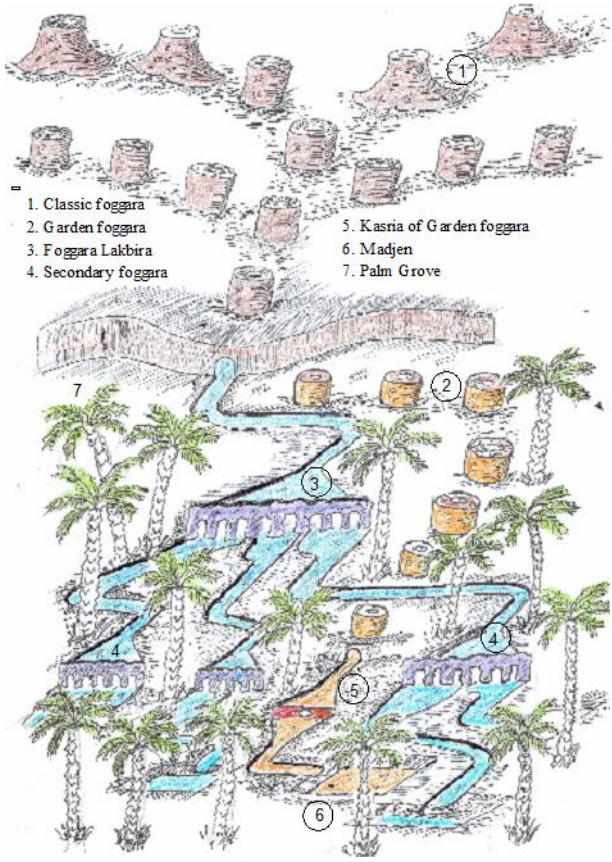


Figure 5: Synoptic diagram of the garden foggara (Diagram Remini, 2024)

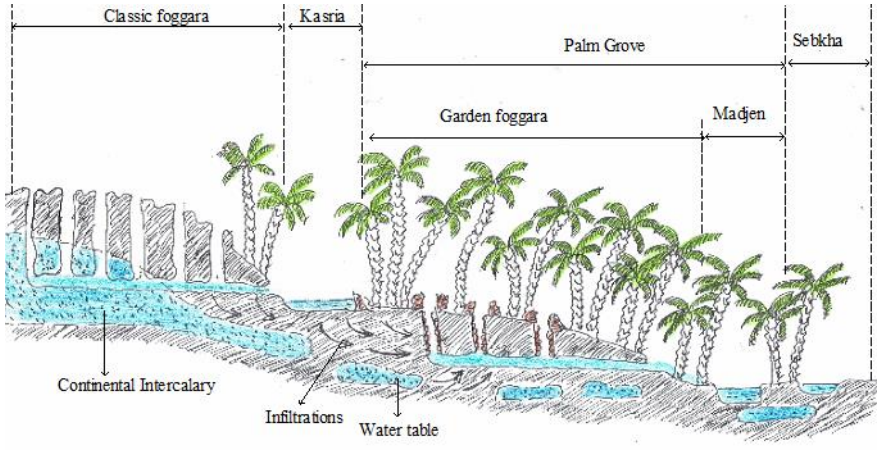


Figure 6: Diagram of a longitudinal section of a garden foggara (Diagram Remini, 2024)

The garden foggara is a family foggara independent of the large foggara. Equipped with a single opening which plays the role of a valve, the kasria of the garden foggara in the shape of a diamond is located just at the outlet of the waters of the gallery. Using a plug connected to a stick will allow you to operate the valve. Closing the opening with the cap stores the water infiltrated in the gallery of the small foggara. Once filled, the cap removed, the water flows directly into the seguia to fill the madjen. The operation takes place continuously over time and each time we give the gallery time to fill and then empty it. The presence of micro foggara in the gardens explains the rational management of water in the oases. We have identified 8 garden foggara in the oases of Timimoun. Even in the oasis of Zaouiet Kounta, we found a garden foggara. It's a shame that today all these micro foggaras are in a very advanced degraded state.

We thus defined the garden foggara as being a small foggara whose length does not exceed 1.5 km (Remini et al, 2015). It is a foggara which belongs to a single family. Its flow rate is low compared to the classic foggara. It is dug downstream of one or more classic foggaras. Unlike other foggaras whose flow is continuous, the garden flow is discontinuous. It captures its water from drainage and irrigation leaching water from the palm grove gardens coming from the large foggaras. Any water lost by the classic foggara; by infiltration of seguias water, madjens is recovered by this small foggara. The operation of such a foggara is very simple and does not require any sharing between the co-owners like the classic foggara: it belongs to a single owner. At the exit of the gallery, we find a diamond-shaped kasria and not triangular like the classic foggara (Remini et al, 2015). In the kasria, we place a rectangular rock plate with a hole in the middle by a circular opening which is closed using a stick fitted at its end with a cloth soaked in clay (plays the role of a valve) (Fig. 7).

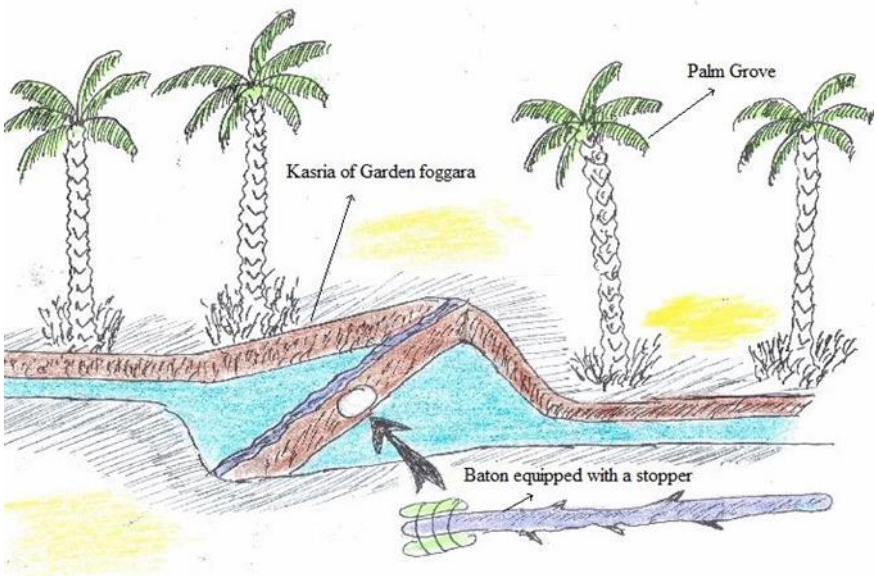


Figure 7: Kasria of the garden foggara (Diagram Remini, 2024)

For a good irrigation operation, we close the hole in the small foggara. Once the gallery is filled with infiltration water from the waters of the seguias, the waters of the madjens and the gallery of the classic foggara, we open the orifice to fill the madjen of the garden foggara within an acceptable time. So, the operation is done discontinuously. By blocking the opening with a diameter of approximately 8 cm with a 3 meter stick which carries at its end a cloth in the shape of a sphere of the same diameter as that of the opening of the kasria (Remini et al, 2015; Remini, 2011). The gallery is filled with infiltrated water. Opening the hole in the kasria, the water collected by the gallery will eventually fill the majen of the garden foggara. It is a particularly spectacular example of oasis art. This type of foggara has never been described or even reported until now in the oases of the Algerian Sahara. Not visible on satellite images or even on aerial photography and topographical maps, because they are small foggaras which do not exceed 20 ventilation shafts and are located inside the palm grove. Unlike classic foggaras, we do not know the exact origin and development of this technique. Is this a local development due to the lack of irrigation water in the gardens located further downstream from the main foggara ? Is it a mastery of the foggara technique which makes it possible to better manage water without waste and to use water well for irrigation? For this first study, in 2008 we identified 7 garden foggaras in the oases of Timimoun, the characteristics of which appear in table 2. According to the testimony of the owners of the foggaras, around a hundred of this type of foggara have disappeared. They have been reported in the oases of In Salah and Adrar and more particularly in the palm groves of Zaouit Kounta.

Table 2: Characteristics of garden foggaras in the Timimoun oasis (Remini, 2022; Remini et al, 2015; Remini, 2011))

Foggara	Length (m)	Number of well	Flow (l/s)
Agalou	100	20	**0.012**
Zahzaa	120	15	**0.02**
Akraf	60	10	**0.01**
Ksar Akdim1	50	2	**0.01**
Ksar Akdim2	90	20	**0.01**
Oukala	Foggara	abandoned	
Bouchouk	Foggara	abandoned	

We note from these values that the Jardin foggara is characterized by low flow and short gallery. For example, it takes 12 hours (during the night) to fill the gallery of the foggara de Zahzaa with a volume of 850 liters (Remini et al, 2015; Remini, 2011). It should be noted that this type of foggara existed in the middle of the palm groves of Adrar, Timimoun and In Salah. According to the testimonies we had with the farmers, it turns out that the number well exceeds a hundred foggaras. For them this type of foggara is called private foggara which belongs to a single person. Other information that we have collected states that this type of foggara is located at the limit of the palm grove with the sebkha to collect as much infiltration water as possible. Generally, when a farmer does

not have a share of water from the classic foggara, he can settle between the border of the palm grove and the sebkha. After laying out his new garden, he digs a small foggara in the palm grove to capture the infiltration water.

The Foggara of Kenadsa

600 km from Adrar to the west, is Saoura; capital of foggara hourly. The Saoura is a region very rich in water sources. With the discovery of the foggara in the oases of Touat and Gourara, the farmers transferred the know-how to the Saoura and adapted these structures to the hydrogeology of their environment. This is how the Kenadsa oasis has its own foggaras which are unique. The topography of the land is very favorable to the creation of such foggaras. Taking advantage of the existence of the El Barga massif in the Kenadsa region and which closely resembles the Tademaït plateau. Delimiting the Oum Sba plateau to the south, the El Barga massif with an average height of 50 m and a length of 55 km from River Guir in the west towards Wadi Bechar in the East. The Jebel El Barga represents the real water tower of the foggaras of the Kenadsa oasis, since in its basement hides a gigantic sheet of water. More than 50 foggaras with a length of 150 m were dug from the outskirts of the El Barga mountain to the palm gardens (Remini et al, 2014d) (Fig. 8 and 9).

Figure 8: Synoptic diagram of the Kenadsa foggara (Diagram Remini, 2024)

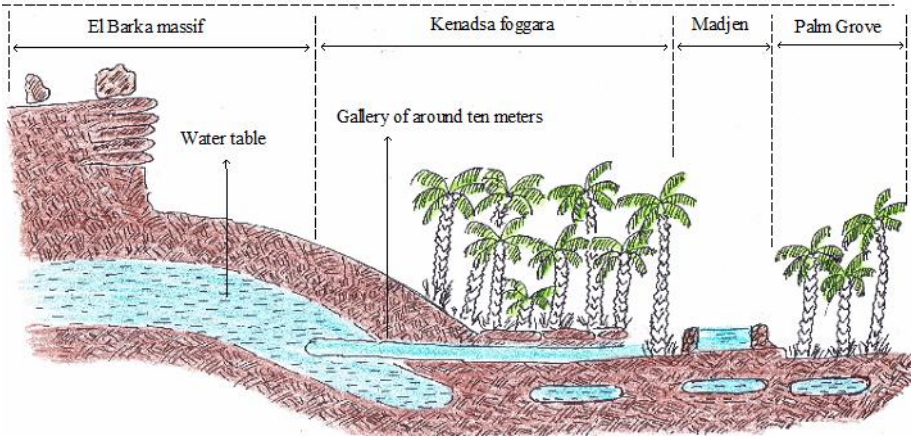


Figure 9: Diagram of a longitudinal section of a Kenadsa foggara (Diagram Remini, 2024)

In 2013, there were only 12 perennial foggaras. Without ventilation shafts, the Kenadsa foggara is an underground gallery with an average length of 150 m and an average slope of 1% which draws water from the resurgences which appear at the foot of the El Barga cliff. (Remini et al, 2014d). The foggara of Kenadsa closely resembles the mountain karez of Afghanistan which has a gallery 15 meters long (Remini et al, 2014d). Called "Ain" (water source), the foggara of Kenadsa is a family property. Taking advantage of the fertility of the soil and the existence of materials (rocks and clays), these families transported spring water to the gardens by digging underground drains. The foggaras bear the name of each family, we can cite the best known: Ain Cheikh, Ain Sidi Mabrek, Ain Eddir, Ain Mahfoudi, Ain Bouazza, Ain Ouled Bouziane, Ain Ouled El Hadj, Ain El Arbi, Ain Ouled Sid El Houcine, Ain Sidi Mohamed. Today, practically all the foggaras are in a very degraded state, with only a trickle of water flowing into two foggaras (Remini et al, 2014d).

The River Foggara

Another particular foggara which developed in several regions of the Sahara. This is the foggara of the wadi. It is a foggara which consists of drawing water from the Inferoflux or alluvial aquifer (Remini, 2020d; Remini, 2020e; Remini at al, 2010) (Fig. 10 and 11). We encountered this model of foggara in the oases of Tindouf, Tamanrasset, Sfissifa and Brezina. Only in these oases, the foggaras have been adopted to the hydrogeology of the environment. It turns out that in these 4 oases, foggaras were dug but in the beds of the wadis.

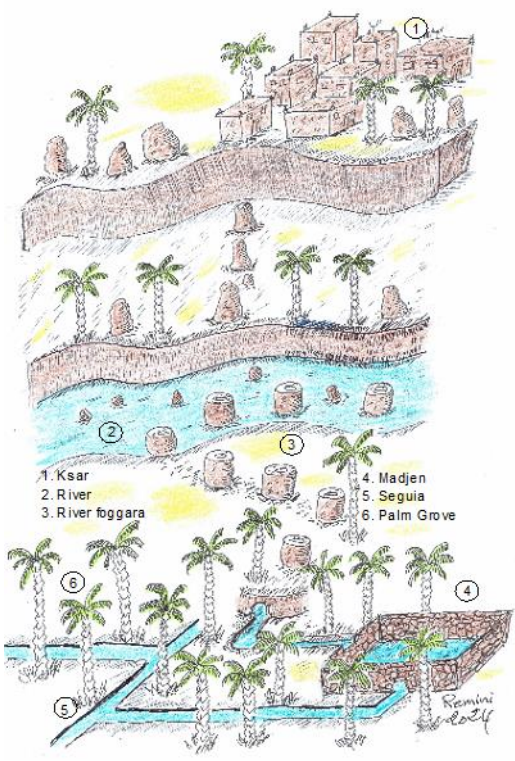


Figure 10: Synoptic diagram of a wadi foggara which exploits the Inferoflux aquifer (Diagram Remini, 2024)

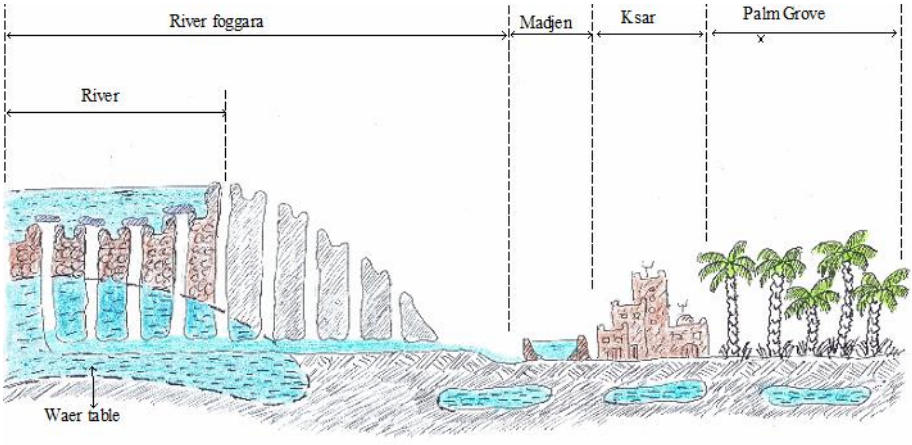


Figure 11: Diagram of a longitudinal section of a foggara of the wadi (Diagram Remini, 2024)

The palm groves of these oases occupy the major river beds. As it is a dry environment, the frequency of floods has increased due to repeated droughts, which has pushed the Ksourians to think about proposing an alternative source of water to compensate for water shortages. Thanks to their genius and know-how in hydrogeology, the oasis knew that below the bed of the wadis, an unestimable volume of water flows in parallel with the surface water. He knew that after a flood passes, surface water evaporates and infiltrates underground and flows through the voids formed by gravel and sand. This quantity of water can remain protected from evaporation for more than a year; we are talking about the Inferoflux layer (Remini, 2020d; Remini, 2020e). Tamanrasset remains the cradle of the foggaras of the wadis, since more than 184 foggaras were dug in the beds of the wadis in the Ahaggar region (Remini and Achour, 2013c). According to Aychoubi M'Barek, the last foggaras which operated during the 1970s in the Ahaggar region numbered 10 (table.3).

Table 3: The last 10 foggaras which disappeared during the end of the seventies (Remini, 2023; Remini, 2022))

Oasis	Number of foggaras	Observations
Tamanrasset	2	7 km long
Tit	1	-
Ableѕs	2	-
Tifirt Tahtania	1	Owner Ben Malef,
Tifirt Foukania	1	-
Iglane	1	-
Silts	2	-

According to Aychoubi M'Barek, the kasria (watershed element) existed in the gardens of the region's oases. The sharing of foggara water in the Ahaggar region is carried out by unit of volume (Remini, 2022; Remini, 2023). Such know-how was imported from the oases of the Tidikelt region. Unfortunately, today, only traces of galleries and wells remain, the distribution network has completely disappeared. On the western side of the Sahara and thanks to the genius of the population of Tindouf, the foggara of Ras El Ma was dug in the River of Tindouf and it draws its water from the alluvial table of the wadi Tindouf. It should be noted that neither the date nor the number of foggaras dug in the Tindouf region have been mentioned by historians. However, Papy (1959) mentioned in a study on the decline of foggaras in the Sahara that there were several foggaras along the Tindouf River, except that the author never specified the exact number of foggaras. Even the local population claims that there were several foggaras exploiting the alluvial water table, but without specifying the number. It should also be noted that during our missions carried out during the period 2000-2024 on the site that no trace of foggaras was detected apart from that of the foggara of Ras El Ma. While visiting the ksar of the Sfissifa oasis, we found by chance two foggaras of the River with an appreciable flow (Remini, 2022; Remini, 2023). However, the ksar population has no information on the number of foggaras dug in the region. These two foggaras in 2015 were still functioning. During our

missions in the Brezina oasis in the wilaya of El Bayadh we learned that there existed a foggara of the River according to the testimonies collected from the Ksourian population. According to water, the foggara had 7 wells in the middle of the River and a length of approximately 1 km. Today, there is no trace of these foggaras which supplied the Brezina oasis for several centuries. We have summarized in table 4 the characteristics of some foggaras of the wadi (Hamdaoui and Remini, 2021)

Table 4: Characteristics of the foggaras of the wadi (Remini, 2022)

Foggara	Tindouf	Ahaggar	Sfissifa	Brezina
Exploited tablecloth	Inféroflux	Inféroflux	Inféroflux	Inferoflux
Number of foggaras	1	200	2	1
Maximum length (km)	2 km	5 km	300 m	1000 m
Flow rate of the foggara (l/s)	variable	Variable	variable	variable
Distribution mode	Hourly	Volumetric	Hourly	Hpurly
Madjen type	Collective	Collective	Collective	Collective

The Foggara of Ouakda

In the Ouakda oasis, the local population dug 22 foggaras for the irrigation of the palm grove with an initial area of 30 hectares. Directed from East to West, these foggaras are distributed along the palm grove with a length of 2.2 km to ensure the irrigation of all of the gardens (Remini and Rezoug, 2018). Each foggara belongs to a group of farmers. The water captured from the groundwater table is conveyed through a gallery to the ground surface. At the outlet, the water flows into a seguia (open channel) to the madjen (storage basin). Water sharing is done according to the hourly method, that is to say, in turns. Irrigation is done garden by garden. The share of water depends on the contribution of each co-owner in the maintenance of the foggara. A network of earthen seguias carries water from the madjen to the farmers' gardens. The functioning of the Ouakda foggara is different from other foggaras. By the way, the Ouakda foggara is a marriage between the khottara and the foggara (Fig. 12).

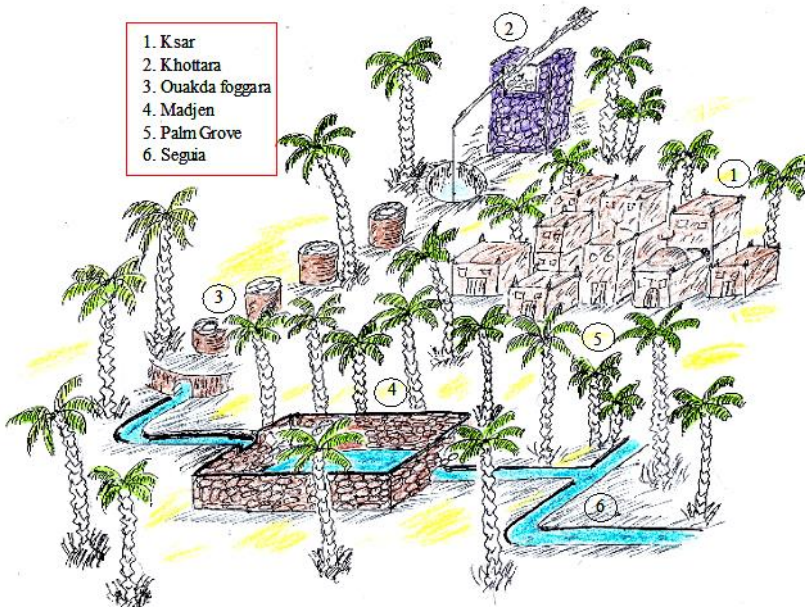


Figure 12: Synoptic diagram of the foggara of Ouakda (Diagram Remini, 2024)

The Ouakda foggara exploits the groundwater (Remini and Rezoug, 2018). With repeated droughts causing the water table to draw down, the farmers added a khottara at the beginning of the gallery. The well is equipped with a pendulum composed of a rod (tree trunk) 4 m long equipped with a counterweight (Remini and Rezoug, 2018). The whole is placed on two stone supports 3 m high via a 1 m long wooden axis to form a real pendulum well (Fig. 12). The coupling between the foggara and the khottara forms the foggara typical of the Ouakda oasis which constitutes the originality of the Ouakda oasis (Fig. 12). In fact, foggara know-how was imported from neighboring oases and more particularly from the oases of Beni Abbes and Taghit which used the foggara system as a technique for irrigating their gardens. On the other hand, the know-how of the khottaras was imported from the oases of Igli, Beni Abbes, El Ouata, Guerzim, Beni Ikhlef and more particularly the oasis of Kerzaz, since it is the one which holds more than 600 khottaras (Remini and Rezoug, 2017). This type of structure: Foggara –khottara works together to cope with the serial drawdown of the water table. The foggara of Ouakda operates normally in wet periods, the drainage of water from the water table is carried out through the draining part and the transport part of the gallery ensures that the flow of water reaches the gardens located below (Fig. 13).

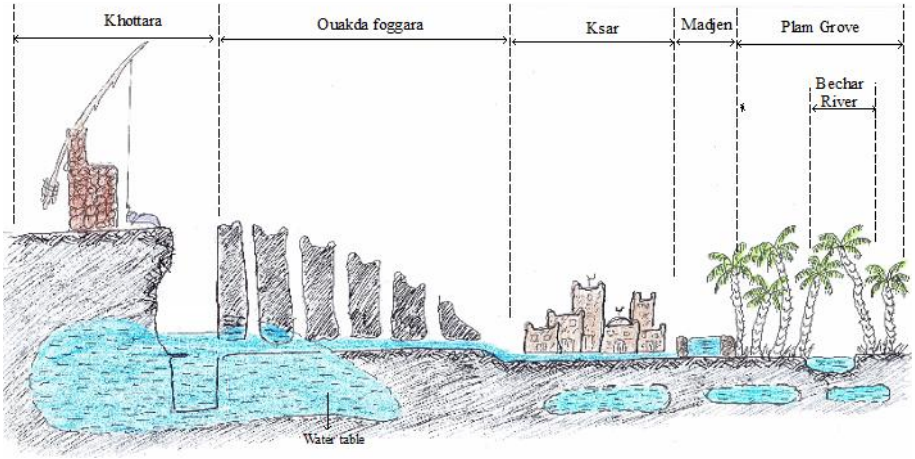


Figure 13: Simplified diagram of the Ouakda foggara in wet periods (Diagram, Remini, 2024)

On the other hand, during periods of drought, the absence of recharge of the water table by rainwater causes the water table to draw down and consequently, the gallery of the foggara is empty with a flow equal to zero. During irrigation hours, the operation of the khottara becomes an obligation. Thanks to a farmer who goes down to the bottom of the well to operate the pendulum. This work is carried out in turn depending on the irrigation period of each farmer. With this process, the foggara of Ouakda ensures the supply of drinking water to the ksar and the irrigation of the palm grove in quantity and quality and continuously over time (Fig. 14).

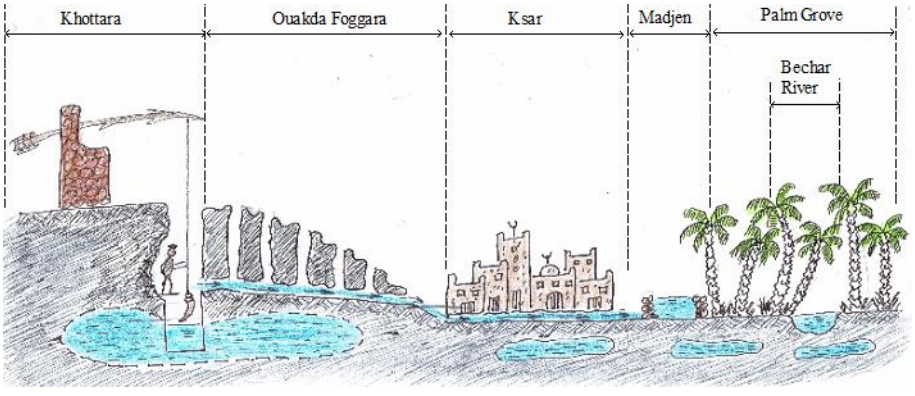


Figure 14: Simplified diagram of the foggara of Ouakda in periods of drought, the khottara comes into operation (Diagram, Remini, 2024)

The Ain Foggara

We call any foggara that exploits spring water as an Ain foggara (Remini et al, 2010). In Arabic, Ain means source of water. We found this type of foggara in the oases of Moghrar, El Bayadh, Laghouat, and Saoura. The Ain foggara is characterized by small galleries. The Moghrar oasis has 2 foggaras of Ain, one Tahtania (located at the bottom of the palm grove) and the other Foukania (located at the top of the palm grove). The foggara of Moghrar exploits the waters of a source which represents the catchment well. It is equipped with a 300 m long, slightly inclined gallery and a single ventilation shaft (Remini and Achour, 2017). It flows permanently into the collective Madjen located in the palm grove (Fig. 15 and 16). Thanks to hourly distribution, water is distributed in turn between the owners. Everyone has their share of water according to their contribution. The water is transported by a network of seguias which distribute water to the gardens.

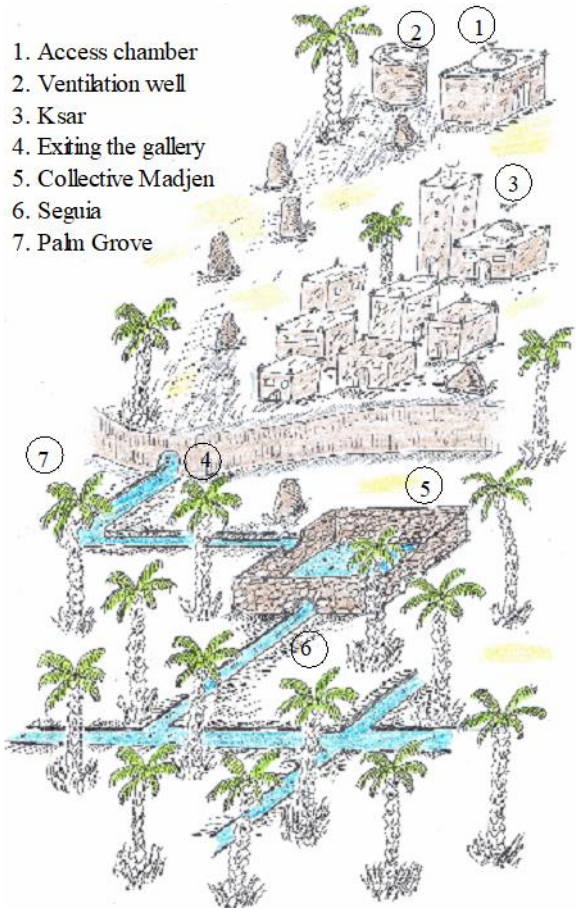


Figure 15: Probable diagram of an Ain foggara of the Moghrar oasis (Remini et al, 2017) (Diagram, Remini, 2024)

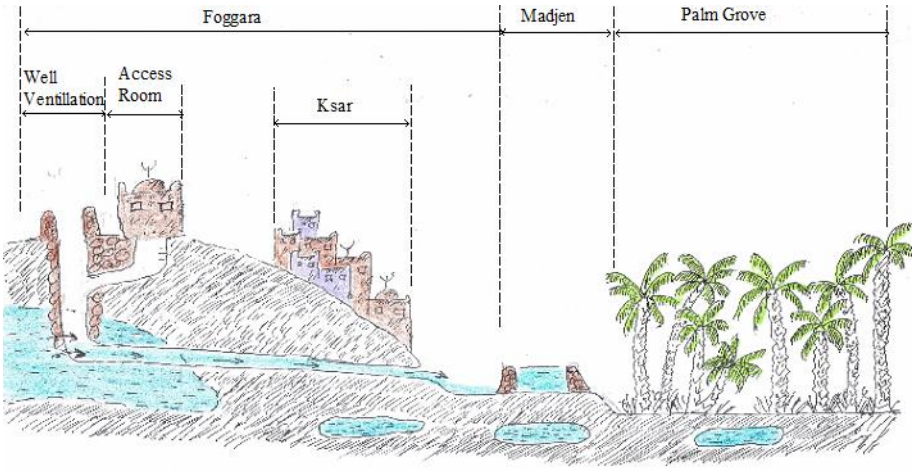


Figure 16: Diagram of a longitudinal section of a foggara from the Ain of the Moghrar oasis (Diagram Remini, 2024)

A single foggara of Ain is located in the capital of foggaras in the middle of the oases of Adrar. It is the only foggara which exploits a water source unlike the hundreds of foggaras which draw their water from the Continental Intercalaire. The Adrar oases are known for their "Albian" type foggaras with the exception of the Hennou foggara, which is a spring foggara which is not fed by the continental intercalary aquifer like the other foggaras of the oasis of Adrar, but by a natural and perennial water source. The Hennou foggara remains a particularity of the region (Remini, 2011). In the oasis of Beni Ounif in the wilaya of Bechar, two foggaras of Ain ensure the irrigation of the palm grove. These two foggaras exploit spring water. Today, this source has dried up and consequently the two foggaras are abandoned (Remini et al, 2017). In the Lahmar oasis in the wilaya of Bechar, the water sources are drained by 4 foggaras which are located in the northern part of the ksar. They are Ain Djemal, Omran and Tawrirt Lahmar. The largest is the Tawrirt foggaras which includes 18 wells with a maximum depth of 25 meters. The smallest, Omran, includes 4 wells of 6 meters. At the exit of the foggaras the water is stored in the collective madjens. At the outlet of the madjen, each owner receives his share of water through seguias. In the oases of Beni Abbes, 65 foggaras were dug according to the GTZ inventory carried out in 2008 (Remini et al, 2017). These foggaras drain the waters of the large spring of Sidi Othmane which come from the Grand Erg Occidental aquifer. With a total length of 12 km, the foggaras of Beni Abbès, 65 in number, irrigate a palm grove with an area of 400,000 m^2 with a total water flow of 4 l/s. Today these foggaras are dried up and abandoned (Remini et al, 2017). In the Taghit oasis, for more than 7 centuries, farmers have exploited the waters of the Grand Erg Occidental aquifer. For this purpose, 45 foggaras of the Ain were dug to drain the water from the gushing springs coming from the Erg to reach the palm grove (Remini et al, 2017). In 2014, around 25 foggaras with a total length of 11 km and a flow rate of 16 l/s were in operation. Today there are only 5 foggaras in operation with a low water flow. The oasis of Mechria Essghira which is located in the wilaya of El Bayadh has 2 foggaras of El Aïn with a 100 m long gallery

equipped with 3 ventilation shafts and each of these two foggaras is intended for irrigation of the palm grove gardens. Visiting the oasis. In the Sttiten oasis which is located in the wilaya of El Bayadh, there were 11 foggaras of Ain which exploit 19 water sources which are fed by water from the groundwater table (Hamdaoui and Remini, 2020). These foggaras were intended to supply the ksar and irrigate a palm grove made up of 640 gardens (Cultural Heritage Service, 2013). Today there remains only one foggara of El Aïn with a gallery 100 m long. According to our investigations in the oases of Laghouat, there were at least 10 foggaras with a length of 4000 km, the foggara of Ain Madhi which is located in the wilaya of Laghouat 400 km south of Algiers is still in function and captures its water from a water source called Ain Sidi Aissa (Hamdaoui and Remini, 2020). Runoff water from the surrounding mountains recharges the water table and therefore feeds the source (Ain Sidi Aissa). In recent years, the flow of the foggara has decreased significantly due to the lack of precipitation. Other unidentified foggaras were located but without traces in the wilayas of Menea, Boussaâda and Ouargla according to information from the ksour population. We have summarized in Table 5 the characteristics of the foggaras of Ain in the Algerian Sahara.

Table 5: Number of foggaras of Ain in the Algerian Sahara (Remini, 2022)

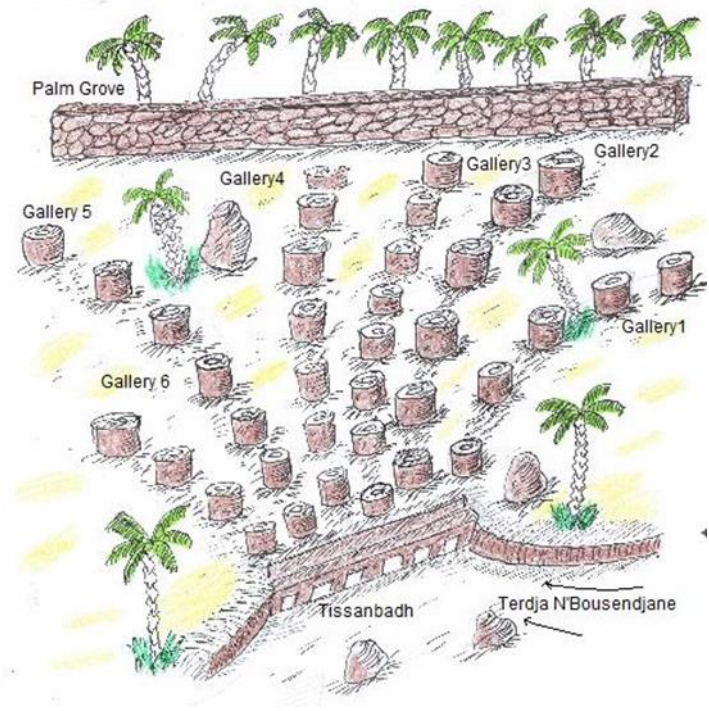
Oasis	Number of foggara	Total length
Moghrar	2	600 m
Adrar	1	-
Beni Ounif	2	700 m
Lahmar	4	1400 m
Beni Abbes	65	12000 m
Taghit	45	11000m (for 25 foggaras)
Mechria Esseghira	2	2x100 m
Stiten	11	100 0m
Ain Madhi	1	4000 m
Laghouat	9	-

The Tissanbadh of Mzab

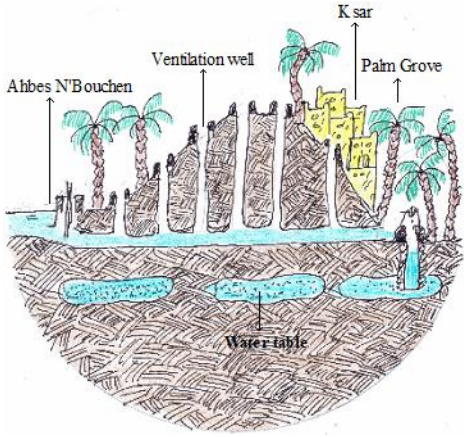
More than 30 missions were carried out in the Mzab Valley during the period 1992-2024. We spotted two Tissanbadh (galleries) in Wadi Mzab, the first is at the entrance to the eastern palm grove of Ghardaïa on the N'Bouchendjane seguia called Tissanbadh N'Bouchendjane. The second is located in the Mzab wadi, 2 km from the eastern palm grove on the N'Takdimt seguia. The eastern part of the Ghardaïa palm grove is irrigated by flood waters drained by the Bouchendjane seguia which is located in the upper part of the Mzab wadi. Water sharing begins once the flood water reaches the level of Tissanbadh (foggara of Mzab). Shaped like a 20-meter-wide dam fitted with 36 rectangular openings which are equipped with sliding gates (Remini, 2018; Remini, 2020a, Remini, 2020b; Remini, 2020c; Remini, 2022). The 36 openings are equipped with sliding flat rock slabs

(today they are made of steel) which, once the irrigation is finished or to avoid flooding in the palm grove, the openings will be immediately closed. The waters, once crossed by the 36 openings of Tissabadh, are distributed through the 6 underground galleries of different sections and flow towards the eastern palm grove of Ghardaïa (fig. 42 (a and b)). The Tissanbadh openings make it possible to regulate flood waters and reduce the energy of the flow before penetrating the galleries. Each drain is sized according to the flow rate to be conveyed for garden irrigation. The flow rate of each gallery depends on the number of palm trees to be irrigated and the contribution of each farmer. In reality, there are 5 underground galleries out of the 6 which have been operational for more than 7 centuries. The sixth gallery which was intended for irrigation of the Chaabet de Toundja palm grove has never functioned. The project to dig the drain at the bottom of the rock mass was not completed. However, more than 40% of the excavation of the gallery was carried out during 40 years of intensive work with rudimentary material resources.

Equipped with 38 ventilation shafts which can reach depths of 40 meters, the galleries of the foggaras of Ghardaïa present different section shapes. Rectangular, triangular and complex sections are observed. The galleries were designed in such a way as to avoid the bursting of the walls and the deposit of silt during high flow rates. 38 vertical wells are drilled vertically on the roof of the galleries which have the role of aerating the pipes to maintain free surface flow and thus prevent the canals from bursting during floods. They also allow access to the gallery for maintenance of the structures (Fig. 17(a and b)).



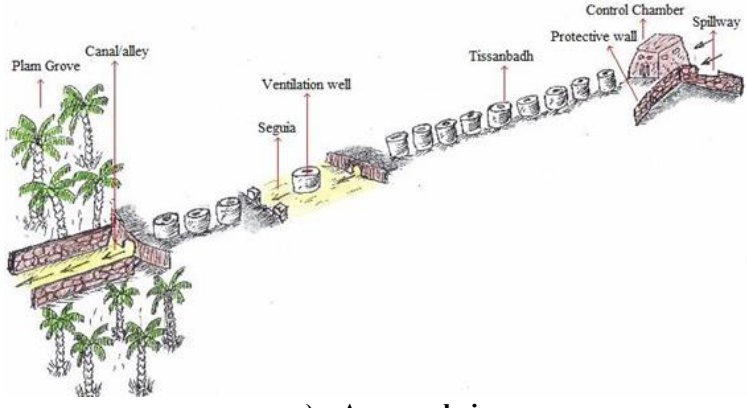
a) A general view



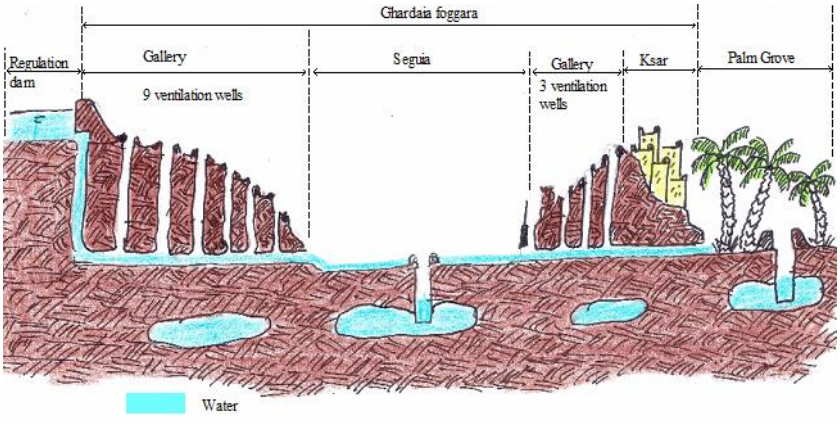
b) Longitudinal section

Figure 17: Synoptic diagram of the underground galleries (Tissanbadh) intended for the irrigation of the upper part (Bouchemdjane) of the palm grove - East of Ghardaïa (Diagram Remini, 2024)

Tissabadh (gallery) N'Takdimt (the foggara N'Takdimt) is intended for the irrigation of the eastern palm grove. It is made up of two parts; an underground gallery and an open channel (Fig. 18 (a and b)). The foggara N'Takdimt exploits the flood waters once stored in the reservoir formed by the rock dike 77 m wide and 1.5 m high created in the middle of the Mzab wadi. The water is conveyed through an underground gallery 170 m long ventilated by 8 vertical wells 3 m deep and 1 m in diameter. At the exit of the gallery, the water is drained by a seguia (open-air canal) 900 m long and 1.5 to 3 m wide, then it will be conveyed again by a gallery 50 m long equipped of a single ventilation shaft to reach the gardens (Remini et al, 2012; Remini, 2020c; Remini, 2022). Once in the palm grove, it will be distributed among the owners by a network of souaguis. An estimated flow rate of the foggara can reach 300 l/s for a significant flood.



a) A general view



b) Longitudinal section

Figure 18: Tissabadh (gallery) N'Takdimt fitted with two sliding valves (Diagram Remini, 2024)

DISCUSSION

Algerian Foggara, Iranian Qanat or FalajOmani; These are just names that designate the same hydraulic system belonging to more than 52 countries on the planet. This is an ancient hydraulic development dating back more than 30 centuries and which revolutionized groundwater drawing techniques. He even changed irrigation habits. What genius, we just had to tilt the usual well (vertical) at an angle of 90° so that it poured its water continuously; this is the principle of the foggara which is none other than a horizontal well. So this part is the same for all the foggaras in the 52 countries on the planet. This is an underground gallery which consists of capturing and transporting water from underground to the surface of the ground. However, of the foggara, this collective good once it has seen the light must be shared between the owners of the foggara. The foggara water distribution and sharing network is a timetable network that has been adopted for foggaras in 52 countries on the planet. However, a more ingenious volumetric sharing than hourly sharing which gave a triangular network is a local invention installed in the oasis crescent: Touat, Gourara and Tidikelt. We are talking about the first particularity of the Algerian foggara and which was treated in the first part of this article. Therefore, Algeria has two modes of distribution of foggara water: hourly and volumetric. The second particularity of the Algerian foggara lies in its diversity. Eight types of foggara were established in the second part of this article. A foggara has been adapted for each type of water source; This explains the immensity of the diversity of the know-how of Algerian foggara. Eight models were highlighted. These are the foggara of Tademaït, the foggara of Erg, the foggara of oued, the garden foggara, the foggara of Kenadsa, the foggara of Ouakda, the foggara of Ain and the foggara of Mzab.

CONCLUSION

In the first part of the article, we showed that the Algerian foggara is different from the other foggaras of the 52 countries of the planet. The originality of the Algerian foggara lies in the sharing of the waters of the foggara between the co-owners which is carried out by unit of volume thanks to the Kasria work. The distribution network takes the form of a triangular network which is different from the other networks of the other foggaras which is rather branched. The second particularity of the Algerian foggara lies in its diversity. This is why we have proposed 8 models of foggaras which adapt to all types of water sources, namely the Continental Intercalaire aquifer, the Erg aquifer, the Inféroflux aquifer, the water table and floods. The foggara of Tademaït, the foggara of Erg, the foggara of wadi, the foggara of garden, the foggara of Ouakda, foggara of Kenadsa, foggara of Ain and foggara of Mzab. What richness, thanks to the genius of the oasis, to each water source; they adapted his ownfoggara. All the models of foggaras existing in the world are gathered in the Algerian Sahara. So should we allow such world heritage to exhaust itself over time without it being registered with 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.

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