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IN THE FOOTSTEPS OF THE FOGGARAS

REMINI B.

Department of Water sciences and Environment, Faculty of Technology, Blida 1 University, Blida 9000, Algeria

reminib@yahoo.fr

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ABSTRACT

Throughout the period 1992-2022, we searched for foggaras in the depths of the Algerian Sahara. Herein, an original classification of foggaras as well as a map of geographical locations of foggaras has been established. We have inventoried approximately 2390 foggaras made in the four corners of the Algerian Sahara for more than 20 centuries. With new names, nine types of foggaras have been established according to the nature of the water resources exploited. These are the Erg foggara, garden foggara, Albian foggara, Kenadsa foggara, Ouakda foggara, wadi foggara, foggara of Mzab, foggara of Ziban and foggara of Ain. Two modes of sharing the waters of the foggaras have been highlighted. Ingeniously, the volumetric mode is more interesting since it allows the distribution of water in parallel, and therefore, the irrigation of gardens can be ensured at any time. Contrary to the time mode, the distribution of water is performed alternately, and therefore, irrigation is carried out in series. The article has highlighted the originality of the foggara of the Sahara, which lies in its diversity of catchment sources and the principle of water sharing between the co-owners. Unfortunately, today, this cultural heritage risks being lost in a few years, since of the 2390 foggaras read, only 15% are in service. It is time to highlight a strategy to safeguard these foggaras.

Keywords: Volumetric Foggara, hourly Foggara, Sahara, Erg, Albien, Garden.

NOMENCLATURE

Aghrissou: open channel that connects the exit of the foggara to the kasria
Ain: water source
Chaabat: tributary
Djamaa: wise council
Delou: a pocket made from goatskin
Foukania: located at the top of the palm grove
Khottara: Pendulum well

Kiel El Ma: the person who measures the flow of the foggaras
Kassem: a structure that divides the waters
Ksar: city of peasants
Ksour: plural of word ksar
Kasria: triangular basin fitted with a distributing comb
Madjen: Water storage basin
Neffad: Galerie
Seguia: open-air canal
Sebkha: a saltwater lake
Tahtania: located at the bottom of the palm grove
Taghanimt: a wild plant
Tisanbadh: gallery

INTRODUCTION

The Sahara, a vast arid territory located in the northern part of the African continent, has an area of 8 million km^2 and a perimeter of 100 km. Very rich in water in its subsoil, the Sahara contains four gigantic underground water reservoirs, namely, the SASS and Nubia. However, despite the existence of modern means, we cannot accurately assess the volume of invisible water.

For centuries, the population of the Algerian Sahara has been exploiting the waters hidden in the subsoil by pulley wells, animal traction wells, and pendulum wells. However, the discovery of foggara more than 30 centuries ago has made it possible to better ensure the water security of oases. Thanks to its success, foggara has been exported to 52 countries around the world (Remini et al, 2014). This is how more than 50,000 qanats were dug in Ancient Iran (Persia). Today, there are 22,000 qanats in service with a total gallery length of approximately 250,000 km (Wulf, 1968). In the Sultanate of Oman, 4117 falajs have been dug for 3000 years, and there are currently 3017 falajs in operation with a total length of the gallery equal to 2900 km (Al Gharfi et al. 2000). In the Tafilalt in Morocco, the underground pipes locally called khettaras were 300 in number with a total length of 450 km. In 2000, only 150 khettaras remained in service (Ben Brahim, 2003). With the appearance of modern groundwater acquisition techniques, these traditional techniques are declining from one year to the next, including the foggaras of the Algerian Sahara.

Although foggaras are taken into account by hydraulic services in the balance of water resources such as dams and boreholes, we have never had the exact number of these ancestral works. The last two censuses carried out by the national water resources agency gave the number of foggaras in service in the regions of Touat, Gourara and Tidikelt. This inventory remains insufficient since it did not give all the foggaras made in other regions of the Sahara. In this study, we highlight the inventory of foggaras made in the Algerian Sahara.

DATA USED AND STUDY SITES

It was at the beginning of the 1990s that we began to take an interest in the foggaras. My first trip to the Sahara took place in 1992 in the capital of the foggaras; Adrar. We were surprised and impressed by this foggaras system. During the same year, we returned to the oases of Timimoun to supervise the foggaras. Assisting with Kiel El Ma (the person who measures the flow of the foggaras) in a hydrometry operation in the oasis of Ouled Said was for us an opportunity not to be missed. These people who have never been to school manage to invent a whole system of capturing and sharing water while inventing their own flow meter and their own units of measurement. During a visit to Bechar, the capital of Saoura, in the year 2000, we had the opportunity to visit the foggaras of Taghit, Beni Abbes, Beni Ounif, Kenadsa and Ouakda. It was at the beginning of the year 2000 that we decided to work seriously on the subject of foggaras. Starting from the proverb "the words go away, the writings remain", our objective was to write and publish on this heritage, which is deteriorating day by day. For more than 30 years, several work missions have been carried out in the four corners of the Sahara. We did this work out of conviction and love to make known the know-how and genius of our ancestors in the world through our writings.

"In the footsteps of the foggaras" is the title we have chosen for this modest paper. Quite simply, this subject is based on travel in the desert in search of foggaras. This is how we have repeatedly visited all the oases of the Algerian Sahara. Bousaada, Biskra, Bayadh, Ouargla, Menea, Saoura, Souf, Mzab Valley, Tamanrasset, Djanet, Tindouf, Tabalbala, Adrar, Timimoun and In Salah, all of these beautiful regions of our beautiful Sahara have been visited. During this period, we conducted surveys among the owners of the foggaras and the population of the ksours. For this study, we used data on the foggaras, maps and old documents recovered from the services concerned, such as the hydraulic services and the services of the wilayas.

RESULTS AND DISCUSSION

The word foggara comes from the Arabic word Fedjara ,فجر which means to spring water. We define a foggara as a slightly inclined horizontal well (Remini, 2017) (Fig. 1).

The foggara is directly connected to its territory of Touat, Gourara and Tidikelt. Moreover, these three regions are designated as the country of the foggaras, and Adrar represents the capital of the foggaras. Only the most studied foggaras are concentrated in Touat and Gourara. Moreover, the inventories that have been carried out on foggaras concern only the regions of Touat and Gourara. The most informative inventory is undoubtedly the one carried out in 1998 by the National Agency for Water Resources. For the region of Tidikelt, there were only the foggaras of the oases of Aoulef, Akabli, Timokten and Tit, 44 of which were inventoried. During the 2011 inventory, the number of foggaras in the Tidikelt region increased to 47 and still concerned the foggaras of Aoulef, Akabli, Timokten and Tit. This is one of the reasons that led us to give more working time and missions in the oases of the wilaya of In Salah to better study these

traditional works. It was only in 2020 that we gave an approximate number of foggaras dug in the wilaya of In Salah. We added 5 foggaras from the Ezzaouia oasis instead of 1 foggara. The correction was made at the level of the oasis of In Ghar, which counts 15 foggaras (table 1) (Remini and Achour, 2013a, Ghachi and Remini, 2018; Ghachi et al, 2021).

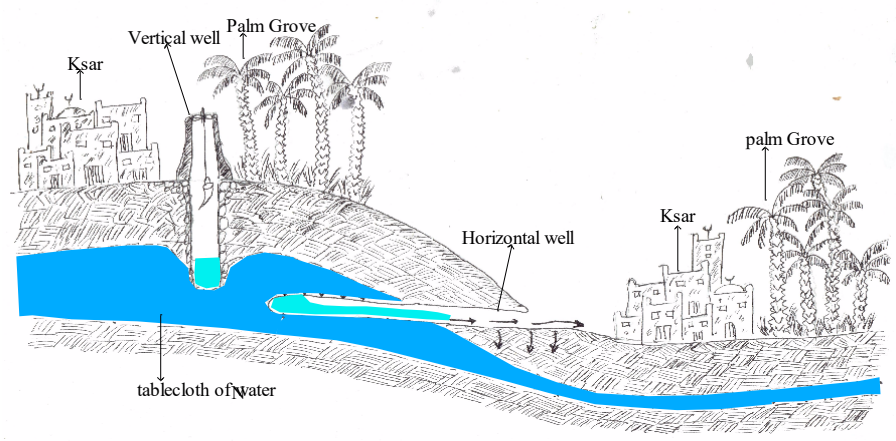

Figure 1: Diagram of the principle of a foggara (Remini, 2022)

Table 1: The foggaras of the oases of the In Salah region

Oasis	Total number of foggaras
In Salah	43
In Ghar	15
Foggaret Ezzoua	07
Total	**65**

The invention of foggara caused considerable agricultural development in the regions of Touat, Gourara and Tidikelt. The success brought by the foggara quickly led to the export of know-how to other regions of the Sahara. This is how the foggara has adapted to the hydrogeology and the environment of each region of the Sahara. The foggara has become an essential hydraulic system in oases to the point where it has diversified according to the nature of the type of water resource exploited. We have defined 9 types of existing foggaras in the Algerian Sahara:

- Albian Foggara
- Foggara of the Erg
- Foggara of the wadi
- Garden Foggara
- Ain Foggara
- Foggara of Kenadsa
- Foggara of Ouakda

- Foggara of Mzab
- Ziban Foggara

Albian Foggara

The Albian foggara is the best known and most described by researchers. This type of foggara is located in the southwest of the Grand Erg Occidental, in the wilayas of Adrar, Timimoun and In Salah, where the plateau of Tademaït constitutes a real water tower (Remini and Achour, 2016; Remini et al, 2014). The deep Continental Intercalary aquifer is brought closer to the surface in the periphery of the Tademaït plateau. This is how the galleries of the foggaras penetrate into the upper part of the sandstone aquifer of the Continental Intercalary on the outskirts of the Tademaït Plateau. These galleries ensure flow by gravity toward the low depressions where the palm groves and gardens are located. This particular foggara, which draws ancient water from the deep aquifer, we have called it the Albian foggara or the Tademaït foggara (Remini, 2017; Abidi and Remini, 2011; Remini, 2011). The diagrams in Figs. 2 and 3 give an overview of the Albian foggara.

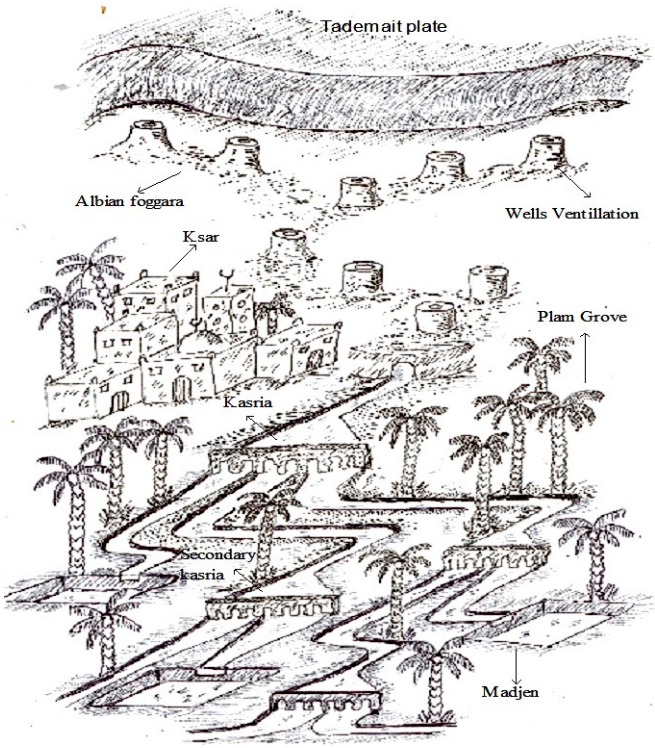

Figure 2: Diagram of an Albian foggara (Remini, 2022)

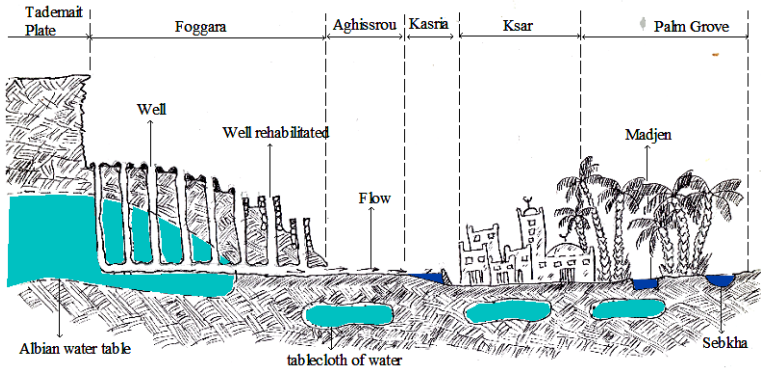

Figure 3: Diagram of a longitudinal section of an Albian foggara (Diagram Remini, 2022)

The first foggara dug in the Algerian Sahara is undoubtedly the foggara, which draws its water from the Continental Intercalary aquifer. However, no one can confirm that the Ksour population was not aware of the size of the Continental Intercalary aquifer for more than 20 centuries. The Tademaït Plateau is a huge 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. With an area of approximately 500 km^2, the Tademaït Plateau is located at an average altitude of 600 m. (Fig. 4).

Figure 4: A view of the Tademaït Plateau (Photo Remini, 2008)

However, at the time of foggaras digging, no one can confirm that the oases of the wilayas of Adrar, Timimoun and In Salah surround one of the largest underground water reservoirs on the planet. More than 1000 foggaras have drawn their water from this invisible sea for more than 20 centuries. The basement of the Tademaït Plateau contains one of the largest aquifers on the planet called the Continental Intercalary, with an estimated capacity of between 30,000 and 100,000 billion m^3 (Remini, 2021). On the periphery of the Tademaït Plateau, the groundwater level is flush. In the past, groundwater flowed over the surface of the ground due to the pressure difference. Over the centuries, hundreds of water sources have ended up disappearing due to the lowering of the water

table. The drying up of water sources is the starting point for the discovery of foggaras. Seeing the stoppage of the flow of spring water, the oasis dwellers go in search of water by digging galleries in the opposite direction of the flow, following the old water path from the dried up spring to reach the water table. This is how the water begins to flow through the dug gallery to reach the ground surface. This is the era of the birth of the foggaras. All the topographical and geological conditions come together to obtain a gravity flow without energy. Thus, all the oases of the wilayas of Adrar, Timimoun and In Salah are located around the plateau of Tademaït but at a coast lower than that of the level of the water table on the outskirts of Tademaït. This encouraged the oasis dwellers to dig thousands of kilometers of galleries to drain and transport the waters of the Continental Intercalary aquifer to the gardens and palm groves. These hydraulic works were dug by rudimentary means (Fig. 5). This testifies to the value of water at the level of the Ksourian population.

Figure 5: Materials used for digging and maintaining foggaras (Ghachi and Remini, 2018)

Paradoxically, once the mother well is located, the foggara is dug from downstream to upstream. In the first stage, we started by digging a section of the gallery with an average length of 15 m from the garden. In a second step, the first vertical shaft 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. In a fourth step, the second section of the gallery is excavated from the first and second shafts until it reaches the mother shaft (Fig. 6).

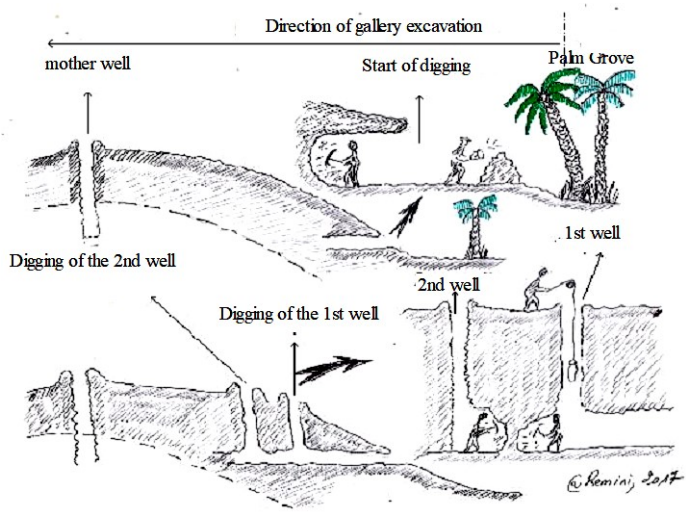

Figure 6: Diagram of the stages of digging a foggara in the oases of Adrar, Timimoun et In Salah, (Diagram executed on the basis of information collected from the owners of the foggaras) (Remini, 2017)

More than 1890 foggaras were inventoried according to the foggara observatory in 2021. Based on this figure, we deduced that 1815 was dug to capture the waters hidden under the stony plateau of Tademaït. Over an area of 15,000 km2 with dimensions equal to 500 km by 30 km, which takes the form of an arc of a circle going from In Salah in the southeast to 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 spread over this surface (Remini and Achour, 2016; Remini et al, 2010). The Tademaït Plateau can be considered the natural water tower of the oases of In Salah, Adrar and Timimoun. Five inventories of foggaras were carried out in the regions of Adrar, Timimoun and In Salah. The last inventory carried out in 2021 by the foggara observatory gave 1890 foggaras, including 330 perennial foggaras, 304 degraded foggaras and 1256 abandoned foggaras.

Erg Foggara

From the floods drained by many wadis, millions of m3 of water are abandoned at the level of the sand dunes of the Algerian Sahara. These waters seep into the sand to reach the bottom of the Ergs. Stored under the sand dunes, immense capacities of very good quality fresh water were treated naturally by this sand dune filter. These waters are exploited by foggaras that we have called the Erg foggaras (Remini and Achour, 2013b).

The Erg foggara is characterized by a part of these wells that are lost in the Erg, and no one can define the exact number of ventilation shafts. The quality of the water is of good quality 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 low 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 (Figs. 7 and 8).

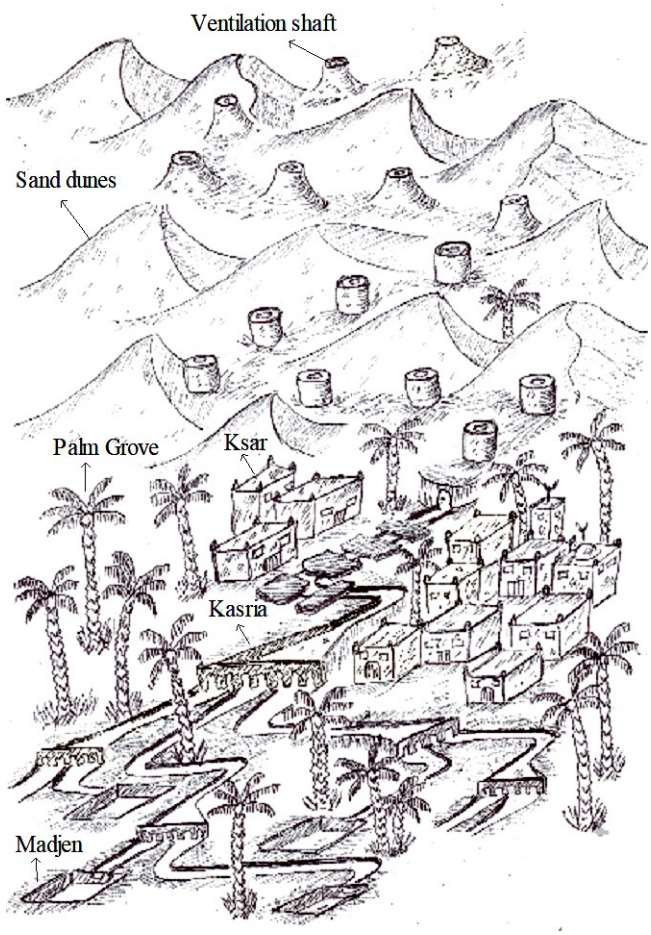

Figure 7: Synoptic diagram of a foggara in the Erg (Remini, 2022)

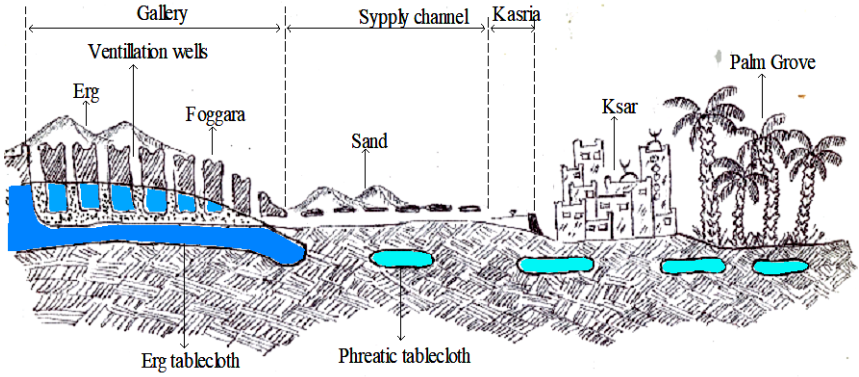

Figure 8: Diagram of a longitudinal section of an Erg foggara (Remini, 2022)

Unlike the Albian foggara, the Erg foggara is narrow with a seguia covered with flat stones to protect against silting. Called Fhel, this open channel has a length exceeding 150 m between the water outlet of the gallery and the main kasria (Fig. 9).

Figure 9: Seguia covered with rocks with a length of more than 200 m connecting the exit of the gallery to the main kasria of an Erg foggara of the Ouled Said oasis (Photo Remini, 2009).

The foggaras of the Erg encounter two environmental problems: silting up and the wild plant Taghanimt (Remini and Achour, 2013b). Silting poses enormous problems to the operation of Erg foggaras. Heavy maintenance work is carried out periodically by the local population. With each sandstorm, the population prepares for the maintenance of the galleries, the seguias and the kasriates. The spring season is too busy for the population since the number of storms is more important. The absence or delay in the maintenance of a foggara will immediately cause the supply of ksar and the irrigation of

the palm grove to stop. The population covers the kasrias and seguias with flat rocks to minimize the deposits of sand in these works (Fig. 10).

Figure 10: Foggara of Tafza: Operation of covering a kasria with flat rocks (Photo Remini, 2008)

The other phenomenon that poses enormous problems for farmers is the filling of seguia and kasrias with the roots of a wild plant locally called Taghanimt. This plant, whose roots can reach a length of 20 meters, develops along the gallery following the existence of water (Remini and Achour, 2013a). When the root penetrates an opening, it propagates inside the structure. In a very short time, roots can easily seal the wetted section of a seguia or kasria. The flow decreases over time until the flow stops completely.

Our first trip to the Timimoun oases dates back to 2008. For us, all the foggaras of Adrar, Timimoun and In Salah capture the waters of the Continental Intercalary. However, once we visited the commune of Ouled Said in Timimoun, the oasis dwellers confirmed to us that the foggaras of Ouled Saïd exploit the water table of the Grand Erg Occidental. It was a discovery for us. According to the local people, no one can give you the exact length of the Erg foggara since it is lost in the middle of the Erg. Much of the foggara is under the dunes. There are even foggaras that are completely invaded by piles of sand. It is for this reason that it is impossible to give an exact number of Erg foggaras. This type of foggaras is located as we mentioned in the oases of Ouled Said (Timimoun), the oasis of Tabelbala, the oases of In Ghar (In Salah) and the oases of Ezzaouia (In Salah).

As we mentioned in the previous paragraph, the foggaras of the ksours, which are located on the limit of the great Western Erg, draw their water from the Erg aquifer (Fig. 11). Numbering 64, 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 2 gives an overview of the number and mileage of galleries.

Figure 11: A view of the Grand Erg Occidental; the water tower of the foggaras of Ouled Said and Aghlad (Photo Remini, 2019)

Table 2: The Erg foggaras in the Timimoun oases

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

In Salah, the oases of In Ghar, which have 11 foggaras, exploit the Erg Miliana aquifer (Table). Eleven foggaras have been dug from east to the west to supply water to the oases of In Ghar for 9 centuries. The foggaras of In Ghar exploit the waters hidden under Erg Meliana. This surface aquifer is fed by the wadis at a place called Taghbana. For nine centuries, the oasis dwellers dug galleries with a total length of 36 km. More than 2,600 ventilation shafts were dug to an average depth of 15 m, i.e., a total depth of the shafts equal to 3,900 m. To obtain an idea of the effort made by the oasis dwellers, approximately 95 million tons were excavated during the digging of the galleries of 11 foggaras. More than 6,500 tons of soil was removed during the digging of the ventilation shafts (Ghachi and Remini, 2018).

The Irsan foggara is the oldest and largest foggara in the In Ghar region and contains 11 foggaras. It was in 1100 that the foggara of Irsan was made. The Irsan foggara has an 8 km gallery, equipped with a succession of 504 ventilation shafts, spaced from 3 to 12 m. The deepest well has a height of 24 meters and is located at the level of the two water reservoirs of the city before the Erg de Miliana. The initial flow of the Irsan foggara (115 l/min). The Irsan foggara drains water from the Erg de Meliana aquifer. The water drained from the foggara of Irsan travels a length of 8 km under the dunes and 300 m in a seguia covered with flat rocks before reaching the palm grove with an initial area of 60 hectares.

The foggara also supplies drinking water to the 400 families of the ksar, i.e., a total flow of 51 l/s. At the beginning of the exploitation of the foggara of Irsan, the flow was 8640 habba (115 l/s); however, today, it is around the value of 51 l/min, i.e., a reduction of 60%. (Ghachi and Remini, 2018; Remini and Ghachi, 2019).

The small oasis of Ezzaouia belongs to the commune of In Ghar of the wilaya of In Salah and has 5 foggaras that operate with appreciable flows (Ghachi et al, 2021). These 5 foggaras, which have not been inventoried by hydraulic services, capture the waters of Erg Ezzaouia, which is considered to be the water tower of these foggaras. Indeed, under the Erg, there is a very good quality water table that feeds these 5 foggaras. This water table is recharged by sporadic high-intensity floods drained by the wadis.

At the exit of the Erg, the water is transported by the supply channel (Fhel) to the main kasria (Fig. 12). This mythical work is the beginning of the water distribution network. The network is made up of several kasrias of different sizes, seguias and water storage basins (madjen). To reach the gardens of the oasis, once the water arrives on the ground, it will be shared by the different types of kasrias. Each part of the water is transported by the seguias to the madjens and then irrigates the gardens (Guemoun).

Figure 12: A secondary kasria in the Tafza foggara network (Ghachi and Remini, 2020)

Of the 5 foggaras dug in the Ezzaouia oasis, only 3 foggaras were operated by 160 owners at a rate of 29 l/min. The other two foggaras Ejdida and El Barka, despite the presence of water in their galleries, are unusable due to clogging at the exit of the Foggara following the collapse of a portion of the gallery. The characteristics are shown in Table 3.

We have classified Tabelbala foggaras as Erg foggaras since they draw water from Erg Er Raoui. Equipped with more than 1,000 ventilation shafts, these 101 foggaras have a gallery with a total length exceeding 100 km (Fig. 13). These foggaras, which functioned for more than 9 centuries, made it possible to irrigate the palm grove and supply the ksar of the oasis of Tabelbala without interruption. Unfortunately, today, no foggara is in service, and this entire hydraulic heritage has disappeared; there are only vestiges and traces of galleries as well as traces of the collapse of the wells.

Table 3: Characteristics of Ezzaouia foggaras (Ghachi et al, 2021)

Name of Foggara	Length (km)	Number of wells	Discharge (l/min)	Number of owners	Observation
Ejdida	0.30	19	Flow	150	Nonfunctional
Kdima	0.45	30	10	100	functional
Nia	0.20	15	10	30	functional
Hanou	0.35	23	9	30	functional
El barka	0.10	3	Flow	90	Nonfunctional

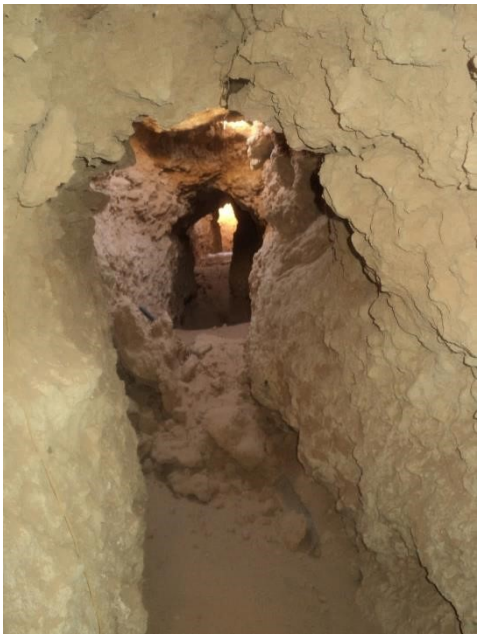

Figure 13: Abandoned Foggara in the oasis of Tabalbala (Abidi and Remini, 2015)

Kenadsa Foggara

Saoura was a region very rich in water sources. With the discovery of the foggara in the oases of Touat and Gourara, the peasants transferred the know-how to the Saoura and adapted these works to the hydrogeology of their environment. This is how the oasis of Kenadsa has its own unique foggaras. The topography of the land is very favorable to the realization of such foggaras. A slope slightly inclined from north to south starting from the foot of El Barga Mountain, which induced a gravity flow of water flows without any energy (Fig. 14).

Figure 14: The cliff of El Barga, the water tower of the foggaras of the oasis of Kenadsa (Photo Remini, 2014)

The existence of water resurgences on the outskirts of the massif has facilitated the task of farmers for the realization of approximately fifty foggaras going from the foot of the El Barga massif to gardens with an average length of 150 m. In 2013, during our visit to the region, there were only 12 permanent foggaras. Without the 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 that appear at the foot of the El Barga cliff. (Fig. 15). Over time, the disappearance of water sources encouraged the owners of the foggaras to dig a drain while following the flow of water (Figs. 16 and 17).

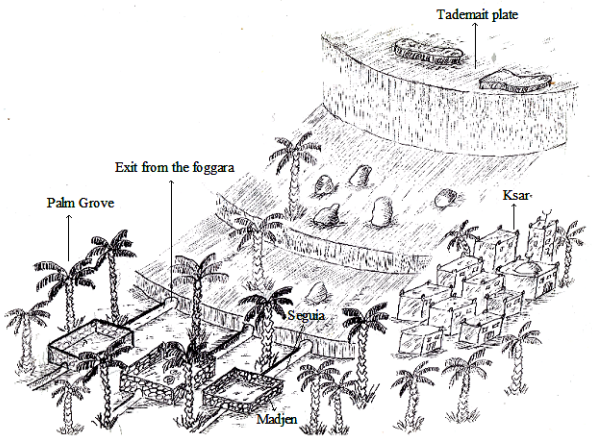

Figure 15: Approximate diagram of a Kenadsa foggara (Remini, 2022)

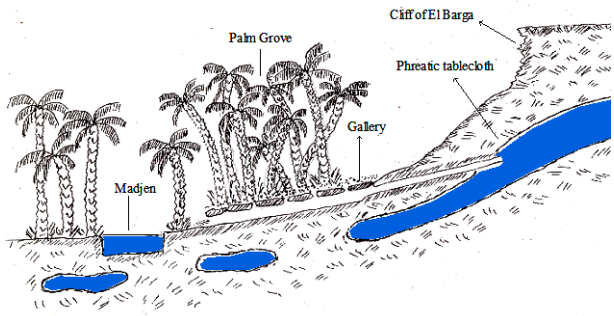

Figure 16: Approximate diagram of a longitudinal section of a Kenadsa foggara (Remini, 2022) phreatic tablecloth

Figure 17: Exit from a foggara in the oasis of Kenadsa (Photo. Remini, 2014)

The foggara is very similar to the Mountain karez in Afghanistan, which has a gallery 15 meters long (Remini et al, 2014). Called “Ain” (water source), the foggara of Kenadsa is a family property. The water sources discovered by the first families became their properties. Let us take advantage of the fertility of the soil and the existence of materials (rocks and clays); these families conveyed the water from the springs to the gardens by

digging underground drains. The foggaras bear the name of each family, and we can mention 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, and Ain Sidi Mohamed. A decrease in the flow of foggaras was observed in the early 1980s. In 2014, there remained approximately ten foggaras in service draining low flows. For example, the flow of the foggara of Sidi Mbarek does not exceed 2 l/s (Remini et al, 2014). The other foggaras only drain a trickle of water not exceeding 1 l/s. It is worth mentioning that the foggara of Kenadsa has never been thoroughly studied. The Kenadsa foggara has a gallery with an average length of 150 meters and drains water from gushing springs at the foot of the El Barga cliff to the gardens. Approximately forty foggaras have been dug for more than seven centuries. Today, practically all foggaras are in a much degraded state, with only a trickle of water flows in two foggaras.

Garden Foggara

We discovered this type of foggara by chance. We were looking for the kasrias of the Albian foggaras in a palm grove in Timimoun and came across air shafts. It was something abnormal for us since the ventilation shafts are generally located outside the palm grove. In addition, these wells belong to a small foggara that was dug inside the palm grove. Its role is to capture the seepage water from the great foggara. We have called this type of foggara the Garden Foggara.

We thus defined the garden foggara as a small foggara whose length does not exceed 1.5 km (Remini et al, 2015). It is a foggara that 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, garden foggaras have a discontinuous flow. It captures its water from drainage water and irrigation leaching from the palm grove from the large foggaras. Any water lost through the classic foggara; by infiltration of water from seguias, madjens is recovered by this small foggara (Figs. 18 and 19). The distribution of water for this type of foggara is simple and requires no sharing. This type of foggara is not equipped with a classic kasria but rather with a special kasria whose comb has a central opening.

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, there is a diamond-shaped kasria (Fig. 20) that is not triangular like the classic foggara. In the kasria, a rectangular rock plate is placed with a hole in the middle by a circular opening that is closed with the help of a stick provided at its end with a cloth soaked in clay (plays the role of a valve) (Fig. 21).

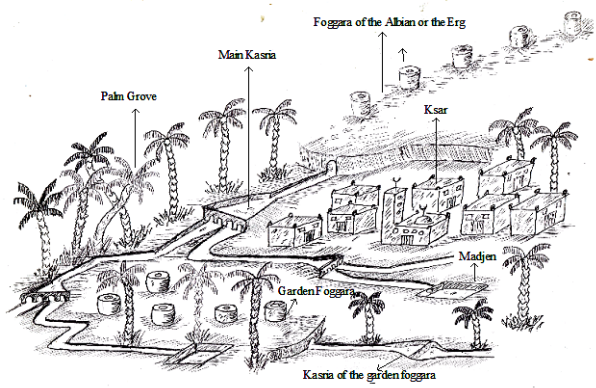

Figure 18: Simplified diagram of a double foggara oasis: classic and Garden (Remini, 2022)

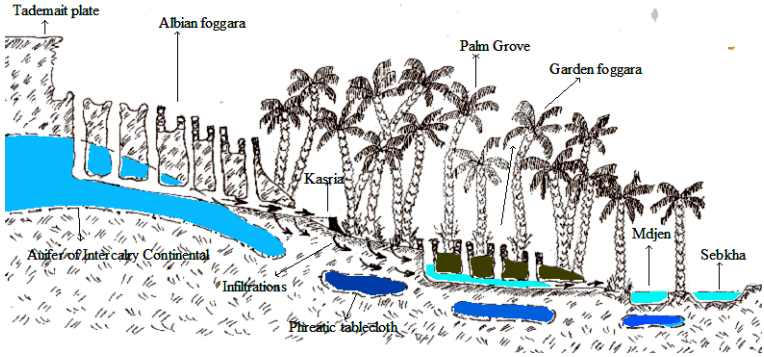

Figure 19: Diagram of a longitudinal section of Garden foggara (Remini, 2022)

Figure 20: A view of the kasria from a Garden foggara in the central Timimoun palm grove (Photo. Remini, 2008)

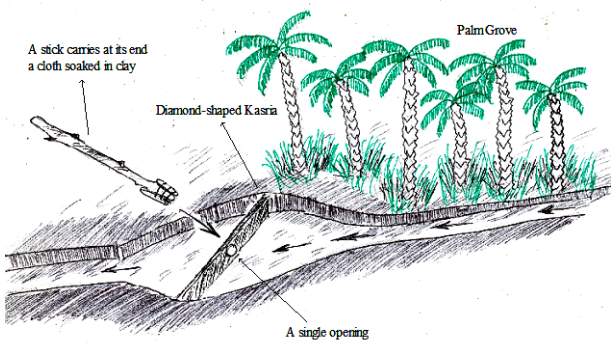

Figure 21: Diagram of the maneuver of the kasria of the Jardin foggara (Remini, 2022)

For good irrigation operation, the opening of the kasria is obtained. Once the gallery is filled with seepage water from the waters of the seguias, the waters of the madjens and the gallery of the classic foggara, the orifice is opened to fill the madjen of the garden foggara within an acceptable time. Therefore, the operation is discontinuous. By blocking the opening with a diameter of approximately 8 cm with a stick of 3 meters that carries at its end a cloth in the shape of a sphere of the same diameter as that of the opening of the kasria. The gallery fills with infiltrated water. With the opening of the kasria hole, the water collected by the gallery will eventually fill the madjen of the garden foggara. It is a particularly spectacular example of the art of oasis dwellers. This type of foggara has never been described or even reported thus far in the oases of the Algerian Sahara. They are not visible on satellite images or even on aerial photography and topographic maps because they are small foggaras that do not exceed 20 ventilation wells 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 for the gardens located further downstream from the main foggara? Is it a mastery of the technique of foggaras that allows better management of water without waste and good use of water 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 4. According to the testimony of the owners of the foggaras, approximately one hundred of this type of foggara has disappeared. They have been reported in the oases of In Salah, Adrar and more particularly in the palm groves of Zaouit Kounta.

We note from these values that the Garden foggara is characterized by low flow and a short gallery. For example, it takes 12 hours (during the night) to fill the Zahzaa foggara gallery with a volume of 850 liters.

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 peasants, it turns out that the number far 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 affirms that this type of foggara is located at the limit of the palm grove

with the sebkha to collect the maximum of infiltration water. 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 setting up his new garden, he digs a small foggara in the palm grove to capture the water from seepage.

Table 4: Caractéristiques des foggaras de jardins dans l'oasis de Timimoun (Remini et al., 2015)

Foggara	Length (m)	Number of wells	Discharge (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	Foggara
Bouchouk	Foggara	abandoned	Foggara

The foggara of Ouakda: a groundwater foggara

In the oasis of Ouakda, 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 the gardens. Each foggara belongs to a group of farmers. The water captured from the water table is conveyed by a gallery to the surface of the ground; at the outlet, the water flows through a seguia (open channel) to the madjen (storage basin). The sharing of water is carried out according to the hourly method, that is, in turn. Irrigation is done garden after 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 gardens of the farmers. The repeated droughts caused the drawdown of the water table and subsequently the drying up of the foggaras. This critical situation prompted farmers to deepen the first well in the foggara to the groundwater level. The well is equipped with a rod (tree trunk) 4 m long equipped with a counterweight. The whole is placed on two stone supports 3 m high by means of a wooden axis 1 m long to form a pendulum shaft (Fig. 22).

Figure 22: The sea well of an abandoned foggara with the stone support of the pendulum (Photo Remini, 2013).

The coupling between the foggara and the pendulum well (called khottara) constitutes the originality of the oasis of Ouakda (Figs. 23 and 24). The operation of this somewhat special work is very simple. The well digger, once installed inside the well at the same level as the gallery, lowers the Delou (a pocket made from goatskin) attached to the pendulum by means of a rope. Once filled with water, the well digger pours it into the gallery, and the water flows directly toward the madjen. The foggara continues to play its role but in a discontinuous way, and the water always flows in the gallery until it comes out on the surface of the ground. The originality of the foggara of Ouakda lies in the marriage of the foggara and the khottara, two traditional works of the Saoura valley. The khottara was added upstream of the foggara just after the sea well played the role of a flow regulator. If there is a drawdown of the water table, the khottara will be used to continue irrigating through the foggara. Otherwise, that is, there is a rise in the level of the water table; the foggara will work on its own.

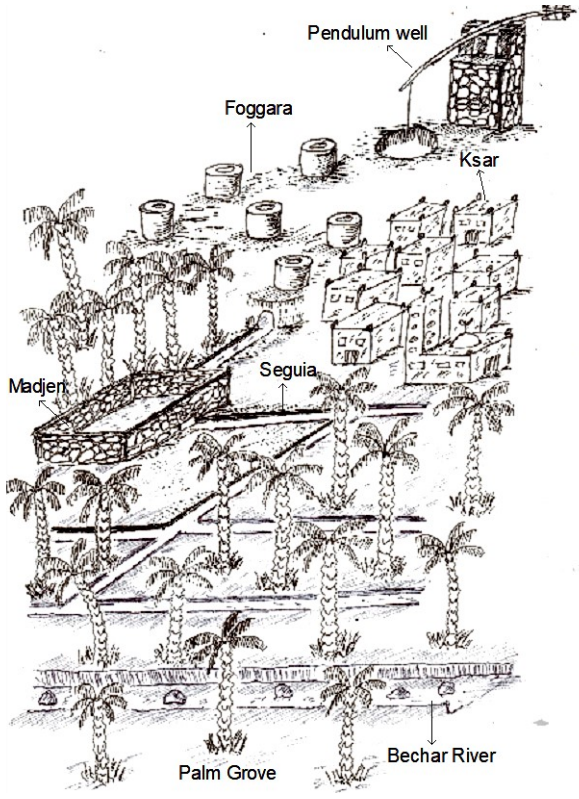

Figure 23: Approximate diagram of an Ouakda foggara coupled with a pendulum well (Remini, 2022)

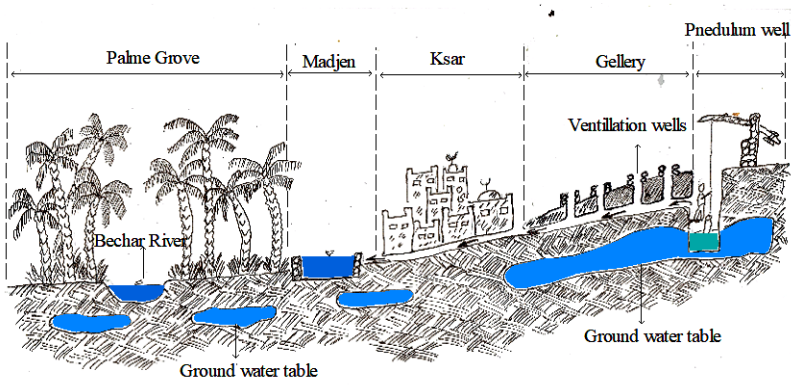

Figure 24: Diagram of a longitudinal section of the foggara complex and the pendulum well in the oasis of Ouakda (Diagram Remini, 2022)

Foggara of the wadi

Thanks to the success obtained by the foggara in the oases of Adrar, Timimoun and In Salah, the know-how of the foggara has been exported to other regions of the Sahara, such as the oases of Tamanrasset, Sfissifa, Tindouf. Only in these oases have foggaras been adopted to the hydrogeology of the environment. It turns out that in these 3 oases, foggaras were dug but in the beds of the wadi. The palm groves of these oases occupy the major beds of the rivers. As it is a dry environment, the periodicity of floods has increased due to repeated droughts, which has prompted ksourians to think about proposing an alternative water source to overcome water shortages. Thanks to their genius and know-how in hydrogeology, the oasis dwellers knew that below the bed of the wadis, an inestimable volume of water flows in parallel with surface water. He knew that after a flood, surface water evaporates and seeps underground and flows through 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 tablecloth. The superficial layers of inferoflux are located at depths varying from 0.5 m to 4 m (Gast, 1995). They are replenished each year after the passage of the floods, and they flow under the beds of the wadi in the alluvium. They flow even if the wadis are dry on the surface. The Inferoflux sheet can last 1 to 2 years without rainfall. The foggaras of the wadi have galleries not exceeding 2 km (Figs. 25 and 26). They are intended for the collection of water from the inferoflux aquifer of the wadis, which classifies them as unstable foggaras, i.e., at each flood, the wells of the foggara are carried away by the force of the flow (Remini and Abidi Saad, 2019).

Tamanrasset remains the cradle of the wadi foggaras, since more than 184 foggaras have been dug in the beds of the wadis of the Ahaggar region (Remini and Achour, 2013). However, during our mission in the Tamanrasset region from December 2022-January 2023, the local population confirmed that there were more than 200 foggaras that have been exploiting the waters of the Inferoflux aquifers for centuries. Today, he is 70 years old, Aychoubi M'Barek, an element who participated in the maintenance of the foggaras in the Ahaggar region, especially after the passage of the floods (Fig. 27). Aychoubi M'Barek even participated in the digging of the gallery of the last foggara in the region of In Salah during the late seventies. Called Rabat El Hadjadj, this foggara had a length of approximately 200 meters with 14 ventilation shafts. According to Aychoubi M'Barek, the ventilation shafts had an average depth of 15 meters, and the digging of the 200 m gallery lasted more than 2 months without stopping. Surely, the knowledge acquired by Aychoubi M'Barek in the digging of foggaras in the region of In Salah has been of great use for the digging and maintenance of foggaras in the Tamanrasset region. According to Aychoubi M'Barek, the last foggaras that operated during the 1970s in the Ahaggar region are 10 in number (Table 5).

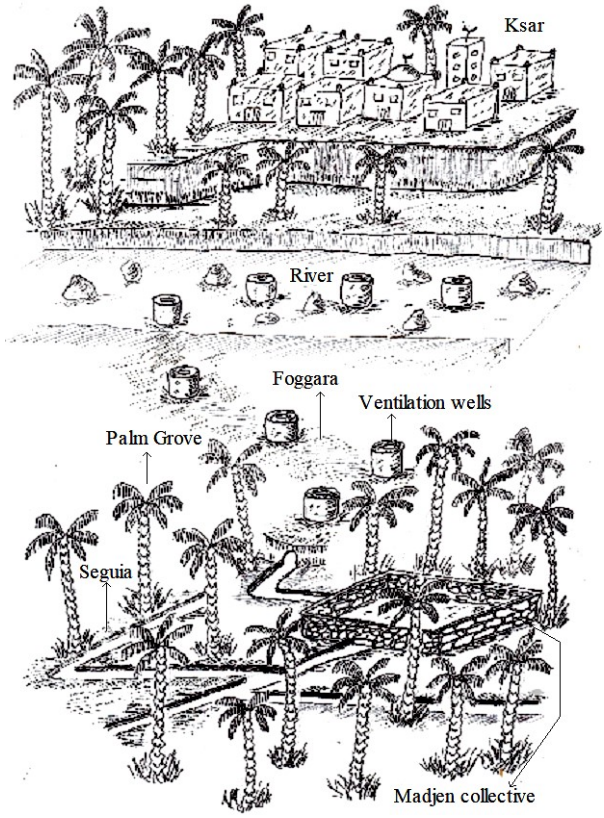

Figure 25: Synoptic diagram of a wadi foggara that exploits the water table Inferoflux (Remini, 2020)

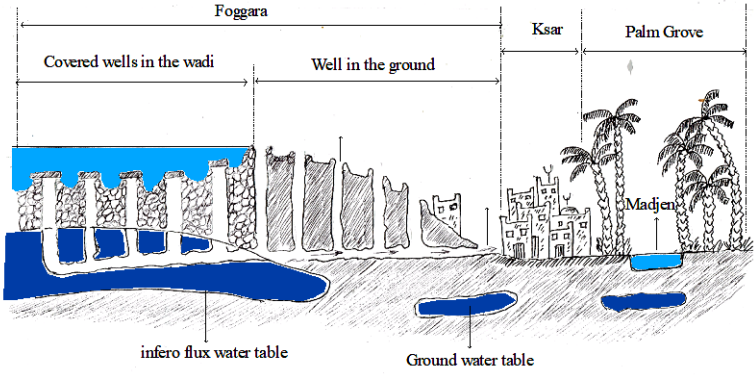

Figure 26: Diagram of a longitudinal section of a wadi foggara (Remini, 2022)

Figure 27: Aychoubi M'Barek, one of the last skilled workers in the digging of foggaras in the regions of In Salah and Tamanrasset

Table 5: The last 10 foggaras that disappeared during the late seventies

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

According to Aychoubi M'Barek, the kasria (element of watershed) existed in the gardens of the oases of the region. The water sharing of the foggaras of the Ahaggar region is done by unit volume. This know-how was exported from the oases of the Tidikelt region. Unfortunately, today, only the traces of galleries and wells remain, and the distribution network has completely disappeared. The abandonment of the foggaras in the Ahaggar region is due to the drawdown of the Inferoflux aquifer following the drought that hit the region during the 1970s.

The Ahaggar foggaras are equipped with ventilation shafts with a diameter of 1 m. Some foggaras are equipped with ventilation shafts with a rectangular section of 1 m x 1 m. The wells are 2 to 4 m apart. The underground gallery of rectangular section 0.5 to 0.6 m wide and 1 to 2 m high. The length of the Ahaggar foggara varies from 500 m to 5 km and captures the waters of the Inferoflux aquifer. The flow rate of these foggaras is generally low, varying from 0.3 l/s to 5 l/s. In Ahaggar, the number of foggaras has increased since 1904 to reach 184 foggaras in 1956. However, the local population produces more than 200 foggaras in the Tamanrasset region.

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 wadi of Tindouf, and it draws its water from the Inferoflux aquifer 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. Only Papy (1959) mentioned in a study on the decline of foggaras in the Sahara that there were several foggaras along the wadi of Tindouf, except that the author never specified the exact number of foggaras. Even the local population claims that there were several foggaras exploiting the Inferoflux aquifer, but without specifying the number. It should also be noted that during our missions carried out during the period 2000-2022 on the site, no trace of foggaras was detected apart from that of the foggara of Ras El Ma. Contrary to the digging of the foggara in the oases of Touat and Gourara, which is carried out in the opposite direction to the flow, the digging of the foggara of Tindouf was carried out in the same direction of the flow. The mother well is located in an area whose piezometric level is higher than that of the surface of the gardens. Called foggara of Ras El Ma, in French means "head of the source", the mother well with a depth of 2.5 meters is located in a spreading zone that is formed thanks to a rapid reduction in the slope of the wadi. A second well is dug approximately 10 m from the first in the wadi bed. In the third stage, the two wells are connected by an east gallery and so on until the entrance to the palm grove. The digging of the gallery begins from downstream to upstream for the foggaras of Adrar, Timimoun and In Salah. and from upstream to downstream for the foggara of Tindouf (Figs. 6 and 28).

With a gallery 2100 m long (DHW Tindouf, 2013), the foggara of Tindouf has approximately one hundred wells with an average depth of 2.5 m each (Fig. 29). If today, we do not know its date of impoundment, the foggara of Ras El Ma dried up in 1950 because of the drop in the piezometric level of the water table. An attempt to recover this ancestral hydraulic system was launched in 1958 by the geologist Bourgeois by adding wells to the foggara in the upstream part (draining part), but without result (DHW Tindouf, 2013). The gallery of the foggara of Tindouf, like any foggara of the wadi, has two parts: draining and transport. The draining part is located in the inferoflux aquifer of the Tindouf wadi. This is the most important part and the most threatened by landslides and fillings.

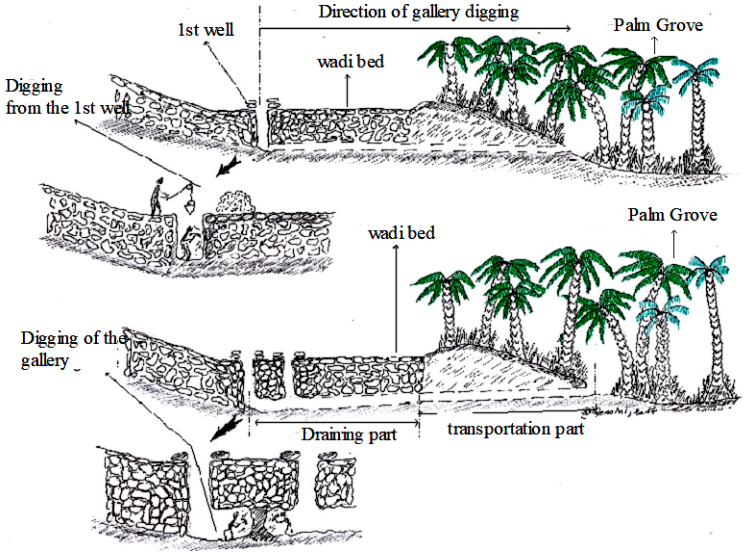

Figure 28: Diagram of the digging of the Tindouf foggara (Diagram executed by Remini, 2019)

Figure 29: View of part of the gallery of the Ras El Ma foggara in Tindouf (Photo Abidi and Remini, 2013)

The transport part is dug in the ground outside the wadi and is used to convey the drained water to the madjen, which is located in the gardens. The wells of the draining part are generally covered by blocks and rocks to avoid clogging of the gallery by aggregates and silt carried by the watercourse. However, during periods of flooding, these wells cannot resist the force of the flow and are destroyed and blocked at each flood. This obliges the

oasis dwellers to reconstitute and clean the wells and the gallery. On the other hand, the wells of the transport part are spared from these problems. During major floods, all objects that are along the wadi can be carried away. Faced with this situation, there is only one solution and only one way, which consists of digging new shafts and galleries. Such an operation, which mobilizes several material and human resources, can take several months of work. Today, although the foggara of Ras El Ma contains water, it does not work and is in a very degraded state. The network of seguias is completely destroyed. Ventilation shafts have become open dumpsters. Such a hydraulic heritage can be recovered and rehabilitated since the water still exists in the gallery, especially during periods of flooding, but still requires maintenance. On the other hand, the wells and the seguias are completely destroyed and require rehabilitation.

While visiting the ksar of the oasis of Sfissifa, we came across two foggaras of the wadi with an appreciable flow (Fig. 30). However, the ksar population has no information on the number of foggaras dug in the region.

Figure 30: Ventilation well of the foggara of Sfissifa (Photo. Remini, 2014)

During our missions in the oasis of Brezina in the wilaya of El Bayadh, we learned that there was a foggara of the wadi according to the testimonies collected at the level of the Ksourian population. According to the waters, the foggara had 7 wells in the middle of the wadi and a length of approximately 1 km. Today, there is no trace of these foggaras that fed the oasis of Brezina. We have summarized in Table 6 the characteristics of the foggaras of the wadi.

Table 6: Characteristics of the wadi Foggaras

Foggara	Tindouf	Ahaggar	Sfissifa	Brezina
Aquifer exploited	Inferoflux	Inféroflux	Inféroflux	Inferoflux
Number of foggaras	1	200	2	1
Maximum length (km)	2 km	5 km	300 m	1000 m
Foggara flow (l/s)	variable	Variable	variable	variable
Distribution mode	Horly	Volumetric	Horly	Horly
Madjen type	Collective	Individual	Collective	Collective

Ain Foggara

We call any foggara that uses spring water a foggara of the Ain. 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 oasis of Moghrar has two Ain foggaras, 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 that represents the catchment well. It is equipped with a 300 m long, slightly inclined gallery and a single ventilation shaft. It flows permanently into the collective madjen located in the palm grove (Figs. 31 and 32). Thanks to an hourly distribution, the 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 that distribute the water in the gardens.

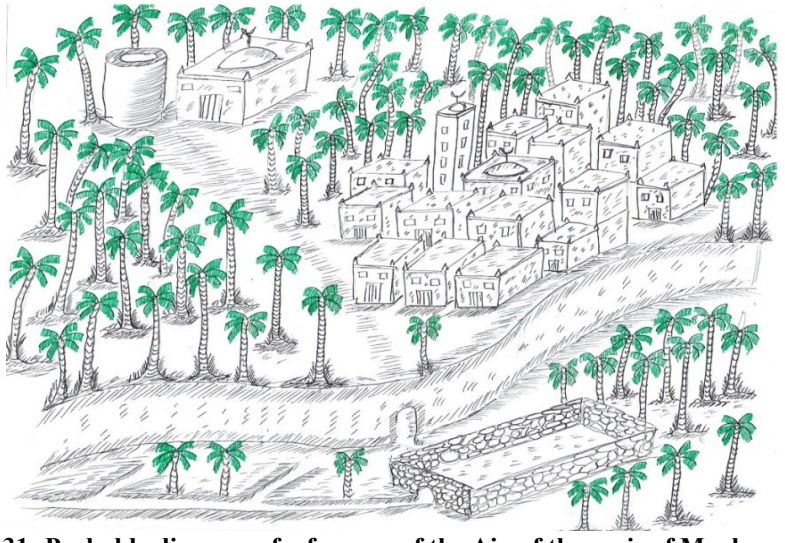

Figure 31: Probable diagram of a foggara of the Ain of the oasis of Moghrar (Remini et al, 2017)

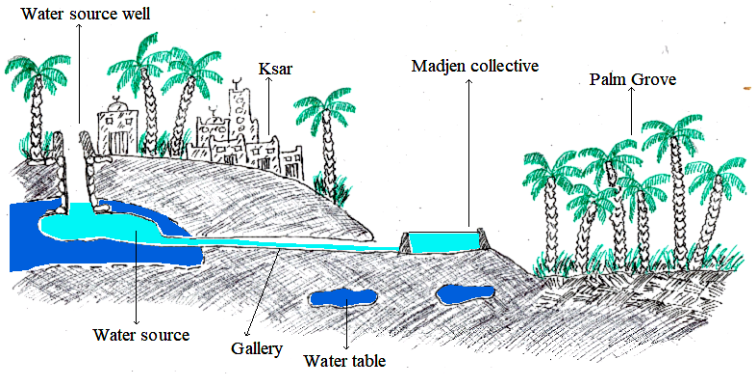

Figure 32: Diagram of a longitudinal section of a foggara of the Ain of the oasis of Moghrar (Remini, 2022).

Only one foggara of Ain is in the capital of the foggaras in the middle of the oases of Adrar. It is the only foggara that exploits a water source, unlike the hundreds of foggaras that draw their waters from the Continental Intercalaire. The oases of Adrar are known by their "Albian" type foggaras with the exception of the foggara of Hennou, which is a source foggara that 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 foggara of Hennou remains a particularity of the region.

In the oasis of Beni Ounif in the wilaya of Bechar, two foggaras of the Ain ensure the irrigation of the palm grove. These two foggaras exploit spring waters. Today, this source has dried up, and consequently, the two foggaras are abandoned.

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. These 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 exit 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. These foggaras drain the waters of the great source of Sidi Othmane, which come from the Grand Erg Occidental aquifer. With a total length of 12 km, the 65 foggaras of Beni Abbès irrigate a palm grove with an area of 400,000 m2 and a total water flow of 4 l/s. Today, these foggaras are dried up and abandoned.

In the oasis of Taghit, for more than 7 centuries, peasants have been exploiting the waters of the Grand Erg Occidental aquifer. For this purpose, 45 foggaras of the Ain were dug to drain the waters of the springs gushing from the Erg to reach the palm grove. In 2014, approximately 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 gallery of 100 m in length equipped with 3 ventilation shafts, and each of these two foggaras is intended for the irrigation of the gardens of the palm grove. Visiting the oasis

In the oasis of Sttiten, which is located in the Wilaya of El Bayadh, there were 11 foggaras of the Ain that exploit 19 water sources that are fed by water from the water table. These foggaras were intended to supply ksar and irrigate a palm grove made up of 640 gardens (Service du patrimoine Culturel, 2013). Today, there remains only one foggara of El Ain 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 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. Runoff water from the surrounding mountains recharges the water table and therefore feeds the source (Ain Sidi Aissa). In recent years, the flow of foggara has decreased considerably due to the lack of precipitation.

Other unidentified foggaras have been located but without traces in the wilayas of Menea, Boussaâda and Ouargla according to information from the population of the ksours. We have summarized in Table 7 the characteristics of the foggaras of Ain in the Algerian Sahara.

Table 7: Number of foggaras of Ain in the Algerian Sahara

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	11000 m (for 25 foggaras)
Mechria Esseghira	2	2x100 m
Stiten	11	1000 m
Ain Madhi	1	4000 m
Laghouat	9	-

Foggara or Tissanbadh of Mzab

More than 30 missions were carried out in the Mzab Valley during the period 1992-2022. We spotted two Tissanbadh (gallery) in the Mzab wadi; the first is at the entrance to the eastern palm grove of Ghardaïa on the seguia N'Bouchendjane called Tissanbadh N' Bouchendjane. The second is located in the Mzab River, 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 seguia Bouchendjane, which is located in the upper part of the Mzab River. Water sharing begins once the flood water reaches the level of Tissanbadh (foggara of Mzab). A dam with a width of 20 meters is arranged with 36 rectangular openings that are equipped with sliding gates. The 36 openings are equipped with sliding flat rock slabs (today made of steel), which, once the irrigation is finished or to avoid flooding in the palm grove, will be immediately closed (Fig. 33).

Figure 33: A general view of the Tissanbadh structure (Photo. Remini, 2014)

The waters, once they have crossed the 36 openings of Tissabadh, are distributed through the 6 underground galleries of different sections and flow toward the eastern palm grove of Ghardaïa (Fig. 34). The Tissanbadh openings make it possible to regulate flood waters and reduce the energy of the flow before entering the galleries. Each drain is sized according to the flow to be conveyed for the irrigation of the gardens. The flow 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 that have been operational for more than 7 centuries. The sixth gallery, which was intended for the irrigation of the palm grove of Chaabet de Toundja, never worked. The project to dig the drain at the bottom of the rock mass has not been completed. More than 40% of the gallery digging was carried out during 40 years of intensive work with rudimentary material means.

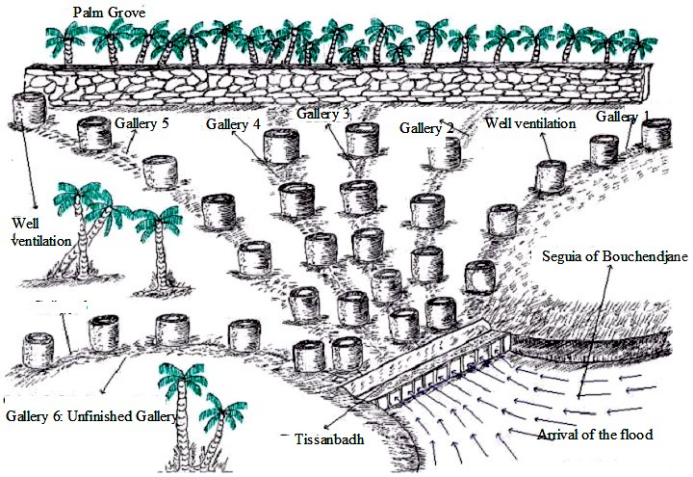

Figure 34: Synoptic diagram of the underground galleries (Tissanbadh) intended for the irrigation of the upper part (Bouchemdjane) of the palm grove - east of Ghardaïa (Remini, 2018)

Equipped with 38 ventilation shafts that can reach 40 meters in depth, the galleries of the foggaras of Ghardaïa present different sectional shapes (Fig. 35). 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 deposition of silt during high flows. Thirty-eight vertical wells are drilled vertically on the roof of the galleries, which ventilates the pipes to keep the surface flow free and thus prevent the bursting of the channels during floods. They also allow access to the gallery for the maintenance of the works.

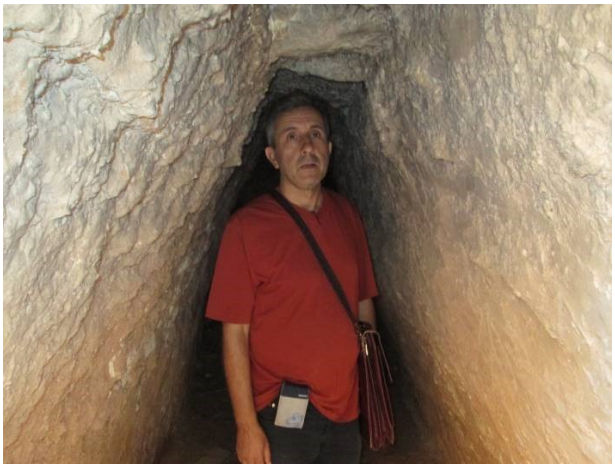

Figure 35: Galleries more than 1.5 meters high carved into hard rocks (photo. Remini, 2013)

Tissabadh (gallery) N'Takdimt (the foggara N'Takdimt) is intended for the irrigation of the western palm grove. It is composed of two parts: an underground gallery and an open channel (Fig. 36). The N'Takdimt foggara exploits the flood waters once stored in the reservoir formed by the rockfill dike 77 m wide and 1.5 m high built in the middle of the Mzab River. The water is channeled through an underground gallery 170 m long ventilated by 8 vertical wells 3 m deep and 1 m in diameter (Fig. 37). At the exit of the gallery, the water is drained by a seguia (open channel) 900 m long and 1.5 to 3 m wide, and then it will again be routed through a 50 m long gallery equipped with a single air shaft to reach the gardens. Once in the palm grove, it will be distributed among the owners by a network of seguia. An estimated flow rate of the foggara can reach 300 l/s for a major flood.

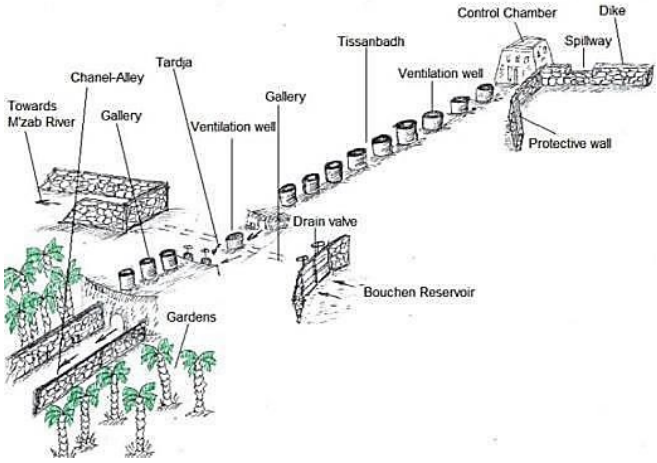

Figure 36: Tissanbadh (gallery) N'Takdimt fitted with two sliding valves (Remini, 2020)

Figure 37: Tissanbadh N'Takdimat ventilation well (Photo. Remini, 2011)

Foggara of the Ziban

In the oases of Chetma and Sidi Okba, we found hydraulic structures intended for the sharing of spring water between farmers. This work is very similar to that of the kasria of the oases of Adrar, Timimoun and In Salah. These dividers are called "kassem" in Arabic, which means the one who shares (Figs. 38 to 40). After an in-depth bibliographical search and several field missions, we did not find any traces of foggaras in the Zibans region. However, we remain convinced that the foggaras were dug in this region given the existence of the works of water sharing, which resemble the kasria of Adrar, Timimoun and In Salah.

Figure 38: A secondary spring water distributor in the oasis of Chetma in the Ziban region (Photo. Remini, 2017)

Figure 39: The main spring water distributor in the oasis of Chetma (Photo. Remini, 2017)

Figure 40: The large dam water distributor of Foum El Gherza in the oasis of Sidi Okba (Photo Remini, 2017)

DISCUSSION

The traditional vertical well is the most common technique for drawing groundwater in arid environments. All you have to do is tilt this well at an angle of 90° to obtain a horizontal well and thus change the dry environment into a humid environment. In this case, we are talking about the Algerian foggara, the Iranian qanât and the Falaj Omani. This gently sloping horizontal well drains groundwater in a continuous, uninterrupted fashion to the ground surface with zero energy. Thousands of oases have been created thanks to this ingenious hydraulic system. These oases, which are wetlands in a dry environment, have changed the Sahara Desert and made it more accessible. Over the centuries, these oases have played a great role in trade between different countries. This hydraulic system has upset traditional hydraulics and has simplified the collection of invisible water, but it has even made the presence of water continuous in palm groves and without interruption. The discovery of foggara in Touat quickly spread its knowledge to other regions of the Algerian Sahara. Thanks to the success achieved by the foggara, the Ksourian population quickly adopted this hydraulic system. She even adapted it to the environment and hydrogeology of each region of the Sahara. Thus, during our long journey in search of traces of foggaras in the Sahara during the period 2000-2022, we were impressed by the number of foggaras found outside the regions of Touat, Gourara and Tidikelt. This encouraged us to pursue this noble mission in the depths of the Sahara to the oasis of Ahaggar and Tindouf approximately 2000 km from the capital. For the first time, we classify foggaras according to the nature of the source of water captured. If the upstream part of the foggara constituted by the underground gallery is the same for all the foggaras identified, the downstream part of the foggara constituted by the water sharing and distribution network is different. To this end, we have highlighted two modes of sharing: volumetric and hourly (Figs. 41 and 42).

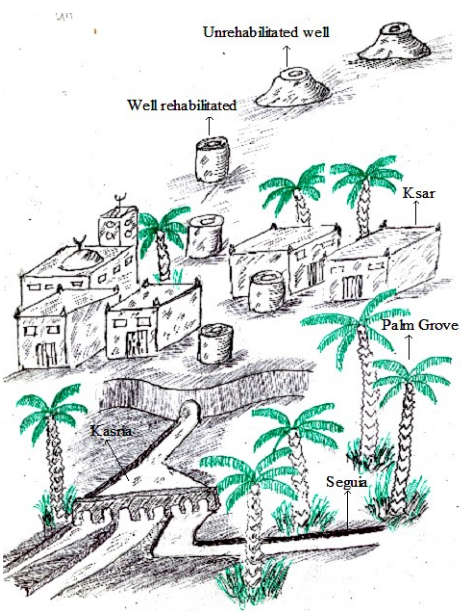

Figure 41: Diagram of a volumetric foggara (Remini, 2022)

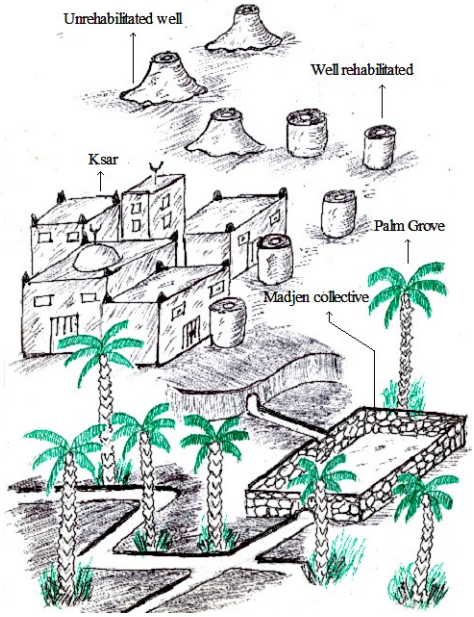

Figure 42: Diagram of an hourly foggara (Remini, 2022)

Only the oases of Adrar, Timimoun, In Salah, Tamanrasset and Ghardaïa have adopted volumetric sharing. Other regions, such as the wilayas of Bechar, Tindouf, El Bayadh and Naama, have adopted time sharing. Only volumetric sharing is more interesting since irrigation is done in parallel, that is, at the same time for all gardens. On the other hand, for time sharing, irrigation is done in series, i.e., alternately or simply garden after garden. This invention of the kasria made the volumetric foggara the most ingenious since the peasants could irrigate the gardens at any time (Fig. 43). On the other hand, for hourly foggara, the farmers irrigated only during the period allocated by the council of elders (Djamaa). Volumetric foggara is found only in the regions of Touat, Gourara and Tidikelt. For the two modes of sharing, we have identified approximately 2390 foggaras dug in the Algerian Sahara, which are distributed over the southwestern part and the extreme south of Algeria (Fig. 44). A classification of the foggaras was carried out according to the type and mode of sharing (table 8). This inventory gives an idea of the richness and diversity of the foggara system in the Algerian Sahara, but it does not reflect reality since this figure is far from the real value. According to the testimonies of ksour populations, many foggaras disappeared during the 1960s and 1970s for various reasons, particularly environmental and social reasons.

Figure 43: Secondary Kasria of the foggara of El Meghier in the Timimoun Oasis (Photo Remini, 2015)

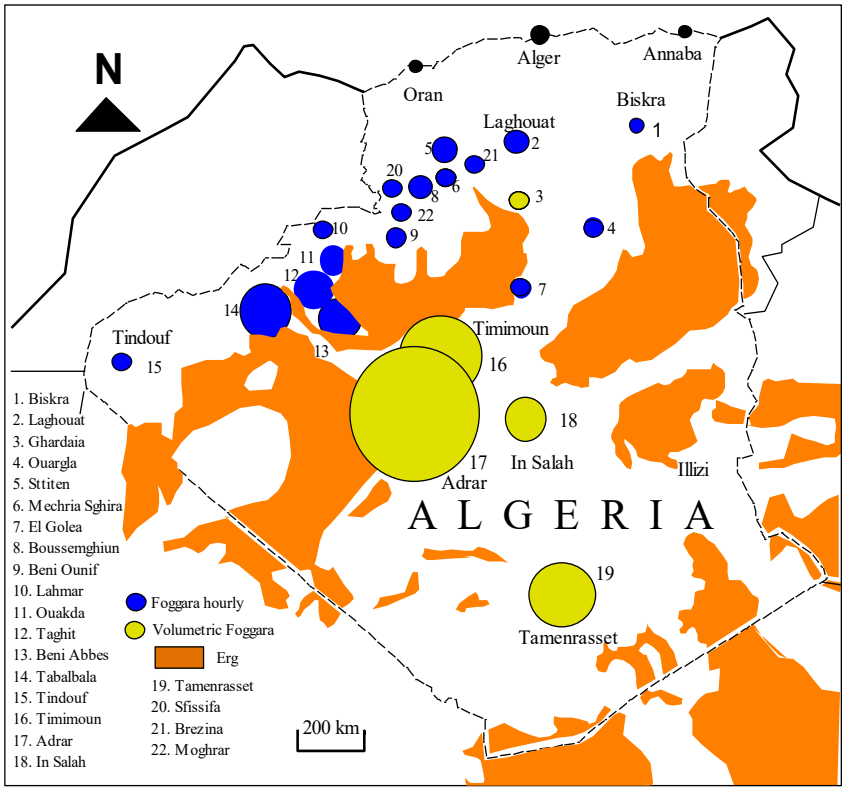

Figure 44: Map of the distribution of types of foggaras in the Algerian Sahara (Remini, 2022)

Table 8: Types of foggaras in the Sahara

Type of foggara	Name of the oasis	Number of foggara	Water source Aquifer
Albian Foggara	Adrar	1215	Intercalary Continental
	Timimoun	550	Intercalary Continental
	In Salah	50	Intercalary Continental
Foggara of the Erg	Timimoun	64	Grand Erg Occidental
	In Ghar	10	Erg of Miliana
	Ezzaouia	05	Erg of Ezzaouia
	Tabalbala	101	Erg of Erraoui
Kenadsa Foggara	Kenadsa	12	Source of Falaise el Berga
Garden Foggara	Timimoun	07	Infiltrations
Ouakda Foggara	Bechar	22	Phreatic tablecloth
Foggara of the wadi	Tamenrrasset	200	Inferoflux Tablecloth
	Tindouf	01	Inferoflux Tablecloth
	Sfissifa	02	Inferoflux Tablecloth
	Brezina	01	Inferoflux Tablecloth
Foggara of the Ain	Moghrar	02	Water source
	Hannou (Adrar)	01	Water source
	Beni Ounif	02	Water source
	Lahmar	04	Water source
	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
Foggara of the Mzab	Ghardaia	02	Wadi Mzab floods
Foggara of the Ziban	Biskra	-	-
Foggara of the Ouragla	Ouargla	-	-
Foggara of the Menea	Menea	-	-
Foggara of the Bou Saada	Bou Saada	-	-
Total		**2390**	

Today, out of the 2390 foggaras identified, only 350 foggaras are in service and are distributed in Table 9. That is, a rate of withdrawal of 85%, a very high value that reflects the acceleration of the degradation of the foggaras. It is time to reverse the situation and raise the number of perennials from 15% to 30% or 40% by saving the 350 foggaras in service and rehabilitating the degraded foggaras

Table 9: Foggaras in use

Oasis	Number of foggara	References
Adrar	203	foggara observatory
Timimoun	120	foggara observatory
In Salah	12	-
Moghrar	2	-
Ghardaia	2	-
Laghouat	1	-
Beni Abbes	3	-
Taghit	2	
Lahmar	1	
Beni Ounif	1	
Sfissifa	2	-
Sttiten	1	
Total	**350**	-

CONCLUSION

Impressively, more than 2390 foggaras have been inventoried nationwide. The foggaras were dug in the southwestern part and in the extreme south toward Ahaggar. Two modes of distributing water from foggaras have been established, namely, volumetric sharing and hourly sharing. A map of Algeria on the distribution of foggaras has been implemented with a table mentioning the characteristics of foggaras. This study showed the existence of a very rich and diversified hydraulic heritage of foggaras. We have implemented 9 types of foggaras. This shows that all water sources are surface water, groundwater, Albian aquifer, Erg aquifer, and inferoflux aquifer. Virtually all water sources have been tapped by the foggaras. From this study, we have deduced that the foggara system of the regions of Adrar, Timimoun and In Salah is original and different from the other types of existing foggaras in the 50 arid countries of the planet. It is the only region in the world that has used foggaras with a volumetric distribution network. It should be noted that the number of foggaras that we recorded during this study is far from the real number. This is due to social and environmental reasons. Today, it is time for this cultural heritage to be rehabilitated and protected.

ACKNOWLEDGMENTS

Approximately 30 years in search of foggaras in the Sahara of Algeria. This long journey into the depths of the most beautiful desert in the world allowed us to discover what our grandfathers achieved in difficult conditions. Throughout this paper, we apologize to our ancestors because we could not save what they did. Through this long journey, we discovered a magnificent, welcoming and unique population. It is thanks to this population that this study comes to an end. We can never give back to these people what they gave us. Through this modest paper, we would like to sincerely thank the Ksourian population, the owners of the foggaras, and the associations that campaign for the survival of the foggaras. Many thanks for the foggara. It is thanks to the foggara that we discovered a beautiful country: Algeria.

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.

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