DOI: 10.2478/jwld-2019-0010

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Section of Land Reclamation and Environmental Engineering in Agriculture, 2019
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JOURNAL OF WATER AND LAND DEVELOPMENT
2019, No. 40 (I–III): 97–102
PL ISSN 1429–7426, e-ISSN 2083-4535
Available (PDF): http://www.itp.edu.pl/wydawnictwo/journal; http://www.degruyter.com/view/j/jwld; http://journals.pan.pl/jwld

Received 06.07.2018
Reviewed 04.09.2018
Accepted 02.10.2018

A – study design
B – data collection
C – statistical analysis
D – data interpretation
E – manuscript preparation
F – literature search

The impact of using modern irrigation techniques on the ancient Mougheul palm grove, South-West of Algeria

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For citation: Rezzoug Ch. 2019. The impact of using modern irrigation techniques on the ancient Mougheul palm grove, South-West of Algeria. Journal of Water and Land Development. No. 40 (I–III) p. 97–102. DOI: 10.2478/jwld-2019-0010.

Abstract

To resist against a hostile environment, the oases of Saoura developed ingenious techniques of catchment and sharing of water to exploit the rare and precious waters of the groundwater. But the intervention of modern irrigation techniques has disrupted the entire oasis system inside the oasis such as the spring, the palm grove and the ksar. These techniques have overexploited the groundwater supplying the palm grove in terms of quantity and quality.

For centuries, the oases of Mougheul used only the source (with a flow of 25 $dm^3 \cdot s^{-1}$ in 2001) which is inside the oasis to irrigate the parcels and herds. After the year 2005, the state decided to supply the city of Bechar with drinking water through the catchment field of Mougheul through five modern boreholes, which had a profound impact on the oasis, its surroundings, and the whole artesian source.

In this work, we study the impact of the use of modern catchment systems on the water source and the life of the Mougheul population. By interviewing farmers and landowners about the impact of groundwater scarcity on the oasis. This allowed knowing the current state of the oasis and the reasons for its deterioration.

Key words: *irrigation, Mougheul, oasis, palm grove, seguia, traditional system, water source*

INTRODUCTION

The scarcity of the surface water in arid region pushed the man to exploit the groundwater. Various techniques of water catchment have been used for centuries. One technique that has marked the history of hydraulics is the qanat. On the Iranian origin [GOBLOT 1979], the qanat is called foggara in Algeria and the khettara in Morocco [LIGHTFOOT 1996]. Then it has been developed in more than 30 countries around the world, including Algeria [HOFMANN 2007]. The ksar Mougheul is among the ancient ksours of the Saoura region, located 50 km far North of Bechar, competing with the city, it is overcrowded for centuries. The palm grove of Mougheul and its ksar are fed by a single artesian source through an underground gallery, seguias and a storage pond (majen), according to the very complicated sharing rules inherited from their ancestors. The water of the spring is shared inside the oasiens by unit of kharrouba (unity of time in 45 minutes) well mastered from their side, through the Jmaa and Islamic customs respectable by all the citizens of the ksar [HEGUI 2018]. The oasiens of Mougheul have exploited well the waters of the aquifer and have managed the water sharing for centuries in an arid and hostile environment, but the intervention of the modern techniques of groundwater abstractions in an irrational way to disturb the operation of the traditional system of irrigation of the palm grove with an area of 80 ha and the supply of ksar in drinking water.

To meet the satisfaction and need for drinking water in the city of Bechar, technicians and decision-makers have exploited the waters of the Jurassic groundwater at Mougheul. The intense use of pumping at Mougheul has led to serious local problems and rapid drawdowns in static levels and drying up of the source [MEBARKI 2013].

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MATERIALS AND METHODS

CHARACTERISTICS OF THE STUDY AREA

Mougheul 50 km in the North-East of Bechar, it is among the oldest ksour populated in the Saoura (Fig. 1), ruled by semi-arid climate. It formed with the two ksour of Lahmar and Boukais, the three ksour of North Béchar. The commune of Mougheul is counted more than 900 inhabitants (2015) on a territory of 645 km^2. The palm grove has an area of 80 ha, it is now suffering from strong competition from the expansion of the urban fabric. The ksar is always downstream of the source of water, it is the amount of water supplied by the source that decides the number of inhabitants of the ksar.

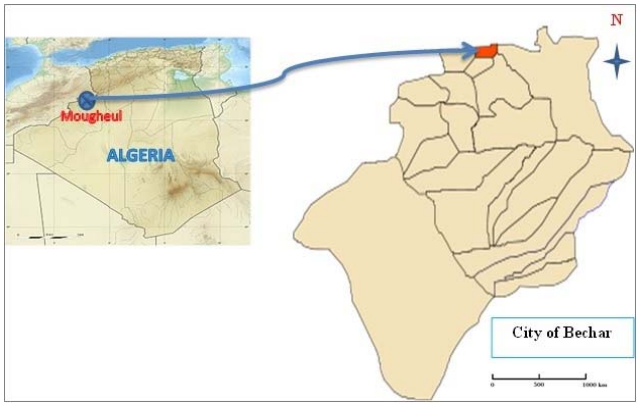

Fig. 1. Presentation of the study area; source: REZZOUG [2018]

The Saoura area is an arid region with hyper rainfall not exceeding 60 mm·year^{-1}. However, the region has a considerable potential in water. The Wadi Saoura which bears the same name as the region is considered the powerhouse of the region [REMINI *et al*. 2014a]. The Wadi Saoura follows the South-West part of the Great Occidental Erg resulting from the junction between the Wadi Guir and Wadi Zousfana at the Igli Oasis. From this confluence, the Wadi Saoura has an average width equal to 250 m, and traverses a length of 250 km, ending in the desert around Bouda in the Adrar region. On its way, several oases have been developed, such as, the oases of Igli, Beni Abbes, Guerguiz, Kerzaz [GUIDO 2005]. The Wadi Guir and Wadi Zousfana are two branches that feed the Wadi Saoura. This is the Wadi Guir that feeds the Wadi Saoura mostly. The Wadi Guir begins in the High Atlas (Morocco) and runs a length of over 350 km to the oasis of Igli. About 60% of the total length of this river is in Morocco. With the contribution of 200 10^6 m^3·year^{-1}, it feeds the bulk of the Wadi Saoura [MERZOUGUI *et al.* 2008].

In the upper the basin of Wadi Guir, the average annual precipitation measured at Tazouguert, Kadoussa and Gourrama, between 1052 and 1360 m altitude, does not reach 155 mm and annual rainfall rarely exceeds 300 mm. Despite this modest rainfall, the Guir sometimes experiences violent floods. At Tazouguert (2392 km^2 basin), from September 1961 to August 2007 (46 years of observation), average daily flows exceeded 200 m^3·s^{-1} over 9 years and peak discharge rates of 1000 m^3·s^{-1} at 8 years course. For these flows, the maximum values reached respectively 652 m^3·s^{-1} on November 15, 1993 and 3300 m^3·s^{-1} on September 25, 1962. Another major flood occurred on October 10, 2008: daily flow of 1397 m^3·s^{-1} and discharge of peak of 3000 m^3·s^{-1}. The flood peaks of September 1962 and October 2008 have a return period between 50 and 60 years [AÏT HSSAINE 2014].

The flows are generally determined by precipitation on the upper basin, breaking more or less downstream, many reach a closed basin: the Sebkha El Mellah, via the Wadi Es Souireg which go down to the North–West to the output of Fourn el Kheneg [REZZOUG *et al*. 2017].

THE CLIMATE

Mougheul is part of the North ksour which benefits from a less torrid climate than those of the rest of the region of Saoura. The winter is rigorous; temperatures fall below 0°C [SALMI, MAMMOUNI 2014].

Table 1. Interannual seasonal average rainfall at the Mougheul station of the Boukais sub-watershed

Period	Rainfall (mm)			
	autumn (Sep.–Nov.)	winter (Dec.–Feb.)	spring (Mar.–May)	summer (June–Aug.)
2008–2009	63.86	16.48	23.89	3.6
2009–2010	29.01	9.56	2.03	16.32
2010–2011	1.79	1.21	26.99	7.84
2008–2016	**31.56**	**8.56**	**18.20**	**8.12**

Source: SALMI, MAMMOUNI [2014].

COLLECTION AND SHARING OF IRRIGATION WATER

Water catchment

The oasis has taken advantage of an artesian source to irrigate the palm grove and to feed the population of the ksar with drinking water. It is a source of emergence as the water gushes from the bottom of a well, being closed precariously. Technically explained is groundwater subjected to pressure sufficient to rise above the bottom of a crack or an opening in the impermeable formation above the aquifer [REZZOUG 2018]. The oasis sprang water from a crack of the fault fed by the Turonian water. They used open channels (seguias) in earth and concrete, main and secondary to

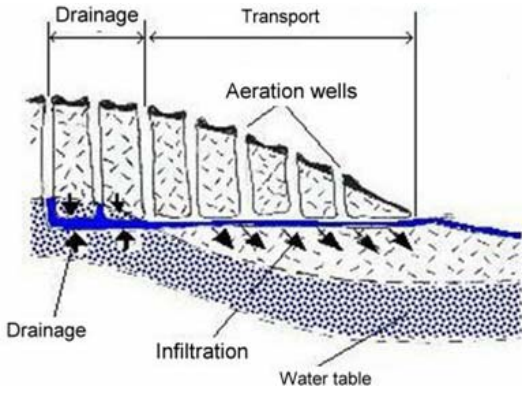

Fig. 2. Schematic of active and inactive parts of a gallery; source: REMINI [2016]

drive water from the source to the storage pond (majen) and these parcels. The flow of a foggara is a function of the length of the draining gallery, which is considered the true pump from the foggara. In this part, the wet section is usually full (Fig. 2). The length of the drainage portion is variable over time for a water table due to the variation in rainfall [REMINI *et al*. 2010].

Sharing water

The so-called "traditional" hydraulic system is based mainly on irrigation. The volume of water regularized by the source is a certain and undeniable attention by the inhabitants of ksar. In addition to the generally accepted and accepted rules of the Sharia law relating to the right of water (property, thirst, irrigation rights), local customs have established strict rules on property, sale, rental, surveillance and jurisdiction [REZZOUG 2018]. The division of the water is in the form of parts of water, it is according to the contribution of each proprietor in digging of the underground channels, the basin and the seguias, of their interviews and the payments of the workers (Fig. 3).

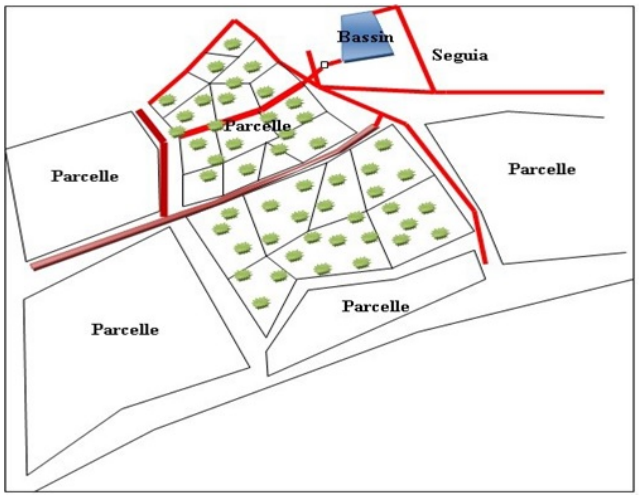

Fig. 3. Diagram of the majen and seguia of sharing the oasis; source: REZZOUG *et al*. [2014]

RESULTS AND DISCUSSION

WATER MANAGEMENT

There are rules governing the sharing and distribution of water from the source, depending on the size of the family, their contribution to the digging of underground canals and seguias, the construction of the water storage basin and the payments of water, maintenance fees. In our study area, the oasis of Mougheul used a unit of measurement to quantify the water share of each owner, this unit called kharrouba according to the time; it is estimated at 45 minutes for the oasis of Mougheul for all the water of the source (Photo 1).

According to a traditional way called the solar clock, which is a wall built at the entrance of the ksar Masjid to remain under the permanent control of the imam (Photo 2), it has a half spherical shape with nine pieces of wood of 10 cm

Photo 1. The water-sharing clock of the foggara; phot. *Ch. Rezzoug*

Photo 2. Placette of Nouaday for sharing foggara waters; phot. *Ch. Rezzoug*

as a semicircle rooted in this wall and a longer piece in the center of the circle. This main piece receives the rays of sun and throws them on the small pieces to determine the time of each kharrouba, when the shadow moves between two pieces of wood, it is the time of unit of measure.

During the whole day, there are practically 16 kharroubas, which are only concerned the daytime period, which poses a problem for the nocturnal, where the oasiens use another system of sharing according to the spring water storage basin in period night. To avoid the mandatory permanence of the owner in the night.

HOW TO DISTRIBUTE WATER FROM THE ARTESIAN SOURCE

Using time

With the expansion of ksar and the development of the palm grove, the water table has suffered a decrease and the drying up of some water sources. This new situation pushed the oasis to channel the waters of perennial sources by the foggaras [REZZOUG *et al*. 2016].

For the inhabitants of ksar de Mougheul, the instrument for measuring kharrouba time units is a solar clock, which is used to measure the 18 units of kharrouba during the daytime period (Fig. 4).

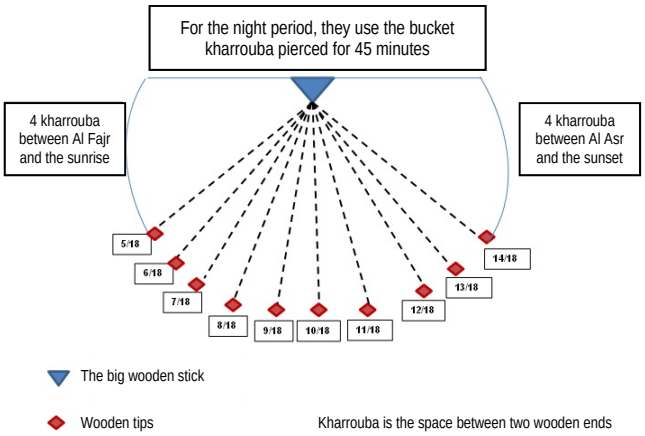

Fig. 4. Method of distribution of kharrouba waters in the day; source: REZZOUG [2018]

The beginning or the end of a part is executed by the transfer of the shadow of a big stick towards one of the wooden ends. This measurement technique was used, but today a simple watch does the trick.

The period between the Elfadjr prayer and the Maghreb prayer is equal to 810 minutes, which theoretically results in the duration of kharrouba 45 minutes with 18 kharroubas. To calculate the duration of the night period, we calculate the difference between 1440 min (24 hours) and 810 minutes (daytime period for 18 units of kharrouba), which is equal to 630 minutes, that is to say theoretically 14 kharroubas of 45 minutes.

Using the volume

The number of kharroubas available per source and therefore fixed, regardless of the flow rate of the source, but the amount of water corresponding to a kharrouba obviously differs depending on the flow rate of the source. The right of water thus defines a period of irrigation and not a quantity of water. In this way, the share of water enjoyed by the irrigator corresponds to all the water of the source during the number of kharroubas that constitutes his right (this system allows an adaptation of the use of the resource to the variations of the flow). This measure of the irrigation right in hour units is found in other oases [BISSON 1992]. As for the water tower, it marks the calendar frequency of access to the right of water of each user [HEGUI 2018].

The calendar organization in water tower and fixed individual schedules is an important constraint for irrigators, since they must use the water at one time and not at another; but it is also a guarantee: everyone knows when the water will be available and is guaranteed to have a share proportional to the quantity of available water. In order to free themselves from this fixed time constraint, the oasiens of Mougheul and Boukais built storage basins in the seguias network. The use of these ponds is an old practice. These basins of generally rectangular shape have volumes of 200 m³ [HEGUI 2018].

Volumes are not measured directly, but via water level variations in the basin (Fig. 5). Owners make these measurements by using a pole that they dive into the basin, the humidified part allows to measure the height of the water accumulated by all the parts during the night. In order to determine the height of water corresponding to a part, they divide (visibly or with the aid of a meter) the height of water thus measured by the number of parts stored in the basin. To avoid repeating this calculation every day, the height obtained by this calculation is marked on a wooden ruler also called kharrouba or memorized in number of fingers. The ruler or the number of fingers will serve as a standard. This standard allows to measure in volume (a kharrouba). The standard represents the drop in water level in a pond when one part of water is delivered [HEGUI 2018].

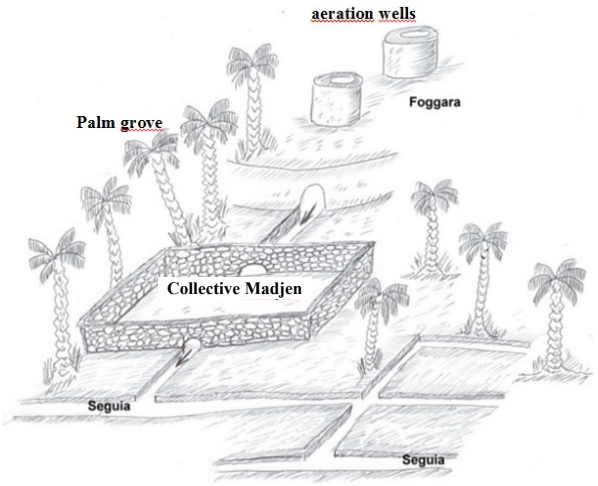

Fig. 5. Synoptic diagram of a sharing basin; source: REMINI *et al.* [2014b]

The causes of degradation of the oasis of Mougheul

The owners used the new techniques for water harvesting (wells for motor pumps, and drilling) and irrigation (drip and sprinkler irrigation). The transition to modern agriculture has been achieved to the detriment of oasis agriculture. The date palm with about twenty varieties has been replaced by vegetable farming. There are all kinds of vegetables and fruits [REMINI, REZZOUG 2018]

Due to population growth, rising living standards and, of course, the great development of the various sectors of the economy, the demand for water is constantly increasing [BENNADJI *et al.* 1998]. Added to this are the effects of climate change affecting the region, like all neighboring countries, which puts a lot of pressure on the region's water reserves, resulting in over-exploitation of these natural sources. In recent years, the over-exploitation of the aquifer has become alarming, the water withdrawals far exceed the natural recharge capacity of the aquifer, which has led to a remarkable deficit. Over the last two decades, the groundwater level has dropped 60 m, an average of 3 m per year. Thus, it is increasingly difficult to meet the water needs of the plain of Mougheul, several sectors suffer, including the agricultural sector. At present, many farms are unable to provide all of their water needs, to the point that some of them are forced to disappear.

With increasing urbanization, increasing population, climate change and the uncontrolled proliferation of motor

pumps, the level of the water table is lowered and water quality is degraded (Fig. 6). The old source has gradually been abandoned which leads to the degradation of the gardens and the old oasis. Nevertheless, they still mark the urban landscape today.

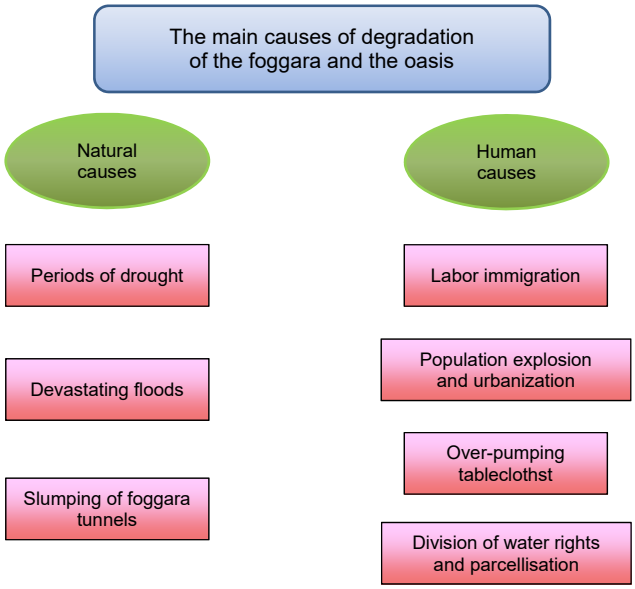

Fig. 6. The main causes of degradation of the foggara system; source: REZZOUG [2018]

SALINITY PROBLEM IN THE OASIS OF MOUGHEUL

The most important problem affecting the oasis is the large uncontrolled spread of the boreholes, which has caused the old and main source of water in the oasis to dry up. Today, the most important obstacle to agricultural development in the Mougheul oasis is the lack of irrigation water and the high rate of recent water salinity that has been imposed on most peasants to bring on the new plain off the traditional oasis to practice their agriculture, and the state's demand to build a water dam to provide water to their crops.

To study the impact of the irrational use of pumps on the soil salinity of the oasis, we focus mainly on the physicochemical analyses carried out in the oasis during two different periods, the first in 2007 before the drilling of the oases (Tab. 2). Water supply for the city of Bechar and the second in 2016 by the ANRH services of Bechar [ANRH 2016].

Compared to the results of the 2016 and 2007 analyses, we note an alarming increase in groundwater salt concentrations in wells and boreholes. The main causes of this jump are: overexploitation of water tables by motor pumps, abandonment of land inside the palm grove, lack of maintenance of gardens, exploitation of domestic wastewater in the irrigation. The rising increase in salinity of water and soils led to the total neglect of the oasis, which caused the loss of profitability of the palms, upon which the inhabitants of the oasis depend.

THE IMPACT OF DRILLING HOLES AT THE PERIMETER OF THE MOUGHEUL SPRING

According to MEBARKI [2013], the zone of influence of the boreholes installed at the perimeter of the oasis touches the water table which feeds the water source of Mougheul. This zone is the seat of a simultaneous pumping of all boreholes are found to cause undoubtedly intense interference resulting in a sharp increase in the drawdown in drilling this interference is most likely the main cause of the drying of the source of Mougheul. Before drilling at the oasis, the estimated flow of the source with the natural outlet of the aquifer is almost 25 $dm^3 \cdot s^{-1}$ in 2001, according to the December 2009 ANRH of Bechar, where the dryness of the Mougheul spring begins to be observed, until the total drying of the source after the completion of the third drilling F3 [MEBARKI 2013].

CONCLUSIONS

For successive generations, the oases have been able to cope with the harsh weather and hostile by operating a legacy irrigation system. It was compatible with rare and valuable water sources in the region through their rational use by a tight and complex technique at the same time. But after the irrational spread of modern boreholes equipped with large pumps inside the palm grove and its surroundings. What led to the massive drought of aquifers has had a profound impact on the oasis and the lives of its inhabitants. The irrational spread of modern boreholes (especially F3) in the oasis area has led to an increase in the salinity of groundwater and soils, which has greatly affected the profitability of the oasis.

To preserve the rest of the oasis, the efforts of all must be intensified to revive this great human heritage. The most important thing has been done in most palm groves is digging a single borehole and building a single pond with a collective distribution. Today, it is necessary for the state to work on restoring traditional irrigation systems and systems and to make farmers aware of their importance in maintaining the source of scarce water important for the survival of the oasis.

Table 2. Physico-chemical quality of water in the oasis of Mougheul

Year	Water source	pH	*EC* ($mS \cdot cm^{-1}$)	RS	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Cl^{-}	SO_4^{2-}	TH (°F)	TAC (°F)
				$mg \cdot dm^{-3}$								
2007	well	7.62	0.72	440	75	19	37	12.8	70	140	26	8
	borehole	7.52	1.41	870	88	49	130	5.5	221	280	42	10
2016	well	7.65	1.14	740	111	27	50	16.1	87	170	36	10
	borehole	7.58	1.70	1 328	169	72	251	9.7	290	401	69	12.3

Source: ANRH [2016].

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Cherif REZZOUG

Wpływ wykorzystania współczesnych technik nawadniania na dawny gaj palmowy w Mougheul, południowozachodnia Algieria

STRESZCZENIE

Aby przeżyć w nieprzyjaznym środowisku, w oazach Saoura rozwijano pomysłowe techniki gromadzenia i rozdziału wody celem eksploatacji ograniczonych i cennych zasobów wód gruntowych. Interwencja współczesnych technik nawadniania zniszczyła cały system oaz z ich źródłami, gajami palmowymi i osadami ludzkimi. Te techniki nadmiernie eksploatowały wody gruntowe zasilające gaje palmowe.

Przez wieki oazy w Mougheul wykorzystywały jedynie źródło (o wydajności 25 $dm^3 \cdot s^{-1}$ w 2001 r.) znajdujące się wewnątrz oazy. Po roku 2005 państwo podjęło decyzję o zaopatrywaniu miasta Bechar w wodę pitną z poziomu wodonośnego w Mougheul poprzez pięć współczesnych odwiertów, co miało ogromny wpływ na oazę, jej otoczenie i cały system studni artezyjskiej.

W pracy przedstawiono wpływ wykorzystania współczesnych systemów pozyskiwania wody na źródło wody i życie ludności w Mougheul.

Słowa kluczowe: *gaj palmowy, kanał nawadniający, Mougheul, nawadnianie, oaza, systemy tradycyjne, źródło wody*