International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 7, 2025
https://www.theaspd.com/ijes.php

The Status Of Traditional Irrigation Systems And The Impact Of Modern Systems In The Maghrar Oases, Southwest Algeria

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Abstract
The traditional water irrigation system is a fundamental element of oasis life in southwestern Algeria. The traditional management of water resources in the oasis of Moghrar Tehteni has been fundamentally questioned in public and academic discourse. Deep transformations in the social, cultural, and economic fabric, along with the demands of modern life, exert numerous constraints on oasis water resources.
The increasing need for irrigation water is generating an imbalanced water situation. As a result, modern irrigation systems such as boreholes and motor pumps have been adopted to meet these growing demands. However, the impact of modern irrigation systems on the oases includes the salinity phenomenon, drying up of foggaras and wells, and morphological changes in the oasis land. This study aims to provide an overview of the foggaras in the region and offer recommendations for the preservation and maintenance of this system as a shared heritage of humanity and history.
Keywords: *Irrigation systems, impact, Salinity, Management, Oasis*

1 INTRODUCTION

The development of water resources is one of the most crucial issues to be addressed in arid and desert zones. These areas, which sometimes contain vast reservoirs, comprise a series of aquifers of different ages and lithologies. These aquifers are part of extensive regional aquifer systems, including the Intercalary Continental and Terminal Complex aquifers.
They flow in relays from the Ksour mountains and the piedmonts of the Saharan platform. The Saharan Atlas, located 450 km south of Oran, is an elongated mountain range, 1,000 km long, running in a southwest-northeast direction. This succession of mountains forms a natural topographical and climatic barrier between the high plains and plateaus to the north and the Saharan platform to the south (Filali.(2011)).
Two major tectonic faults bound the Saharan Atlas: the North Atlas fault to the north and the South Atlas fault to the south. In the Algerian Sahara, several foggaras were constructed in the Ahaggar (Remini et al. 2014a, 2014b), in the Mzab valley (Remini et al. 2014a, 2014b), in the region of Naama (Hadidi et al. 2016).This environmental system gives rise to wetlands such as the Moghrar and Tiout oases, the only oases in the Nâama Wilaya, making them unique in their characteristics. The Moghrar oasis consists of the village of Moghrar Tahtani and the palm grove on its west side. The Oued Moghrar, which originates 46 km west of the village, runs through the middle of the palm grove. The total surface area of the palm grove is 45,144 hectares. The central part of the palm grove, located on the left bank, consists of nine blocks covering a total surface area of 36,121 hectares (80% of the total surface area of the palm grove).
In comparison, the secondary part on the right bank consists of three blocks covering a total surface area of 9 hectares (20% of the total surface area of the palm grove).

2 MATERIALS AND METHODS

2.1 Characteristics of the study area

The commune of Moghrar is the administrative centre of the Daira of the same name. It is located in the southern part of the Nâama Wilaya, at the southern end of the western high plains and the Saharan Atlas, covering an area of 1,792.50 km² (Fig. 1). It is bordered to the north by the communes of Ain Sefra and Tiout, to the south by the Wilaya of Béchar, to the east by the commune of Asia, and to the west by the commune of Djinien Bourezg. The population of Moghrar is 4,715, spread over an area of 1,792.5 km², resulting in a population density of 2.63 inhabitants per km² (MRE, 2020).

Fig.1. Presentation of the study area (D.P.S.B. Naama [2013]).

2.2 Hydrogeological setting

The Moghrar oases are bounded to the north by Djebel Bou Amoud (1,692 m) and Djebel Cheracher (1,726 m), to the east by Djebel Boulerhad (1,690 m), and to the southeast by Djebel El Haïmeur (1,337 m). Djebel Touzamet (1,370 m) borders it to the south. These djebels surround vast glacis and regs, with altitudes varying between 500 and 1,000 m, drained by a dense hydrographic network (claws of oueds), which join the Oued El Rhoubia. These areas are part of the commune of Moghrar.

Jurassic Aquifer: There are a few water points, but they have low flow rates. In this category, we would particularly mention the wellsprings and the Foggaras, which are 1 to 2 meters deep and are primarily exploited along the southern edge of the Sidi Brahim El Guerich dome. This corresponds to the right bank of Oued Namous, where the latter contributes to the recharge of this water table.

The Barremo-Albo-Aptian aquifer is the region's leading resource. It generally occupies topographical depressions, favouring rainwater and runoff's aquifer recharge. It is a reasonably large groundwater reservoir exploited by many water points.

Quaternary Aquifer: When large and powerful, the alluvial deposits of the main wadis serve as good reservoirs. Oued Namous has left significant alluvial deposits on the right bank, containing an underground water table primarily fed by floods and exploited by many water points used for garden maintenance.

2 .3. Geological setting

The Moghrar region is characterized by the Upper Jurassic, consisting of formations of dolomitic limestone, sandstone, and clay (D.G.F., 2003).

2.4 The climate

The climate of the Algerian steppe, which is one of the main characteristics of the Arid and Semi Arids Mediterranean regions, is the subject of several works, we cite in particular, those : Stewart (1946); Bagnouls and Gaussend (1957); Stewart (1968); Dubief (1959); Pouget (1980); Djellouli (1981); Djellouli and Daget (1987); Djellouli (1990); Le Houerou (1995); Benabadji and Bouazza (2000); AIDOUD ET AL (2006) and HIRCH and AL (2007) in (Haddouche, 2009). All show that the climate is a very important factor due to its preponderant influence on stepple areas and precipitation exert a higher action for the definition of global climate drought.

In this oasis is sub-arid to semi-arid. It has two main seasons: a freezing and rainy winter (23 mm) and a desert summer with almost no significant rainfall (3 mm). Rainfall is irregular (<160 mm/year) (ANRH rainfall data (2000-2018)), and temperatures are often high.The climate consists of a very cold continental half-year from November to March, with an average temperature of around 10°C, and a dry, very hot half-year in the summer, with an average temperature of approximately 15°C, influenced by the Saharan continental regime. During extreme summer, absolute maximum temperatures can reach 42°C or even 48°C in sirocco weather. Winds are frequent throughout the year, averaging 18 days per month. The dominant winds are northerly (north, northwest, northeast), accounting for 48% of the total frequency. Winds from the south (south, southeast, southwest) account for 31.4%, while winds from the west and east account for 16% and 4.6%, respectively (ONM, 2010).

3. RESULTS AND DISCUSSIONS

3.1. Irrigation system

- **Distribution and sharing of water in a Foggara**

The foggara system is divided into two parts:

- The drainage and transport part is standard for all Algerian Sahara foggaras.
- The distribution part comprises a network of seguias, which has two modes: distribution by volume unit (volumetric foggara) and distribution by time unit (hourly foggara).

Table 1: Distribution and sharing of water in a Foggara (Magister B.A thesis 2015)

Distribution Type of Foggara	Madjen	Location of madjen	The shape of madjen	Measuring instrument	Flow	The path network of seguias	Places for measuring water shares
Hourly foggara	Collective	Outside	same sections	water watch (Tassa) or sun watch (El Hadjra)	Not permanent	Same	ksar plot
Volumetric foggara	individuals	The inside	Various sections	two copper seals (the Hallafa or the Louh. The un of flow is the Habba)	Permanent	Various	At kasria level

This measuring system is widely used in the oases of Saoura, Tamanrasset, Tindouf, and Moghrar. Its principle is based on determining the filling time of the semi-spherical container through an orifice at the bottom of the capsule.

3.1.2. Traditional irrigation system:

The oasis has 65 wells used for irrigating the palm grove gardens. The unique hydrography of the area can be identified by the almost flat surface water concentration conditions, which explain the existence of numerous water tables (D.G.F., 2003). The water needs of the oases are met through the rational use of the foggara system. Water comes from springs and groundwater wells, which accumulate to replenish the reserves of vast deep and shallow aquifers. The deep aquifers are exploited through drilling, while the shallow ones are accessed by wells ranging from 4 to 30 meters deep. (Bellal et al. 2015).

Of the 60 traditional wells, 20 are operational (the others have been silted up due to flooding). For 100 families, each family spends 1 hour at the well and returns every 4 to 6 days. The production from the 8,000 palm trees grown on 40 hectares is between 3,000 and 4,000 quintals of dates per year. The crop intensification coefficient is 1.7.

It is important to note that, following the removal of the trees, the palm grove is now exposed to sandy winds. The Commission for the Agricultural Development of the Saharan Regions (CDARS) recently conducted a study on the grove's redevelopment. The grove has also benefited from a rehabilitation program following the silting caused by the exceptional flood of March 2008 (MRE, 2012).

- **Water management method:**

For the hourly foggara, the quantities of water allocated to the beneficiaries are grouped in the collective *madjen*, and their use is carried out. This quantity of water is translated into an irrigation time, which is measured by a water watch (*Tassa*) or a sun watch (*El Hadjra*), both of which are graduated on the number 24. Each beneficiary is assigned an irrigation period, which depends on their contribution to managing the foggara (maintenance and construction). The total of the irrigation times of all the beneficiaries must equal 24 hours (Remini B.2019).

For this type of network, the *seguias* (irrigation channels) have a constant cross-section and are built outside the gardens in the alleyways to efficiently manage the beneficiaries' irrigation periods (Fig. 2).

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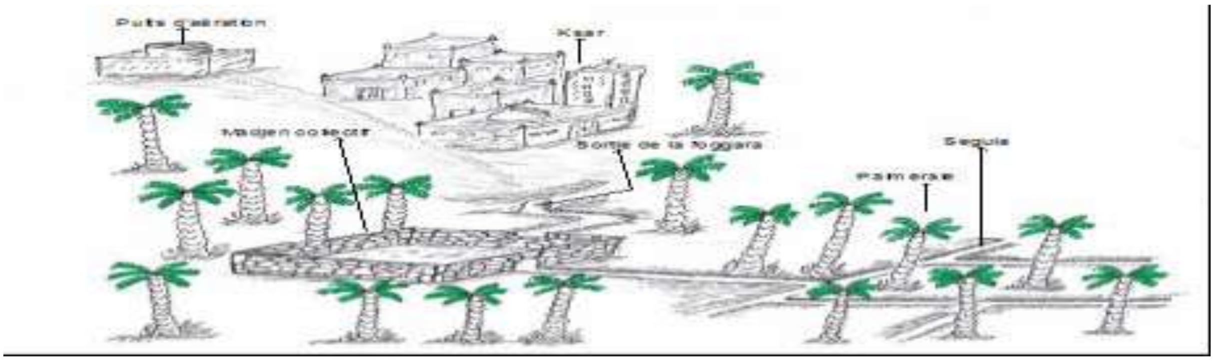

Fig.2. Synoptic diagram of a source foggara from the Oasis of Moghrar Tahatani (Remini, 2017)

The gardens are irrigated by the foggara system, with two major water sources: one in the upper part, *Ain Kebira*, and the other in the lower part, *Ain Sidi Bahouas* (Fig.3). The oasis farmers have adopted rules for sharing water between co-owners(Bellal et al. 2015; Rezzoug et al. 2016). The farmers agreed on the following principle: "The share of water is a function of the contribution of each co-owner."

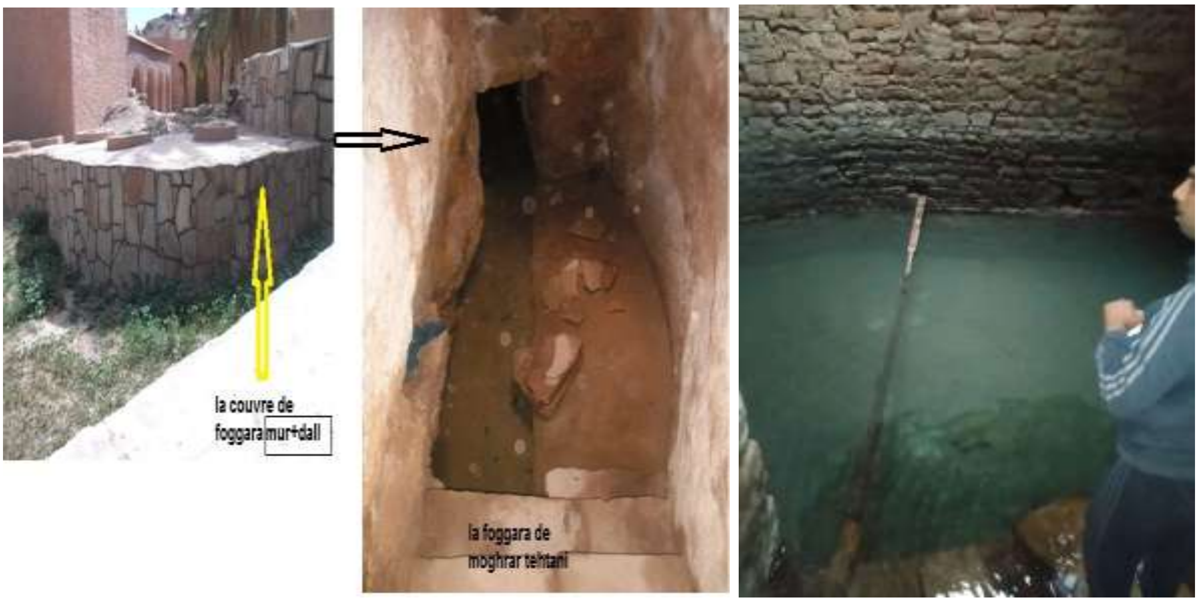

Fig 3. Foggaras from Moghrar spring (Boutera, A 2014.2021)

Distribution is carried out using the *khoroba* method, a large bowl filled with water and containing an open container at the bottom (H EGUI 2018). The irrigation cycle starts at a quarter of an hour and lasts up to 50 minutes. The water is divided according to each family's ownership, with watering occurring every six days, although some families receive their share after twelve days.

Fig. 4. Time is measured by the water watch (Tassa)(2014)

In addition to the *Mordjen* (or *Tassa*) method, other ancestral techniques for quantifying water shares were used in the oases we visited.
Used during daylight, *El Hadjra* (the stone) or *Saat Echems* (the sun watch), made from an engraved flat stone, is based on the principle of a watch. The watch contains 32 graduations in a semi-circle, with a nail (or wooden stick) placed at the circle's centre. The time taken for the nail's shadow to fall between two segments, each representing 5 minutes, corresponds to one part of the irrigation water. The number of graduations depends on the efforts made by the oasis farmer. One graduation represents one part of water, which exactly corresponds to the filling time of the *Tassa*. The operation of the sundial (*El Hadjra*) is based on the movement of the stick's shadow. This method cannot be used at night, even in winter.

For the hourly foggara, each share of water is quantified at the collective *madjen*. For the *El Foukania* foggara in Moghrar, the *madjen* is a rectangular basin measuring 6 meters in length and 1.2 meters in height. An opening at the bottom allows the water to flow towards the *seguias* (REMINI, ACHOUR 2017).

Fig. 5. El Hadjra sun watch (the stone) 2019

The opening is closed using *Mohguen* (a wooden stopper surrounded by a piece of cloth), attached to a stick about 1.5 meters long to make the task easier for the oasis dweller.

3.1.2. Modern Irrigation System:

- **Regulation Dam**

A 29-meter dike will be constructed to regulate or store floodwaters from Oued Moghrar in the vicinity of the palm grove, which may exacerbate the risk of flooding in the palm grove. The planned dike will have a total length of 35 meters (Fig6.7), a width of 1.50 meters, and a maximum height of 1.50 meters. The construction materials will include stone masonry with a reinforced concrete base, sails, and crest. Two 250mm steel strainer pipes will collect the water stored upstream of the dike (rapport d'intervention, 2007). These two strainer pipes will be connected to a strainer pipe by a 250mm diameter flanged T-junction, channelling the captured water to a 250mm solid pipe. This pipe will then convey the water to a collection and sedimentation chamber.

Fig 6. Regulation Dam 2021

- **Use of Solar Energy Systems**

Work on this project began in 2007 and was completed in 2012. To date, 40% of the date palms have been preserved. This project is being carried out to prevent water wasting from Oued Moghrar through drainage or evaporation and to improve water flow through the gutters in the oasis(Mahmoudi.2014).. It involves storing the water from the wadi in catchment chambers and redistributing it to the *seguias(Fig7.8)*.

Fig 7 : Projet de mobilisation des eaux d'oued de Moghrar (Mahmoudi.2014).

The additional water flow provided to the south of the palm grove by the project to transfer the water collected from the wadi is 4 litres per second (L/s). More importantly, this water is pumped using energy-powered pumps(rapport d'intervention, 2007). This method is an excellent alternative for domestic energy, utilizing the sunlight to produce electricity or heat. The sun's rays are captured by solar panels, which can convert the energy into heat, both heat and electricity or directly into electricity. Installing the pumping system will enable the effective startup and operation of the project to extend the Moghrar Tahtani palm grove. The objectives set by the project's initiators are:

- Increase the area planted with palm trees.
- Improve living conditions for farmers.
- Create jobs in our oasis farms.

Fig 8. Use of Solar Energy Systems 2021

➢ **New Agricultural Extensions at Moghrar**

An agricultural area of farmland has been created as part of homeownership initiatives. This phenomenon became more widespread in 1985/86, with the implementation of the law on access to agricultural land ownership in Algeria (A.P.F.A.). These areas were developed close to oases, on wadi spreading areas, or any land considered by farmers (*fellahs*) suitable for development (in the case of land outside agricultural perimeters), (Figure 5).

New oases recently created through development areas created within the framework of the APFA (Professional Forestry Association) with 13,189 hectares, allocated to 3,214 beneficiaries, where phoeniciculture is by no means the main source of support.

Initiation into the development of a type of development is perhaps the easiest role to define. It can be carried out in two ways:

- An explicit request for the application of development or the expression of a desire to create a development.
- A passive initiation linked solely to the consent of the farmer. Political/economic actors are aware of the farmer's needs and begin a selection process to meet the demand.

This agricultural area is vast in the Ain Ben Khelil and Moghrar zones (245,981 hectares and 141,189 hectares, respectively) and relatively small in Ain Sefra (53,262 hectares) and Tiout (59,510 hectares).

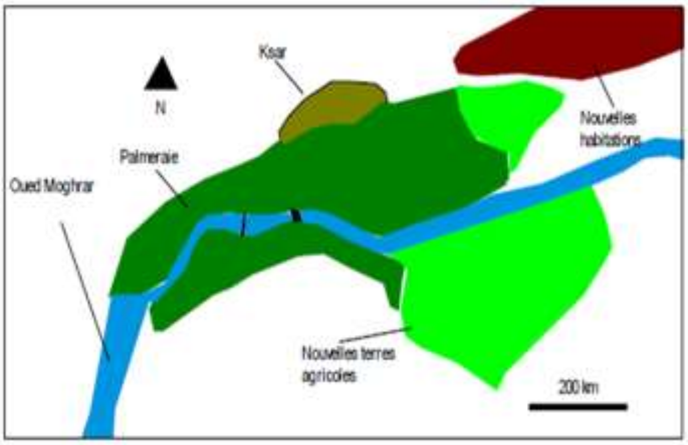

Fig 9.Location of the Moghrar palm grove about the wadi(Remini,2017)

3.2. The Impact At The Perimeter Of The Oasis.

The owners used the new techniques for water harvest-ing (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 ag- riculture. The date palm with about twenty varieties has been replaced by vegetable farming. There are all kinds of vegetables and fruits [REMINI, REZZOUG 2018]

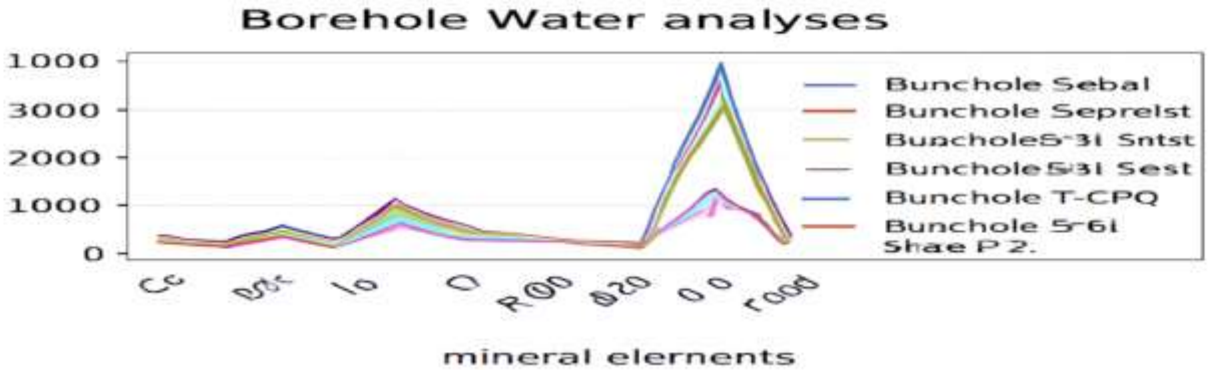

Fig10. The samples taken from the boreholes are drawn from the water table of the Barremo-Albo- Aptian complex.

a) The samples collected from the boreholes were collected from the Barremo-Albo-Aptian complex aquifer in the study area. Eight samples were analyzed at the ANRH (National Research Agency for Natural Resources) in Oran.

- Interpretation of measurement data and analysis results:
- Physicochemical characteristics:

➢ pH:

The pH of the Lower Cretaceous aquifer waters in our area varies between 7.3 and 8, which corresponds to waters with a basic pH. The highest values are found to be poorly mineralized and are located in the northern part of the syncline (upstream) due to downstream inputs.

➢ Total hardness:

Total hardness, or total hydrometric hardness, corresponds to the sum of the Mg++ and Ca++ concentrations and is given in French degrees. The hardness calculated for the waters of the Lower Cretaceous aquifer in our area varies between 37.9 °F and 93.65 °F. According to the standards, these waters are very hard.

- Mineralization:

Mineralization corresponds to the content of dissolved salts in the water, it varies between 567 mg/l and 3472 mg/l. The mineralization values show that low concentrations are found in the Zaouch region, the central part of the study area. Going northwest in the ES Sobai region, we notice the strongest mineralization of 3472 mg/l, immediately towards the southwest of the basin in the region near Sidi Brahim, the mineralization remains weak at 2860 mg/l, this increase probably due to Triassic upwellings along the major faults that cause the sandstone formations.
In the eastern part of the syncline, mineralization remains below acceptable standards; it does not exceed 1500 mg/l.

- Dry residue:

Dry residue values, ranging from 640 mg/l to 3220 mg/l, are high in the western part compared to the eastern part. The concentration decreases toward the center, with low values observed, varying between 640 mg/l and 880 mg/l.

- Water salinity:

The sodium adsorption coefficient S.A.R. : If the water is rich in sodium it can be fixed on the soil complex and then exert a defloching action, to appreciate the alkaline risk, we compare the concentration in Na+ ion+, that in Ca++ and Mg++:

S.A.R =

$$\frac{Na^{+}}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}}$$

Avec : Na^{+}, Ca^{++} et Mg^{++} en (meg/l)

Tableau 2 : Calculate and classification of alkaline risk have been defined, in relation to the Salin Risk:

Boreholes	Sebai	Nessissa	Sidi Brah P1	Sidi Brah(HCDS)	Sidi Brah P2	Sidi Brah (source)	Sidi Brah P3	Sidi Brah P4
S.A.R	12.19	39.75	12.53	4.66	11.64	44.56	47.18	14.88
Salin	Average	Very High	Average	Weak	Average	Very High	Very High	Average

The groundwater naturally loses its water through gravitational flow, springs, evaporation, and absorption by vegetation. However, today, human activities significantly influence the groundwater balance. The extraction of groundwater has a definite impact on the characteristics of the aquifers. When the pumping rate exceeds the recharge rate, the water volume decreases. As a result, the water depth, drawdown increase, and salinity levels increase. The deeper the well or borehole and the more powerful the pumping system (flow rate), the greater the drawdown around this point.

b) Analysis of a soil and water sample at the Western Regional Soil and Water Analysis Center 2023.

Table 3: Physico-chemical soil analyses
western regional laboratory for soil and water analyses2023

	pH	Ced 1/5 (ds/m)	$CaCO_3$ Total (%)	Organic Matter (MO) (%)	NAtotal	P2O5(ppm)
	6.5-7.5	<0.6	5-15	3 - 6	>0.15	180-220
P_1 h_1(0-30cm)	8.33	9.06	11.5	0.74	0.037	43
P_1 h_2(30-60cm)	8.47	4.44	14.9	0.52	0.026	39
P_1 h_3(60-90cm)	8.59	2.20	12.7	0.21	0.01	39

Table 4**:** Analysis of the irrigation water sample

	pH	CE (ds/m)	TDS (g/l)
Water	7.47	6.22	3.9

western regional laboratory for soil and water analyses2023

The results of the physico-chemical analyses of soil samples show that the soil in the parcel has an alkaline pH. The electrical conductivity of the diluted extract (Ced 1/5) is very high (Ced 1/5 > 6 dS/m: extremely saline soil). The levels of total limestone are moderate. The organic matter content is very low (MO < 1%). Concerning fertilizing elements (Nt and P2O5- Jorêt-Hebert), nitrogen content (Nt) is very low (Nt < 0.1%), and the assimilable phosphorus content (P2O5) is also very low (P2O5< 100 ppm). (Fig11,12)

The decline in the productivity potential of agricultural land is the result of accelerated soil degradation, which destabilizes the ecosystem and pulverizes the physical and physicochemical quality of the soil (Mrabet et al., 2008).

To address the pollution issue of the Moghrar Oasis, the water resources sector, aiming to combat the pollution of the old palm groves of Moghrar due to the discharge of polluted waters, has opted for the construction of an outlet for wastewater away from the site, in

addition to launching other actions likely to contribute to the protection of the environment and the oasis ecosystem in the region(En quête d'intérêt et de protection2014) .

According to the officials of the technical control body for hydraulic works and the study's designers, these actions involve correcting the river course and bed of Oued Moghrar, which is responsible for flooding and the degradation of large agricultural and orchard areas. Soil degradation in the arid zones of southwestern Algeria (Ksour mountain oasis) is concerning. Over 7 million hectares are directly threatened by desertification in Algeria (MATE, 2002).

What we observed during our visits to the oasis was the death of palm trees, resulting in a reduction in the number of orchards in the oasis. We conclude (Koller, 2004) that the introduction of foreign substances into the soil, water, and air alters the natural conditions of a site. When plants are exposed to very high concentrations of these substances, they develop disease symptoms or die. Using new production method through the development of modern agriculture has favored the implementation of new agriculture based on large monoculture exploitation and irrigation from powerful pumping means (Benaradj A, Boucherit H, Kadri A, Bouallala M.(2015)) . This large consumer system of energy and capital is the source of a low water supply, which results in a decrease or a drying up of the flow of the Foggara, the current oases are in the long time it is the whole oasian system which seems to be condemned if measures are not envisaged to safeguard the Foggara and with it an ecological, biological, social and cultural heritage. Subsistence agriculture in oases has converted to market agriculture.

The Moghrar region palm tree is already threatened by extinction. It is the main reason for the establishment of the population in the region. The disappearance of this tree will generate sociological, economic and ecological problems, limit input and introduce areas of conflict such as disputes over the right to water between villages and new users. Traditional water distribution techniques are being lost, while the oasis communities are gradually disintegrating (Hadidi, A., Remini, B., Habi, M., & Saba, S. (2018)).

Fig11 . The state of the wells in the Moghrar oasis: Salit and pollution 2021

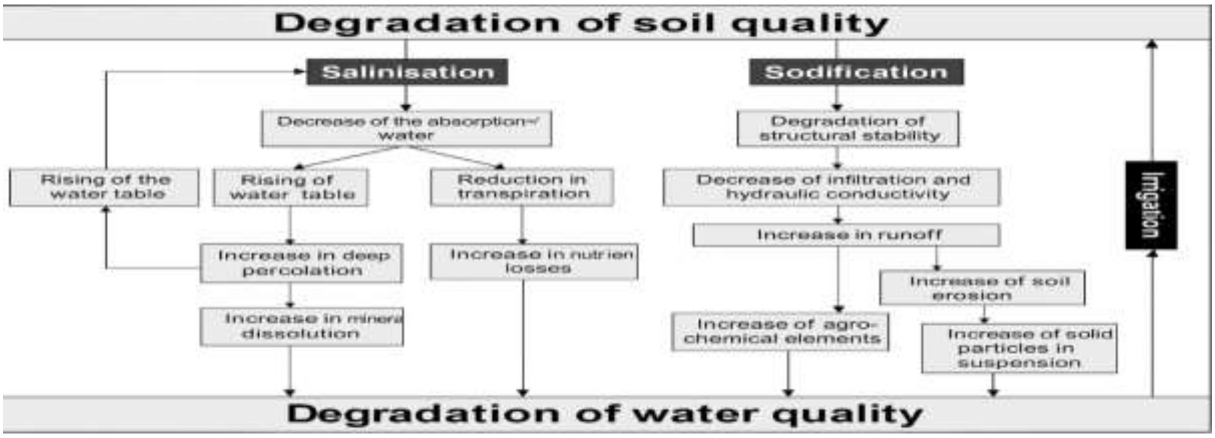

Fig12. Soil quality degradation process following irrigation. (Lahlou, M., et al. (2000).

5. CONCLUSION AND RECOMMENDATIONS

The rapid and extensive deployment of modern wells equipped with large pumps within and around the palm grove has led to the drying up of groundwater aquifers, which has had a profound impact on the oasis and the lives of its inhabitants.

The results of soil and water analyses indicate a serious salinity issue, particularly in the farm's soils. This salinity can hinder plant emergence and cause significant damage to crops, especially salt-sensitive crops. Regarding the salinity of irrigation water, the water sample analysis reveals that it is severely restricted for irrigation use. It should only be used with great care on light, well-drained soils and salt-tolerant crops (e.g., palms, barley). Leaching is essential. Therefore, it is advisable to conduct periodic soil salinity analyses (once a year) on plots irrigated with this water to monitor changes in soil salinity. The installation of a drainage system should be considered in all development projects. The intensity of salinization is linked to the quality of the irrigation water used. Soil salinization in this region is related to climatic conditions and poorly controlled irrigation practices. According to the Food and Agriculture Organization (FAO, 1996), most salinity and sodicity problems are associated with irrigation systems, and drainage should always be part of the design of an irrigation system. The rate of salinization accelerates significantly in the absence of drainage (Fereres, 1983). To address salinity at the plot level, the following approaches should be prioritized:

A drainage network must be installed to leach salts away from the root zone.

- The use of organic and mineral soil improvers enhances the soil's physical and chemical fertility
- Choosing a water-efficient irrigation system (e.g., drip irrigation).
- Choosing salt-tolerant crops (e.g., date palms).
- The use of acidifying fertilizers lowers the soil's pH and prevents the immobilization of certain elements such as iron, phosphorus, manganese, boron, zinc, and copper. These fertilizers should be nitrogen—and phosphate-based.

To mitigate the threats of salinity and drawdown, we recommend:

- Protecting water catchment areas and hydraulic structures: Tools for preserving hydraulic capital.

The pollution issues mentioned above raise the unavoidable question of protecting water tables, catchment areas, and hydraulic structures from the harmful effects of pollution. This requires the simultaneous management of land use and the implementation of groundwater quality objectives.

The purpose of the close perimeter is to protect the water table. It entails several restrictions, which vary according to the hydrogeological characteristics: spreading less fertilizer, treating agricultural effluent, avoiding independent sanitation, restricting industrial activity, and so on. In short, it prohibits anything that could harm the quality of the resource.

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