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THE IMPACT OF AGRICULTURAL DYNAMICS ON THE AQUIFER IN THE OUED SOUF REGION

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ABSTRACT
The Oued Souf region in southeastern Algeria, characterized by an arid and semi-arid climate, relies heavily on groundwater for its socio-economic and agricultural activities. Over recent decades, agricultural practices, particularly the adoption of pivot irrigation systems, have facilitated a transformation from subsistence farming to intensive commercial agriculture. This shift has resulted in the overexploitation of groundwater resources, notably from the phreatic aquifer, with observed water aquifer declines of up to 30 meters between 2016 and 2021. The study highlights the region's reliance on three main aquifers—phreatic, Complex Terminal, and Continental Intercalaire—with the shallowest aquifer being the most impacted by overuse.Through field surveys, interviews, and piezometric analysis, the research identifies key drivers of groundwater depletion, including inefficient irrigation practices, unregulated well drilling, and extensive agricultural expansion. Despite advancements in irrigation technology, traditional practices and socio-economic pressures contribute to unsustainable water management. The findings underscore the need for efficient water use strategies and regulatory frameworks to ensure the long-term sustainability of groundwater resources, which are critical for the region's economic development and food security.

Keywords: Oued souf, Agricultural practices, groundwater, overexploitation, irrigation, food security

Introduction

Oued Souf, characterized by its arid and semi-arid climate, relies heavily on groundwater as its primary resource. However, the decrease and rise in groundwater levels in the study area are primarily attributed to human activities, with agricultural activity being the leading activity (Barkat et al., 2022). Algeria has implemented large-scale pivot irrigation systems modeled after the Californian design, initially introduced by American companies in regions such as Ouargla and Adrar. These systems, capable of irrigating 30 to 50 hectares at a time, were initially costly and complex but inspired widespread adoption across the Algerian Sahara. A prominent example of such a system stands at the entrance of Oued Souf.

The people of Oued Souf recognized the potential of these pivot irrigation systems and adapted them to their local context. They constructed smaller, makeshift machines capable of irrigating 1/4 to 1/2 hectare using locally available materials such as steel cables, car bearings, and salvaged gears. Only the sprinklers were specialized components. Only the sprinklers were specific. These pivots, comprising a double articulated arm, have their two ends bent, and turn under the sole pressure of the irrigation water sent by the motor-pump (Cote, 2006).

In the early 1980s, the Algerian government launched the A.P.F.A. 18/83 program, which granted land ownership to individuals who developed it. This marked the beginning of a transformation in the date palm industry and the emergence of an "evolved oasis system" gradually replacing the traditional Ghout-based oasis model. The modernization effort continued with the National Agricultural Development Program (PNDA) in 2000, which provided substantial financial support to new farms. These initiatives emphasized intensification and rationalization of agricultural production.

systems Souf craftsmen carried out a process of innovation from an imported traditional pivot (Januel, 2006). Where knowledge was obtained through practice (Rebai et al., 2017), innovating the irrigation system (axial drive pump), and adapting to local conditions. Among the determinants of the development of agriculture in the Souf region (Ouendeno, 2019), each farm has its own well and automatic pump, and large farms often contain many pumps and wells with sounding rods (Cote, 2006).

Over the past few decades, Oued Souf has transitioned from subsistence farming to commercial agriculture. This shift, combined with the expansion of agricultural land, has significantly increased the extraction of water from deep aquifers (Remini, 2006). This transition represents an agricultural revolution, accompanied by advancements in technology such as bulldozers and motor pumps. Currently, approximately 75% of potato cultivation in the region is conducted using pivot irrigation systems, with the remainder utilizing sprinklers or drip irrigation methods (Cote, 2006).

The latter is mainly due to an overexploitation of the groundwaterby the new market gardening revolution, among other things the cultivation of potatoes, for which a drop in the water table has been, recorded (Laghrissi, 2012). According to the study of the management of water resources and their estimation in the agrarian space of El Oued, there is overexploitation and waste of the resource in irrigation water and the groundwater suffers from intense withdrawals exceeding its recharge (Meissa, 2016). The pivot irrigation system practiced in El Oued has contributed to the overexploitation of the groundwater through unsuitable irrigation schedules (Meissa, 2016).

Unequivocally, irrigation is the determining factor of agriculture in Oued Souf (Nichane, 2015), earning the region the title "El Dorado" of Saharan agriculture. Despite limited resources, Oued Souf has become a leading national producer of crops such as potatoes, peanuts, dates, tomatoes, and olives. Access to land has been another critical driver of agricultural expansion. Historically rooted in Saharan customs, the principle of granting land ownership to cultivators was formalized during the agrarian revolution of the 1970s. This policy, outlined in the Charter of the Agrarian Revolution and Ordinance 71–73, emphasized the principle that "land belongs to those who work it" (Official Journal of the Algerian Republic, November 1971).

Although these rules have had a positive impact on the spectacular extension of the irrigated area in Oued Souf, they also constitute a danger for the uncontrolled exploitation of agricultural land, which will be difficult to control in the future by the agriculture department (Mani, 2014). This study aims to assess the impact of agricultural practices on groundwater depletion, focusing on the modern pivot sprinkler system. This system has contributed to groundwater flooding and unregulated drilling of individual wells, raising concerns about the sustainability of water resources in the region.

Study area

The study area, Oued-Souf (Fig. 1), lies within the arid Grand Erg Oriental Basin in the northeastern Algerian Sahara. Geographically, it is located in southeastern Algeria, within El- Oued province, between latitudes 32°30′00″ and 34°12′00″ N, and longitudes 6°15′00″ and 7°20′00″ E. From an administrative point of view, Souf oasis includes 18 of the 30 municipalities within this province (Khechana and Derradji 2014). The study region is bordered to the north by the salt lake zone (Chott Melrhir and Chott Merouane), to the south by the dunes of the Great Oriental Erg, to the west by the

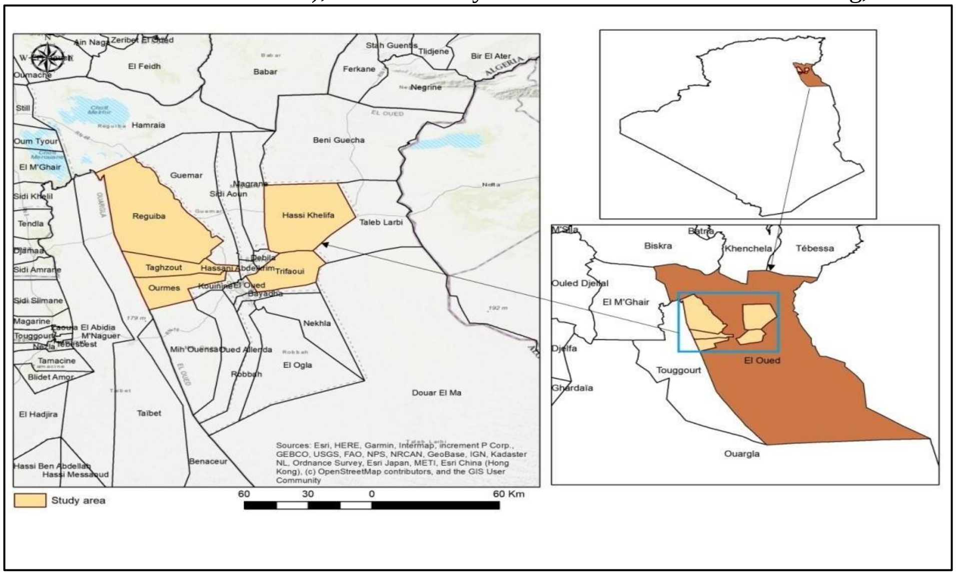


Fig. 1. Study area location Geology and hydrogeology

Oued Rhir Valley, and to the east by the Tunisian border. In 2015, the population of this oasis exceeds a half million who mostly live in a group of major cities in the region (Khezzani and Bouchemal 2017). Agriculture is the primary activity in the region, originally focused on date palm cultivation. However, in recent years, it has expanded to include other crops such as potatoes, olives, wheat, and various types of vegetables. El-Oued region is diversified between a hot and dry summer and a mild winter, making it very similar to other regions of the Algerian Sahara (Dubief 1959). Based on climatic research by (Barkat et al , 2023), which analyzed 42 years of data (1978–2020) from the Geumar meteorological station in Oued Souf, the study area is characterized by a prolonged dry period throughout the hydrological year and a bioclimatic stage of Saharan vegetation. The research covers five municipalities (Hassi Khalifa, Trifaoui, Taghzout, Ourmas, and Reguiba) situated within the study area, as shown in Figure 1.

The geological formations of southern Algeria host two principal aquifers that belong to the North Sahara Aquifer System (SASS): the Continental Intercalaire (CI), the deepest aquifer, and the Complex Terminal (CT) aquifer, which lies above it. These aquifers hold the largest water reserves in the region. However, harsh climatic conditions characterized by low rainfall, high temperatures, and significant evaporation indicate a negative water balance, with minimal recharge of the aquifers in southern Algeria. These aquifers hold the largest water reserves in southern Algeria. The region of study is part of the Northern Sahara Sedimentary Basin, which covers an area of 780,000 km^2 (Kilian 1931; Cornet and Gouscov 1952; Cornet 1964). In the Souf oasis, groundwater is the only water resource available for all kinds of uses (Chebbah and Allia 2014; Drouiche et al. 2013). From a hydrogeological perspective, the three distinct aquifer systems being utilized (Fig. 2) vary in depth and physicochemical characteristics (Khechana et al. 2011; Messekher and Menani 2010; Meziani et al. 2011). They are, respectively from top to bottom: the phreatic aquifer, the Complexe Terminal aquifer, and the Continental Intercalaire aquifer.

The Phreatic aquifer is the shallowest one, with a depth fluctuating from 1 to 40 m, with a thickness of 100 m (Guendouz and Michelot 2006).

The Complexe Terminal formations, which are heterogeneous, lie between the phreatic aquifer and the Continental Intercalaire aquifer. The depth of this aquifer is between 100 and 600 m and its mean load is 300 m (Guendouz ; 2006). It is confined within the limits of the investigated area and extends over the major part of the northern Sahara basin (∼350,000 km^2) (Paix 1956; Bel and Cuche 1970; Bel et al. 1970; UNESCO 1972).

The third and deepest aquifer, known as the Continental Intercalaire (CI) aquifer, is found within the Lower Cretaceous formations (Table 1) . Its depth reaches locally 2000 m while its thickness ranges between 200 and 400 m (Bel and Demargne 1966; UNESCO 1972). Water from this aquifer is harnessed for drinking purposes and is estimated to be at least 20,000 to 30,000 years old (Cornet, 1946).

Fig. 2. Hydrogeological cross-section illustrating the aquifers within the study area (UNESCO 1972).

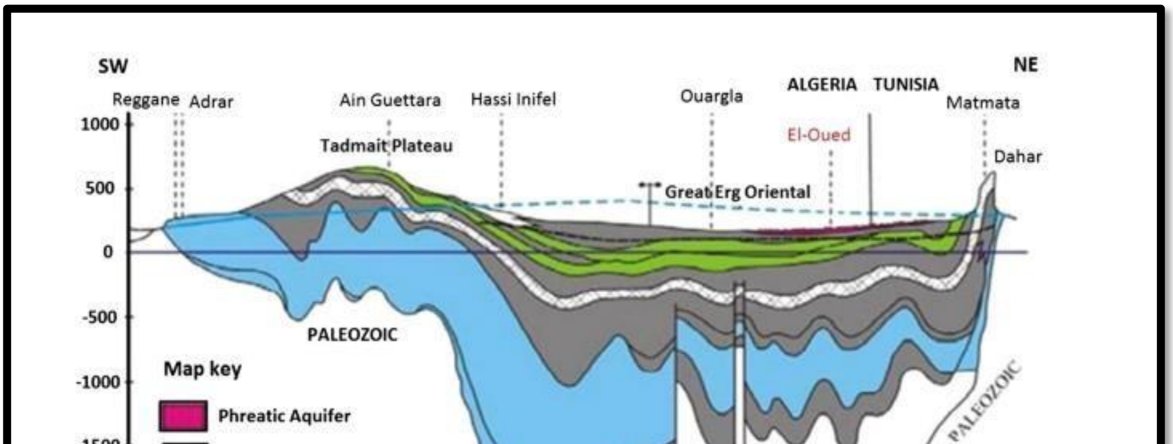


Table 1 : Local hydrogeology and stratigraphy of the Souf oasis (Ben Hamida and Ben Zeguir 1993)

Era	Period	Sub period	Epoch	Lithology	Hydrogeology
Cenozoic	Quaternary		Holocene	Sand	Phereatic aquifer
			Pleistocene	Clay, evaporite	Impermeable substratum
	Tertiary	Neogene	Pliocene	Sand	1st Sandstone aquifer (CT)
			Miocene	Gypseous clays	Semi-impermeable substratum
		Paleogene	Oligocene	Sand, gravel, sandstone	2nd Sandstone aquifer (CT)
			Eocene	Laguna clay	Impermeable substratum
			Paleocene	Dolomite, calcareous	Calcareous aquifer (CT)
Mesozoic	Cretaceous	Upper	Upper Senonian		
			Lower Senonian	Clay, evaporite	Impermeable substratum
		Middle	Cenomanian	Clays, marl	
		Lower	Albian	Sand, sandstone	Albian aquifer (CI)

Materials and methods

The study employed a descriptive-analytical approach and was conducted across five municipalities: Hassi Khalifa, Trifaoui, Taghzout, Ourmas, and Reguiba, which are key agricultural producers, particularly for potatoes. Field surveys and interviews with 120 farmers were carried out, and data on well depths, water usage, and farming practices were collected and analyzed to evaluate fluctuations in groundwater levels. Results indicated that approximately 70% of potato production is concentrated in these five municipalities, while the remaining 30% is distributed across 25 other municipalities within the wilaya of Souf.

Results and Discussion

Phreatic Groundwater Static Level Fluctuation

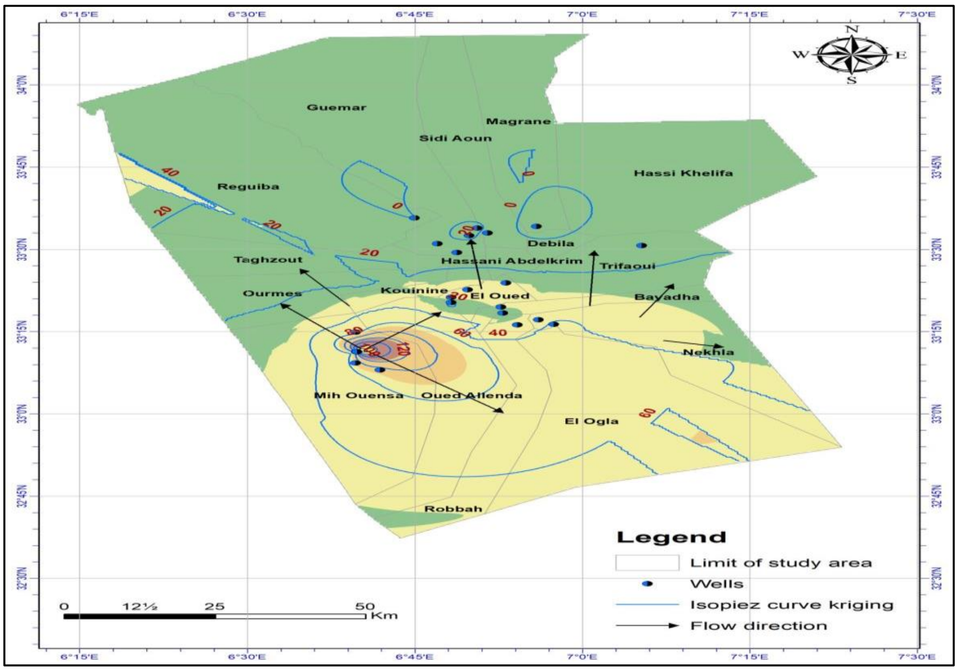


Fig. 3. Piezometric map of the phreatic aquifer in the study area (2016)

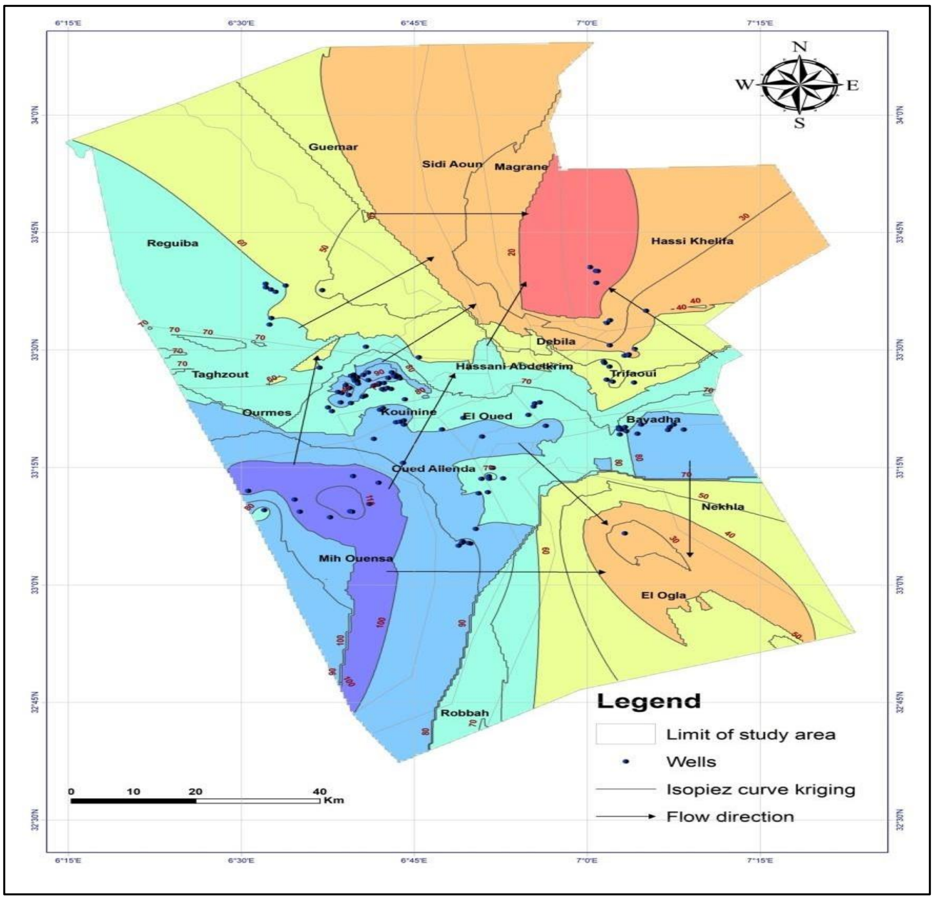


Fig. 4. Piezometric map of the phreatic aquifer in the study area (2021)

The piezometric measurement campaign carried out in 2016 by ANRH in the Souf region shows that the resulting piezometric map (Fig.3) lacks detail compared to the one from 2021. However, both maps exhibit similar patterns, with the groundwater flow direction consistently oriented towards the southeast and northeast.

The 2016 piezometric map (Fig.3) shows piezometric levels ranging from 0 to 160 m.The general flow direction is primarily oriented towards the southeast (e.g., from Mih Ouensa to Oued Allenda and Robbah) and towards the northeast (e.g., from El Oued to Trifaoui and Hassi Khalifa). The central area around Mih Ouensa shows a significant concentration of piezometric contours, with high values reaching 160 m. This indicates an important cone of depression,

likely caused by excessive pumping or intensive exploitation of the aquifer. The peripheral areas display more widely spaced piezometric contours, indicating a lower hydraulic gradient and slower groundwater flow.The map highlights overexploitation of the aquifer in certain areas, particularly around Mih Ouensa, where the water level has significantly dropped. The regions of Trifaoui, Debila, and El Oued could face water resource challenges due to the progressive depletion of groundwater reserves.

The 2021 piezometric map (Fig.4) indicates piezometric levels varying between 0 and 110 m. The main groundwater flow appears to be oriented toward the northeast and southeast, following the hydraulic gradients.

Zone 1 (Mih Ouensa): This area shows low piezometric levels, likely indicating a depression cone caused by intensive exploitation or a lack of recharge.

Zone 2 (Hassi Khelifa and El Ogla): Here, the higher piezometric levels suggest the presence of natural recharge zones or lower exploitation pressures.

The Mih Ouensa region exhibits particularly low piezometric values, indicating significant overexploitation of the aquifer. Conversely, areas such as El Ogla and Nekhla show relatively high piezometric levels, which may point to natural recharge or reduced water extraction. Depression zones, notably at Mih Ouensa, reflect excessive groundwater exploitation. Finally, the variable hydraulic gradients directly influence the groundwater flow velocity across the region.

The observed decline in groundwater levels ranged from 40 meters in 2016 to 70 meters in 2021. The study's findings indicate a reduction of approximately 30 meters in groundwater levels over this period.

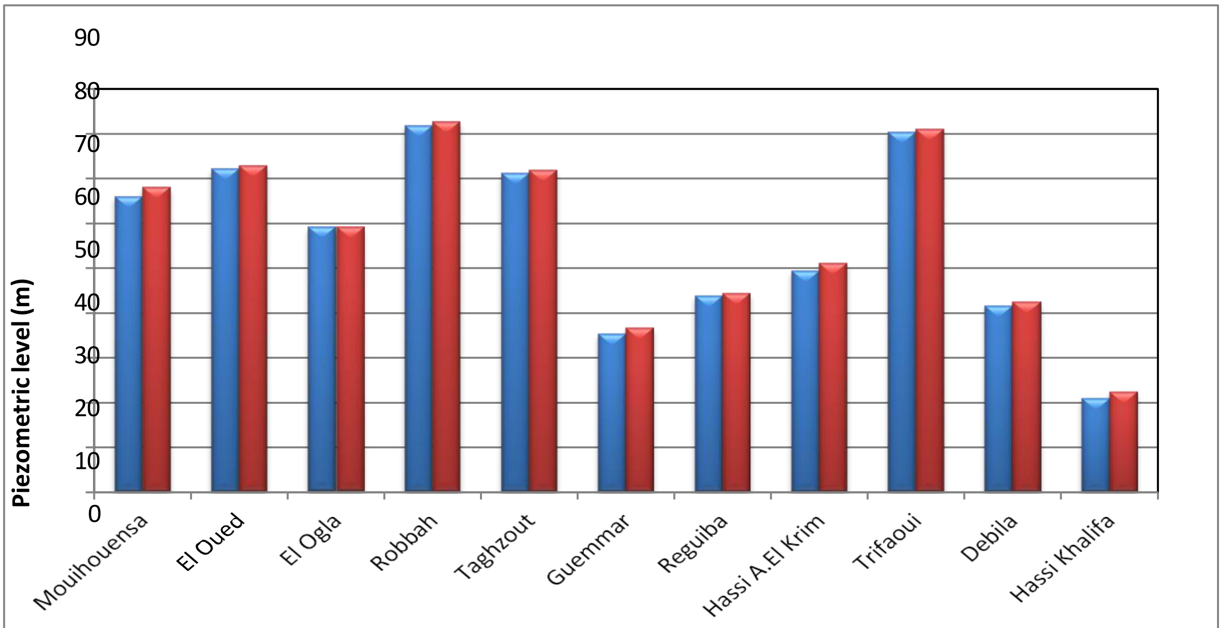


Fig.5. Variation in the piezometric levels of the CT aquifer between 2010 and 2011

According to the piezometric measurements taken in 2010 and 2011 by the Water Resources Directorate (DRH) of El-Oued, the following results were obtained:

We observe that the piezometric level has decreased for all water points. The piezometric level of the aquifer declined between 2010 and 2011, which can be explained by the overexploitation of this aquifer.

It is evident that the piezometric level has decreased for all water points studied. This decline in the piezometric level of the aquifer, observed between 2010 and 2011, can be attributed to the overexploitation of this water resource. The excessive extraction of groundwater, often exceeding the natural recharge capacity of the aquifer, has likely caused this significant drop. Overexploitation is typically driven by increased demands for agricultural irrigation, industrial activities, and domestic water use. Such a continuous decline not only threatens the sustainability of the aquifer but also risks causing long-term consequences, such as reduced water availability, land subsidence, and degradation of water quality.

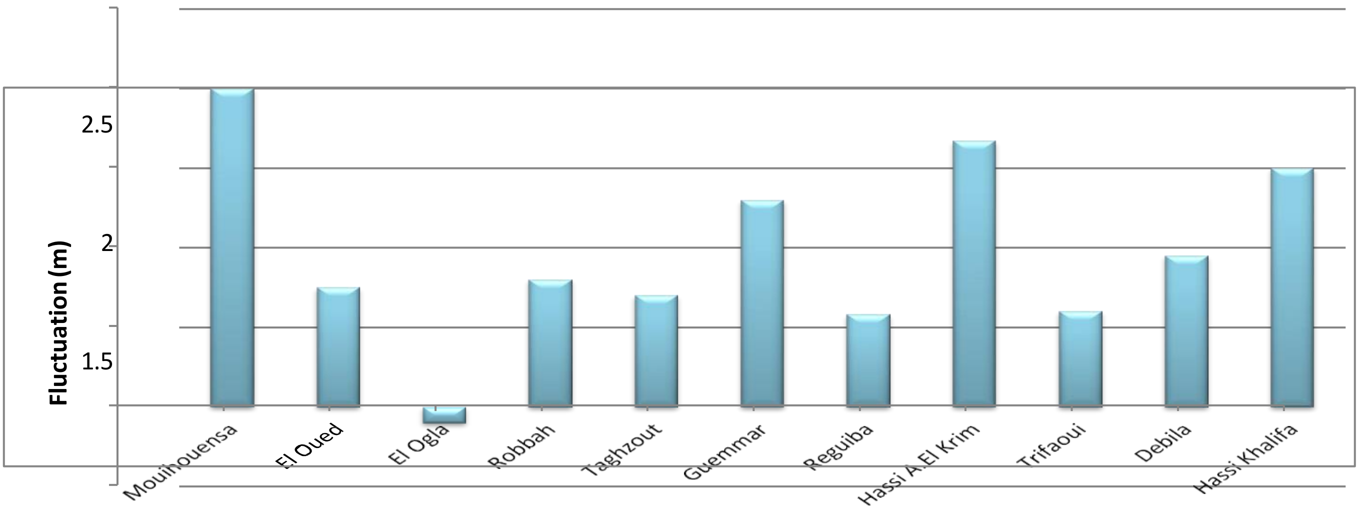


Fig.6. Piezometric fluctuation of the of the CT aquifer between 2010 and 2011

The graph above shows the variation in the piezometric level (fluctuation) between March 2010 and March 2011 for each municipality.

The municipality of **El Ogla** shows a slight decline (-0.10 m), while the other municipalities display an increase in the water level.

The Oued Souf region in Algeria faces significant challenges in groundwater management due to multiple factors that influence the water levels and overall sustainability of agricultural activities. Here's a detailed breakdown of the factors contributing to groundwater depletion and the region's socio-economic impact:

Factors Influencing Groundwater Levels
The steady and significant decline in groundwater levels observed across the Oued Souf region can be attributed to several key factors:

1. **Irrigation Practices** The region utilizes three primary irrigation methods: flood irrigation, sprinkler irrigation, and local irrigation systems, including the traditional Ghout technique (DSA, 2022). Despite the availability of modern irrigation systems, the continued reliance on traditional flood irrigation, which is highly inefficient in water usage, has exacerbated groundwater depletion. Widespread use of locally manufactured pivot irrigation systems has also contributed to inefficient water use and overextraction.

2. **Unregulated Well Drilling** Random and unregulated well drilling has significantly increased groundwater extraction, further depleting the aquifers and contributing to the observed decline in water levels.

3. **Dependence on Groundwater** The Oued Souf region heavily relies on the phreatic aquifer due to its shallow depth, low cost, and easy accessibility. The phreatic aquifer provided the majority of groundwater in 2015, providing about 90.5% (65,429 l/s) of the water needs, followed by CT which meets about 9% (6346 l/s). Only, about 0.5% (347 l/s) of groundwater is provided by the CI aquifer (Khezzani and Bouchemal , 2018).

4. **Water Sources** The region relies on 72 CT medium and deep groundwater wells, alongside approximately 35,128 shallow wells, with a combined flow rate of 72,000 L/s. This extensive groundwater extraction places significant stress on the aquifers, particularly the phreatic aquifer, which is most susceptible to overexploitation.

Addressing these factors requires a shift toward efficient irrigation systems, such as drip and sprinkler techniques, and a reduction in the dependence on traditional flood irrigation to mitigate further groundwater depletion.

Sociocultural and Economic Impact
El Oued is renowned for its significant economic, industrial, and tourism activities, as well as its strategic location as a border region. It is particularly well-known for its agricultural sector, especially its extensive palm plantations (pheoniciculture). Agro-pastoral activities remain one of the most stable and secure sectors in the state. The agricultural workforce comprises 96,100 individuals, accounting for 38% of the active population (Table 2).

The economy of El Oued is predominantly agro-pastoral, with 1,055,027 heads of livestock across all species and a total Utilized Agricultural Area (UAA) of 86,270 hectares (CA 2020- 2021). Key agricultural productions include:

- **Date palm cultivation:** 1,216,669 quintals of dates harvested from 15,374 hectares.
- **Market gardening:** A total production of 19,257,425 quintals, including 12,938,925 quintals of potatoes and 3,292,230 quintals of tomatoes during the 2020-2021 agricultural campaign.

Table 2: Breakdown of employed population by sector of activity

Activity area	Men	Women	Total
Administration	26434	16467	42901
Building and civil industry	24695	1649	26344
Agriculture	91430	4670	96100
Industry	6161	1017	7178
Services	21356	2255	23611
Trade	21689	2733	24422
Total	191765	28791	220556

Farmer Demographics and Education

According to the data in Table 3, the majority of farmers fall within the age group of 31 to 41 years. Among them, 28 have agricultural experience ranging from 11 to 20 years (Fig. 7), with the highest proportion having 18 years of experience. Additionally, 12 farmers possess more than 21 years of experience. Their education levels vary across primary, secondary, and tertiary education. These findings indicate that 60% of farmers with over 10 years of experience are at an entry-level stage in terms of formal agricultural education (Fig. 8).

Fig. 7. Age of farmers

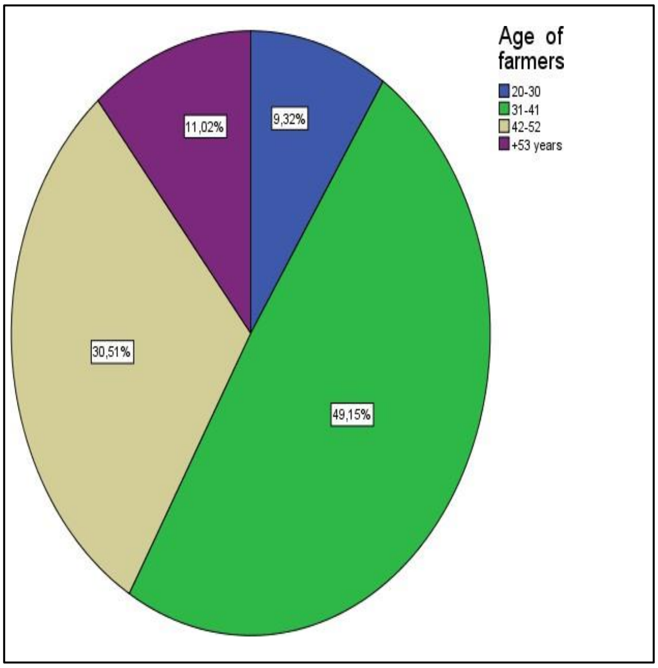
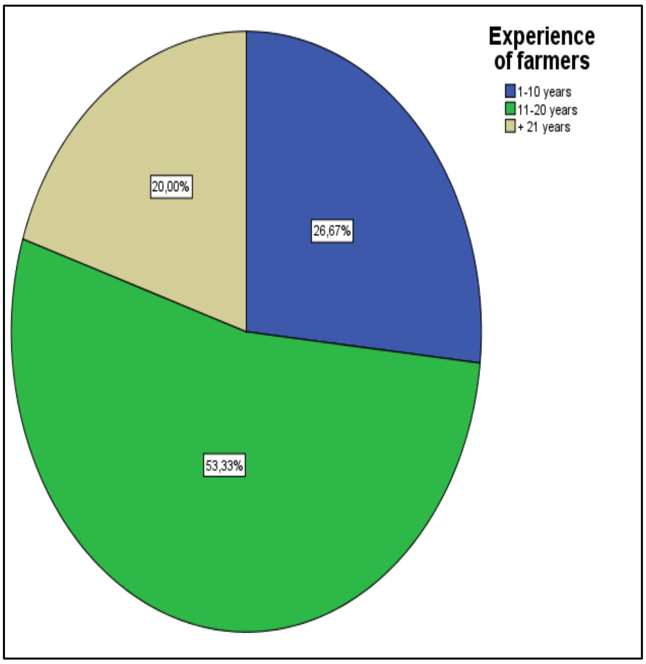


Fig. 8. Experience of farmers



Irrigation Systems and technology

The majority of farmers in El Oued rely on groundwater for irrigation purposes. Among the farmers surveyed :

- 79.17% use the pivot irrigation system,
- 20.83% utilize a combination of drip and pivot irrigation systems (Fig . 9).

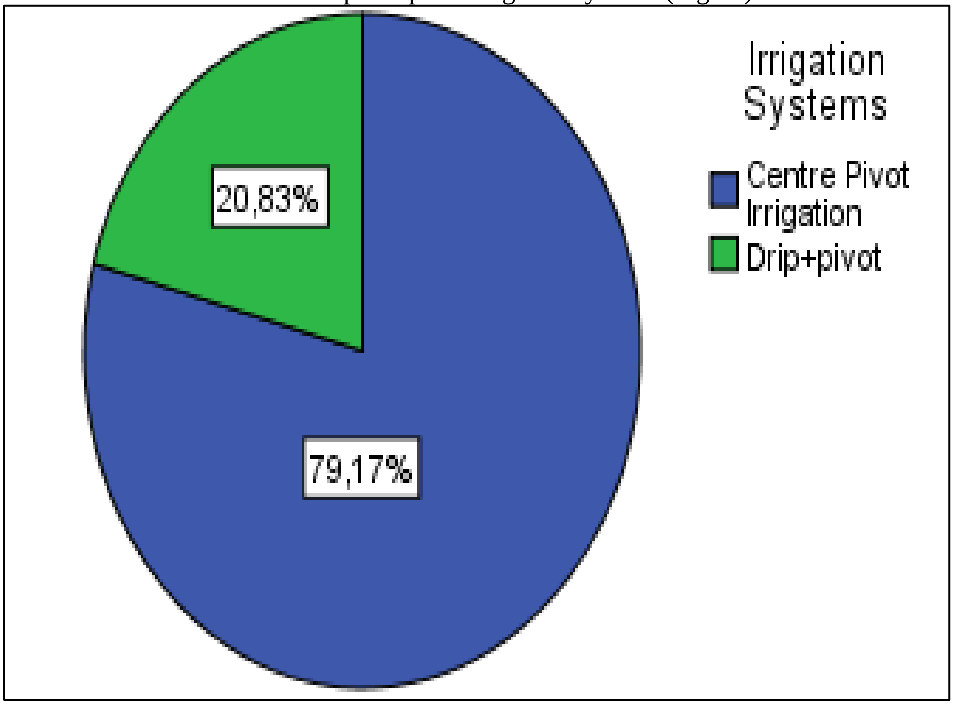


Fig. 9. Irrigation systems

Table 3: Level of education and farming experience

Experience of farmers years	**Your education level**			**1-10 years**	**11-20 years**	**+21 years**	**Total**
	Illiterate	Age of farmers	42-52	-	2	-	2
years			+53	-	2	-	2
		Total		-	4	-	4
	Koranic school	Age of farmers	20-30	1	0	-	1
			42-52	0	1	-	1
			+53	2	1	-	1
years		Total		3	2		5
	primary school	Age of farmers	20-30	0	3	3	6
			31-41	11	17	9	37
			42-52	5	9	6	20
			+53	2	3	1	6
years		Total		18	32	19	69
	secondary school	Age of farmers	20-30	1	0	0	1
			31-41	3	5	2	10
			42-52	1	8	0	9
			+53	1	0	0	1
years		Total		6	13	2	21
	university	Age of farmers	20-30	0	3	0	3
			31-41	4	6	1	11
			42-52	0	3	1	4
			+53	0	1	0	1
years		Total		4	13	2	19
	Total	Age of farmers	20-30	2	6	3	11
			31-41	18	28	12	58
			42-52	6	23	7	36
			+53	5	7	1	13
		Total		31	64	23	118

Water Sources and Well Characteristics

The region benefits from relatively shallow aquifers (less than 60 meters), enabling farmers to utilize wells for water extraction. These wells provide flow rates between 4 and 91 m³/s, sufficient to irrigate areas of about 1 to 2 hectares. The average depth of agricultural wells is 32 meters, with water levels ranging from 50 to 120 meters depending on the location.

Table 4: Agricultural Wells and Hydraulic Sources by Municipality

municipality	**Well for agriculture**	**Number of wells**	**Water aquifer depth (m)**
Hassi Khalifa	10	4782	Up to 120
Trifaoui	01	3508	70
Taghzot	-	1400	60
Ouermas	-	2017	60
Reguiba	09	2837	70
	Total	14500	

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Mini-Pivot Systems

Farmers in El Oued have developed innovative irrigation machines, such as the Mini-Pivot. This system, made from recycled materials, consists of a rotating arm supported by wheels and driven by an electric motor. It covers areas between 1 and 2 hectares, offering advantages like reduced manpower and water consumption compared to traditional irrigation techniques. However, it has limitations, including high water losses and sensitivity to wind.

The average cost of a locally produced Mini-Pivot with accessories is approximately 230,000 DA, with a lifespan of 8 years or 16 growing seasons. The pivot can irrigate a hectare in 4-6 hours, depending on its configuration.

Energy Sources for Irrigation

Farmers rely on electricity (79%) and diesel (7%) for irrigation. Due to restrictions on fuel supplies, many farmers have shifted to electricity. Diesel usage requires generators, which involve significant investment. The average cost of a generator is subsidized by the state but remains inaccessible to some farmers due to ownership status.

Decline in Water Levels

The Souf region benefits from a relatively shallow aquifer (less than 60 meters), allowing farmers to extract water using regular wells (Medjani et al., 2013). With groundwater depths averaging around 50 meters, these wells yield flow rates between 4 and 91 m^3/s, sufficient to irrigate areas of 1 to 2 hectares (Maiza, 2014). A survey found the average depth of irrigation wells to be 32 meters, while the Water Resources Directorate (DRH) notes that water levels generally remain below 70 meters, occasionally reaching depths of up to 120 meters. These wells, all individually owned and primarily approved by the National Agency for Water Resources (ANRH), are essential for agriculture, with 78% owned by farmers surveyed during the study.

However, despite their extensive use, the region's water table is declining at an annual rate of 0.5 to 1 meter, a trend confirmed by respondents and state authorities (DSA, DRH, and ANRH). Farmers have reported an acceleration of this decline, attributing it to inefficient water management practices that result in significant resource wastage.

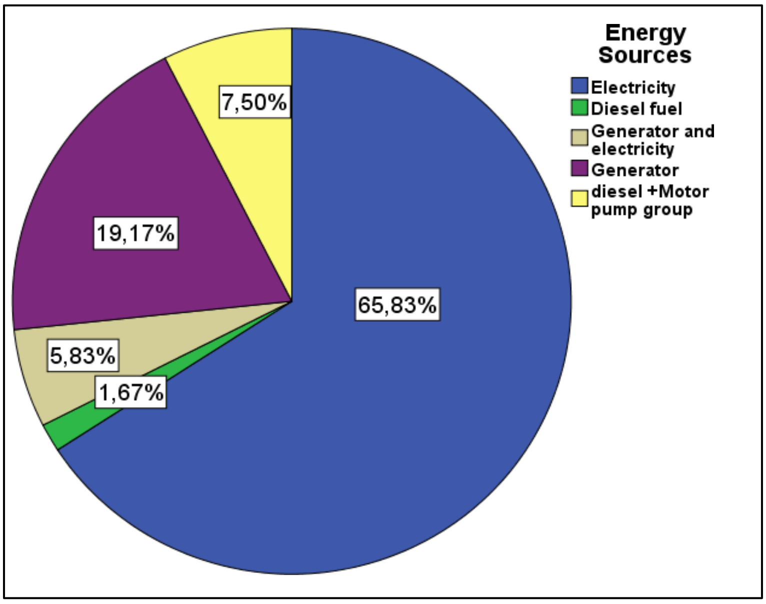

Fig. 10. Energy source

A

Completion date (1990-2012) Until 2018	Water level drawdown (m) 15-10
2013-2018	5-1

B

C

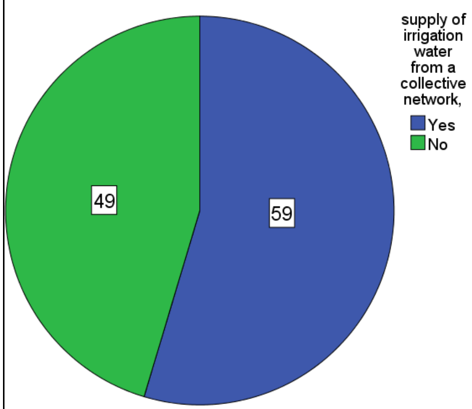

Figure 11: A) Water level data; **B)** Abandoned collective water well; **C)** Irrigation water supplied via a collective network

CONCLUSION

The Oued Souf region exemplifies the transformative potential of agriculture in arid environments but also highlights the challenges of groundwater management and sustainable resource use. While the adoption of innovative irrigation systems like the locally adapted pivot irrigation system has spurred agricultural productivity and economic growth, it has also led to significant groundwater depletion. Overextraction, inefficient irrigation practices, and unregulated drilling are driving the decline in aquifer levels, with potentially severe long-term consequences for water availability and ecosystem stability.This study underscores the importance of transitioning to more efficient irrigation techniques, such as drip irrigation, and implementing stricter regulations on well drilling and water extraction. Additionally, increasing farmer education on sustainable practices and improving water resource management are crucial for ensuring the long-term viability of agriculture in Oued Souf. The use of clean energy, such as solar power, and state-subsidized supplies are also key factors. A balanced approach that aligns economic development with environmental sustainability is essential for preserving the region's groundwater resources for future generations.

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