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THE GHOUT OF EL OUED IN ALGERIA: A PATRIMONY AND A NATURAL HYDROAGRARIAN ALARM SYSTEM TO ADVANCE

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ABSTRACT

The Ghouts of Sandrous location situated in the municipality of El Ogla, El Oued are an example of the protected original agrarian system of the Soufis people compared to other Ghouts areas. Six Ghouts have been visited to better understand the concepts of this ancestral patrimony. The anthropogenic constraints causing the deterioration of the Ghouts have been determined, notably the evolved oasis system, the pivot irrigation system, and the hydrodynamic disequilibrium where two scenarios are determined. The first is related to the rise in the static level of the watertable. This scenario indicates for the first time a flooded Ghout due to a lithological subsidence phenomenon. However, the second scenario relates to the drawdown in the static level of the watertable. This last scenario evokes the drying up of Ghout. Other anthropogenic constraints have been raised to find solutions. The field technique of El Beneia built to plant new palm trees called Baalis is used to determine the watertable static level in Ghout. It allows the introduction of Ghout's technique for the first time as a reference technique named the hydroagrarian alarm system for better managing the watertable.

Keywords: El Oued, Algeria, Ghout, Patrimony, Watertable, Self-irrigation, Alarm system.

INTRODUCTION

Living in the lower Sahara, notably El Oued, Algeria is adapted to stressed climatic conditions. Maintaining life's aspects as well as the historical, sociological, cultural, and agrarian aspects in a particular system could mean the Ghout system in Souf. For a long time, this system has been considered a typical example of the Soufis people's intelligence. The Ghout is an agrarian system that ensures good palm production without any classical or modern irrigation system. However, the watertable hydrodynamic disequilibrium negatively influenced Ghout's existence. Since 1990, the number of Ghouts has decreased (Senoussi, 2012) because of the rise in the watertable static level, but the situation is actually more complicated. The watertable static level in some places is rising, and in others, the modernization of irrigation methods using pivot irrigation systems (Remini, 2019) causes a drawdown in the watertable static level. This causes Ghout to dry up. In addition, urban hypertrophy (Medarag Narou Boubir and Farhi, 2009) amplifies the deterioration of this ancestral and special agrarian system. Many authors have discussed the Ghout system, notably Despois (1958), Claude (1960), Remini, (2006), Medarag Narou Boubir and Farhi (2009), Senoussi et al. (2012), Bernaoui, (2015), Brahim (2016), and Remini (2019). This work aims to highlight the intelligence of the Ghout conception, which adapts perfectly to the Erg geomorphological nature. It allows determining the advantages of this agrarian system. The potential theoretical and methodological contributions of this paper are as follows: (i) a new role of Ghout is introduced for the first time as an excellent hydroagrarian alarm system. It aims to preserve the environment and to indicate the watertable disequilibrium and the lithological instability; (ii) a new flooding Ghout scenario different from that discussed before is presented, by which a relationship is made between the water salinization, the rise of the watertable static level and drilling. This scenario allows us to review the strategy of drilling for WSD and irrigation by establishing a map of the lithological vulnerability of the subsoil to evaporitic rock dissolution. (iii) This hydroagrarian alarm system allows, in addition to the preservation of the environment, the indication of lithological instability to protect agricultural land and dwellings from subsidence. Consequently, Ghout is considered a preservative and an excellent indicator system of hydrodynamic disequilibrium and lithological instability. This new role allows for recommending Ghout as a world heritage site by UNESCO and considering this technique as a hydroagrarian alarm system. All these technical and environmental advantages of Ghout allow the preservation and protection of the environment for better management of the water table in Souf and the surrounding areas by introducing protective, preventive and proactive measures.

Geographical setting

El Oued is located in the northeast of the Algerian Sahara. It is limited to the north by Khenchela and Tebessa; to the west by El M'ghaier and Touggourt; to the east by the Tunisian borders; and to the south by Ouargla (Fig. 1).

Figure 1: El Oued geographical setting

Geomorphological setting

El Oued is covered almost entirely by dunes. The center of El Oued is called Souf, which means valley. The Souf is a fossil wadi (Ballais, 2010) where a mosaic of palm trees grows. Oued Souf forms the eastern branch extension of oued Righ. It is limited to the south and southeast by the Erg dunes. The sand of wind origin covers these fossil wadis, where the thickness can reach 8 m. They come from Tinrhert and Tademaït and are located in the axis of Igharghar, which disappears between the plateaus of Tademaït to the west and Tinrhert to the east. They are subdivided downstream in Oued Souf into two sinuous alignments of Ghouts: the more western, sometimes double, is locally called Oued or Horra, and the more eastern, shorter, is called Daya. They are then individualized very clearly downstream in Hobba (Ballais, 2010). These Ghouts have a discontinuous bead form that appears in the dunes of the Grand Erg Oriental. The photo below taken by Khebizi (2023) shows the Sif form.

Figure 2: Erg dunes

Going toward the north, evaporitic material dominates as well as Chotts depressions, where the ground level is below the sea water level. Chott Haloufa and Chott Dheba form the outlet of the groundwater and the wastewater. The temperature elevation causes water evaporation, which allows the precipitation of evaporitic and saliferous minerals that form white crusts. The photo below taken by Khebizi (2023) shows Chott Dheba.

Figure 3: Chott Dheba

Geological and hydrogeological setting

El Oued is formed by a sedimentary succession from a few meters to 700 m depth, called the Terminal Complex, covered by Quaternary sand. It includes the Senonian formed by three members, notably carbonate Senonian, lagunary Senonian, and saliferous Senonian; dolomite Eocene and sandy Mio-Pliocene. These formations contain interconnected aquifers that belong to the same groundwater. Lithostratigraphic correlations were performed using six (06) petroleum wells in southern Souf (Khebizi, 2022) in a direction going from east (El) to west (EH) to better understand the lateral evolution of the host rock (Fig. 4).

The correlations performed by Khebizi et al., 2022, show that the dolomite Eocene formation disappears in some areas, notably in the south, where the sandy Mio-Pliocene groundwater is in direct contact with the carbonate and lagunary Senonian. In the southouest, dolomite Eocene forms the Mio-Pliocene host rock in El Oued, but it has a bevelled shape in Toggourt (Fig. 5). Mineralization is caused by water–rock contact and varies according to the host rock lithology.

Mineralization is more significant where the sandy Mio-Pliocene is in direct contact with the evaporitic Senonian, where it is enriched by the dissolution of sulfate and chloride minerals. However, when dolomitic Eocene formed the host rock, salinsation was less significant. The waterflow direction of the Terminal Complex is from the southwest to the northeast (Khebizi et al., 2022) (Fig. 6).

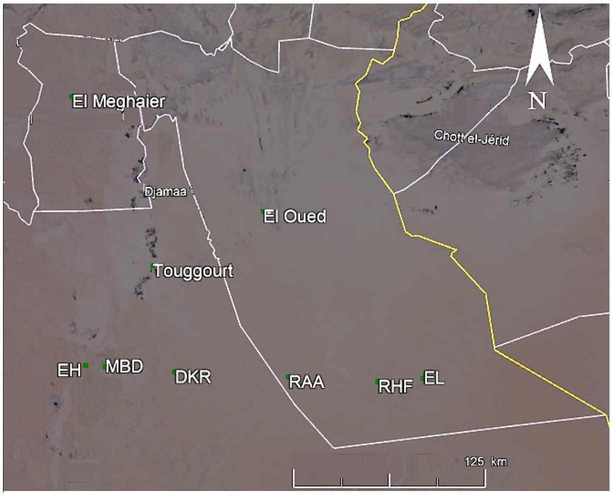

Figure 4: Lithostratigraphic logs position

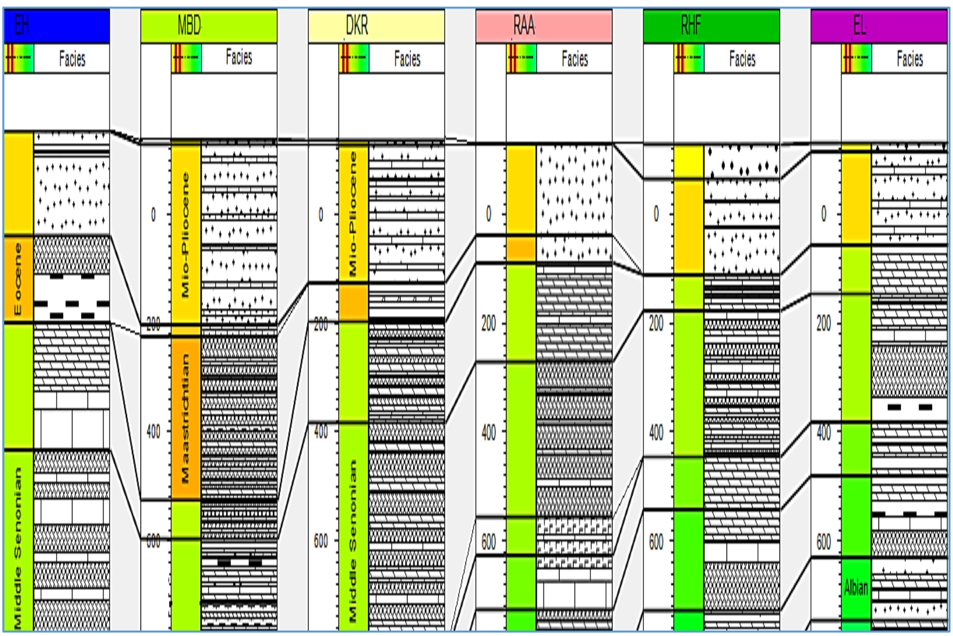

Figure 5: Lithological correlations

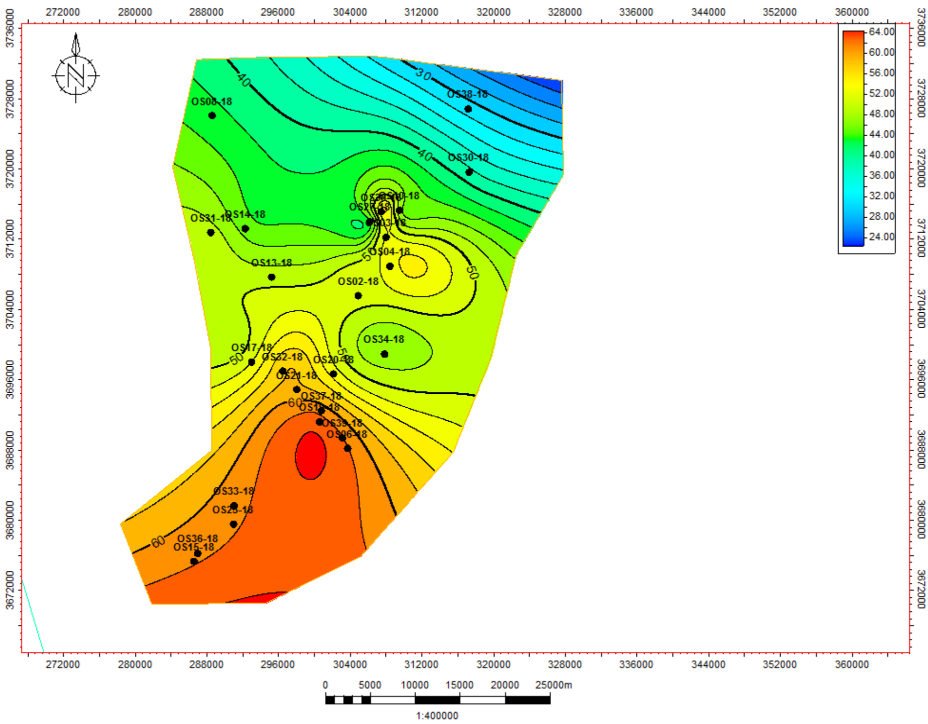

Figure 6: Groundwater flow

MATERIAL AND METHODS

A field trip was organized from 5 to 9 February 2023 to visit the Ghouts of the Sandrous location situated in El Ogla municipality. Six Ghouts were visited, and discussions with the Fellahs allowed a good understanding of the Ghout's conception and techniques. In addition, the different Ghout management constraints were discussed, notably the watertable static level disequilibrium. For this, two scenarios of underground hydrodynamic disequilibrium are presented. The first scenario is related to the rise in the static level of the water table, which shows the flooding of Ghout. This scenario indicates for the first time a flooded Ghout due to a lithological subsidence phenomenon. However, the second scenario relates to the drawdown in the static level of the watertable. This last scenario evokes the drying up of Ghout. Other anthropogenic constraints have been raised to find solutions. The field technique of Fellahs used to determine the watertable static level in the Ghout allows us to introduce this technique for the first time as a reference technique. It is called the Ghout hydroagrarian alarm system.

RESULTS AND DISCUSSION

Ghout's technique

Date palm cultivation in Souf is well known for its natural irrigation system named Ghout. It is an ancestral system based on the self-irrigation of palm trees without using known irrigation techniques such as drilling. In Ghout, palm trees directly draw water from the watertable by their roots. The means used are mainly local and manual. The Ghout building steps are as follows: First, it is necessary to have (i) a shovel to remove the sand; (ii) baskets made by the leaves of the palm trees in which the sand is put; (iii) a tape made of palm leaves to build the protection hedge of the palm groves; and (iv) the plaster "Gepse" to build El Beneia, which is the hole where the palm tree is planted. Second, the Fellah delimits his Ghout area by the protection hedge and chooses a place that will be considered a permanent entry of the Ghout. Finally, the Fellah removes the sand from the Ghout to cope with the dune obstacle and to plant the palm trees named Baalis.

Funnel-shaped depressions

The Soufis people made funnel-shaped depressions 10 m deep and 80 to 200 m in diameter (Fig. 7). Their shape varies according to the proximity of the water where the crater's bottom is brought to less than 1 m above the watertable. The work organization in the Ghout was limited to the owner's family members, while external laborers helped with sand transport during the creation of these Ghouts using traditional baskets "Ghouffas" and animals. This operation is continually performed when building Ghout and during the periodic maintenance of Ghout after silting up.

Figure 7: The Ghout manual building technique

The palm trees

The palm trees are planted in a north–south direction. Palm trees are planted in a juxtaposed way to let sunlight. Looking from afar, only the leaves of the palm groves appear below the level of the dune crests (Fig. 8).

Figure 8: The palm trees

The protective hedge

The palm trees are planted in groups of 20 to 100 in the center of craters surrounded by a protective hedge (Fig. 9) and touching each other. The protective hedge aims to delimit the owner area and to separate it from the other Fellahs' properties. All the craters occupy an area of 9500 ha between 1990 and 2000 with a total number of 10.000 Ghouts. In addition to the varieties of dates cultivated by the Fellahs, fruit trees and vegetable crops adapted to the local climate are cultivated. In fact, new Ghouts are planted in the north and northeast of El Oued.

Figure 9: The protective hedge

The indicator hole

The indicator hole method allows us to have an idea about the static level of the water table. The Fellahs dig a hole of a few meters similar to an ordinary well to have an idea about the drawdown in the water table static level. (Fig. 10). The holes are used as a reference during the construction of Beneias that are closely linked to the static level of the watertable. In this way, the roots of the newly planted palm tree called Baali draw water directly from the water table.

Figure 10: The indicator hole

El Beneia

The principle of El Beneias is to dig a hole that reaches the water table static level. The walls of El Beneia are cemented by the gypsum "El Gepse" (Fig. 11). In the normal case of the water table static level, El Beneia is 1 to 1.5 m deeper than the Ghout ground level. It is used for planting a new palm tree called by the Soufis “El Baali”.

Figure 11: El Beneia

El Baali

Baali is a date palm tree that differs from ordinary date palm by its self-irrigation, where the roots draw water directly from the water table. El Baali is planted in El Beneia to continuously insure water (Fig. 12). This method has good data quality. The size of dates is small compared to that of flat palm groves, but it is sweeter. El Baali is irrigated without causing water evaporation or water wastage, and the El Beneia conception is an incomparable water preservation technique. When El Baali grows, the size of its stem increases and occupies all of the El Beneia volume.

Figure 12: El Baali

The fertilizer

To obtain a good date quality, the Fellahs use natural fertilizers as well as camel excrement. These fertilizers are carried to the level of the water table to mix them with water. This natural fertilization method offers more organic matter, which can be decomposed and absorbed directly by the roots of Baalis (Fig. 13).

Figure 13: The fertilizer

The ordinary water well

Sandrous water is fresh, and the Fellahs drill ordinary wells in Ghout for their DWS needs (Fig. 14). In this region, the water table is not influenced by the salinization phenomenon, as identified in the other regions in El Oued. Thanks to this exceptional geometric system created by the Soufi man who responded remarkably to the Saharan requirements, agrarian life resisted for millennia.

Figure 14: The ordinary water well

The Ghout management constraints

The Ghout is suffocating due to human mismanagement. The evolved oasis and irrigation systems (Ouled Rebai and al., 2017), the pivot irrigation system (Remini, 2019), the rising water table static level (Remini, 2006), hypertrophy (Medarag Narou Boubir and Farhi, 2009), and simply the abandonment of Ghout (Medarag Narou Boubir and Farhi, 2009) are the reasons for poor Ghout management.

The drip irrigation system

The evolved oasis system has been chosen to intensify the production of dates. It is a flat agricuture technique using the drip system, which encourages more important date quantity with less mechanical effort (Fig. 15).

Figure 15: The drip irrigation system

The pivot irrigation technique

The pivot irrigation system was introduced in 2000 in El Oued and is adapted according to local specificity (Oueld Rebai and al., 2017). It is used as a traditional pivot by the Fellahs for growing vegetables, notably potatoes (Fig. 16). The number of traditional pivots is approximately 35.000 (Oueld Rebai and Farhi, 2017). It has led to good quantities that cover 35% of the national production. However, it caused the drawdown in the water table static level (Remini, 2019) and thus the drying up of the Ghouts.

Figure 16: The pivot irrigation technique

The disequilibrium of the watertable static level

The rise in the static level of the water table

In El Oued, the areas affected by the rise in the static level of the water table from the most flooded area to the least affected are Mihouensa, Oued Alenda, Reguiba, Hassani Abdelkrim, Z'Goum, Ourmes, Douera, El Oued, Ogla, and Guemmar. The degradation forms of the Ghouts are shown in flooded Ghouts with the suffocation of date palms (Fig.

17) and wet Ghouts in areas less affected by the rise in the watertable static level. Several authors, notably, Guendouz and Moulla (2003), Daddi Bouhoun et al. (2011), Barkat et al. (2021), and Khebizi et al. (2022), have discussed the phenomenon of water table salinization. In addition, numerous authors, particularly Remini (2006), Boulifa, (2012), Brahim (2016), Barkat et al. (2022), and Khebizi et al. (2022) have discussed the problem of the rise in the static level of the water table.

Figure 17: Flooded Ghout

The flooded Ghout scenario that was already linked to over pumping from the Intercalary continental and Terminal Complex (Remini, 2006) is differently explained in this work by putting into account for the first time a relationship between salinity, drilling and the rise in the static level of the watertable. The anarchic exploitation of the terminal complex without any knowledge about the host rock lithology immediately led to a visible impact on the Ghouts. They have been flooded and transformed into marshy areas. The underground dissolution of the evaporitic Senonian host rocks generates cavities, which are filled by the sandy material of the overlying layers, causing gradual subsidence. The creation of cavities is amplified by pumping, which accelerates the dissolution rate and thus the water salinity. The subsidence phenomenon occurs simultaneously with a rise in the static level of the water table. The scenario of the flooded Ghout due to the rise in the watertable static level is shown in Fig. 18.

This scenario cannot be applied where wastewater treatment plans are planted, notably the Kouinine wastewater treatment plan. In this area, an artificial rechage is done by spreading, but the amount of the evacuated water causes a rise in the static level of the watertable.

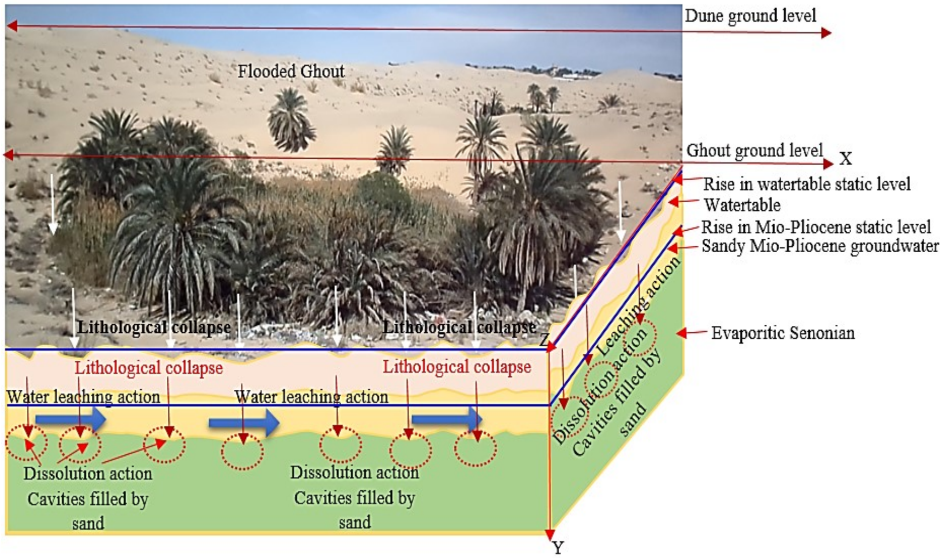

Figure 18: Scenario of flooded Ghout

The drawdown of the water table static level

In Sandrous, the drawdown in the static level of the water table is more than 5 m. This is caused by the intensive use of the pivot irrigation system for vegetable farming, in particular potatoes. As a consequence, El Beneias built for new Baalis to extend the agrarian area is drying up, and the new Baalis planted wither and die (Fig. 19).

Figure 19: Drying up of El Beneia

The drying up of the El Beneia scenario is shown in Fig. 20. The difference in the watertable static level is defined by δd, which is measured in meters. δd is given by the approximate difference in depth between the watertable static level in an old Beneia and a new Beneia recently built or a new indicator hole of the watertable static level. δd can be used to indicate the approximate amount of water consumed by the pivots of the Ghout neighboring areas. The consumed water volume is proportional to the pivot surface number. In a permanent regime, the watertable flows along oued Souf and discharges into the Chott. The flow occurs in the saturated zone while considering the sand incompressible. δd is the drawdown of the water table, and $\delta d = d_{bd} - d_{bw}$, where d_{bw} is the static level of El Beneia at rest and d_{bd} is the static level of El Beneia in the pumping regime. d_{bw} is considered to be equal to the drawdown in the well. The drawdown is a function of the flow as follows (Ababou, 2007):

$$d_{bd} = \frac{Q}{2\pi T_0} \ln\left(R_0 / r\right)$$

where Q is the specific flow rate, $R_0 = 1.5(Dtp)^{1/2}$, D = T/C, $T = Kh_0$, K is the hydraulic conductivity, C is the storage capacity, r is the distance from the well, and h_0 is the initial water static level.

This mathematical method allows us to calculate the maximum water amount that can be drilled to avoid reaching a drawdown level. Actually, the drawdown level of the watertable static level causes the drying up of Ghout in Sandrous. In such situations, the Fellahs are obliged to use the drip irrigation system to save their Ghout. However, Ghout cannot maintain its self-irrigation specificity and becomes an ordinary palm grove.

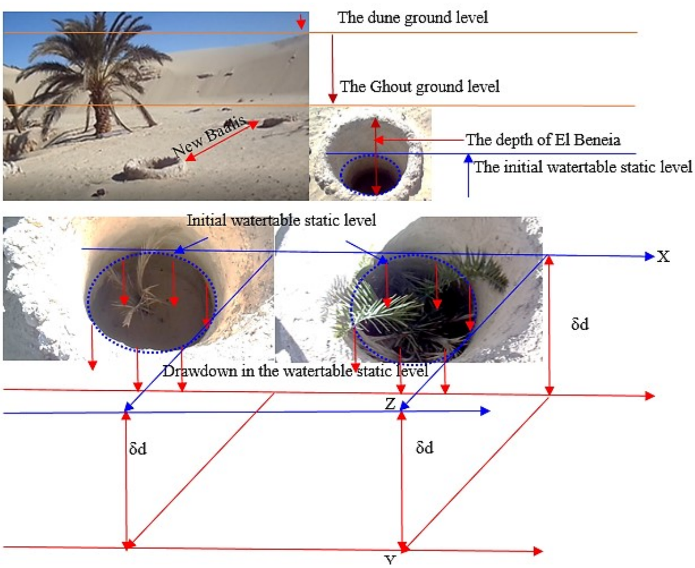

Figure 20: Drying up of El Beneia Scenario

The urbanization of the Ghouts

The urbanization process in the Ghouts fields and the surrounding area resulted from population growth. The anarchic occupation of the space and/or the disengagement of the owners themselves from their Ghouts caused the Ghout reduction. Other factors amplified Ghout urbanization, notably the increase in land prices and the proximity of Ghouts to the city center with the extension of electricity, gas, drinking water, and wastewater treatment plants. The life conveniences in the city have encouraged landowners to sell off their Ghout. Urban agglomerations have invaded a large number of Ghouts in El Oued, especially those located in the southeast of El Oued city, notably 128.01 ha of Ghouts. However, the Ghouts located in the west of El Oued are the least affected by the hypertrophy limited to 40.88 ha toward the northwest of the city (Medarag Narou Boubir and Farhi, 2009). In addition, the use of modern means of exploitation at the expense of Ghouts has become systematic for Fellahs. Some owners find the development and rehabilitation operations costly and/or painful. This finally leads them to leave their Ghout. In addition, the problems of inheritance caused the fragmentation of the Ghouts and their abandonment.

The Ghout new role

Soufi Fellah thought about a new way to reach the static level of the watertable after the drawdown problem. He digs a small hole similar to an ordinary drinking well to use it as a static level reference to build new Beneias of the same depth. The hole and the beneias technique could be considered a hydroirrigation alarm system. They allow us to follow the fluctuation of the watertable static level in Souf and can be used in some new extension surrounding areas of Ghouts, notably the north, east and southeast of El Oued. In addition, the mathematical method used to calculate the drawdown in the watertable static level, using El Beneia and the indicator hole technique, allows us to quantify the water amount that should be used without exceeding a threshold that could cause Ghouts to wither. Since the Ghouts can be georeferenced, artificial applications can be developed to know the water table static level fluctuations in the linked hole and Beneias. Associating digital technology with the Ghout traditional technique to obtain information about water table static level anomalies and to control irrigation pivots can be a progress idea for better management of the watertable.

CONCLUSION

The Ghouts of Sandrous is the example of the protected ancestral agrarian system of the Soufis people. However, anthropogenic constraints cause the deterioration of Ghouts. The evolved oasis system, pivot irrigation system, and hydrodynamic disequilibrium cause Ghout to disappear. A scenario that indicates for the first time a flooded Ghout due to a lithological subsidence phenomenon explains the rise in the static level of the water table differently. In this scenario, the dissolution of sulfate and chloride minerals of the evaporitic Senonian host rocks by rock–water contact causes a lithological subsidence that occurs simultaneously with a rise in the static level of the water table. Another scenario is presented that relates to the drawdown in the static level of the watertable and evokes the drying up of Ghout. The field technique of El Beneia built to plant a new palm tree called Baali is used to determine the watertable static level in Ghout. It allows the introduction of Ghout's technique for the first time as a reference technique named the Ghout hydroagrarian alarm system for better managing the watertable. In addition, the mathematical method used to calculate the drawdown in the watertable static level using El Beneia and the indicator hole technique allows us to quantify the amount of water that should be pumped for the pivot irrigation system to prevent Ghout from drying up. In addition, it allows calculating the adequate distance that could be taken between the Ghout and the pivot area to better manage the Ghout agrarian system and to develop other agrarian products.

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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