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The Added Value of Geographic Information System (GIS) in Monitoring and Management of Foggaras

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Abstract: This paper aims to describe the implementation of Geographic Information Systems (GIS) in the engineering practices of water resources management using Foggaras as a case study. Geographic Information Systems (GIS) are used essentially for spatial analysis. They can lead to the development of methods for analyzing and planning the use of geographical space and, consequently, are helpful to the decision-making process, assisting those responsible for planning the use of a certain territory. The use of Geographic Information Systems (GIS) in the management of foggara becomes very necessary because foggara is one of exploitation water in an arid region whose good management depends on the means of knowledge and access to information. Use new technologies in mapping sciences which are used to collect all information about foggara to understand precisely that system of foggara to study and develop many scenarios of management to make the right decision.

Key words: Foggara · Wells · Inventory · GIS · Hydrogeology · Oases · Arid environment

INTRODUCTION

The Sahara is the third-largest and hottest desert in the world. Water is scarce in this hyperarid region, with annual precipitation rates of less than 100 mm and as little as 20 mm in some places. Surface water in the form of small seasonal streams is rare and populations rely on non-renewable fossil groundwater reserves [1]. Through history, the population of the Sahara has adapted to the arid conditions, migrating to less arid regions in times of extreme drought and adapting their lifestyle to water-scarce conditions by developing sophisticated ways of exploiting local groundwater reserves [2]. One of the techniques used in the Algerian Sahara is the foggara, a groundwater collection and distribution technique that relies on a network of wells and tunnels. Historically, the development of foggaras in the Algerian Sahara allowed for irrigation of crops, the maintaining of palm groves and the supply of towns and villages in an extremely arid environment. Today, the implementation of a regional water management strategy and regular maintenance and monitoring of foggaras allows for the development of sustainable forms of agriculture [3]. To obtain water the population of the Sahara has achieved 2285 foggaras; he drilled more than 276831 wells, he dug more than 558.272 km of underground canals to connect the wells between them and he built huge irrigation networks inside palm-groves [4]. This irrigation networks divided into main and the second irrigation networks. The ending of that irrigation networks is a comb, that permits to measure of foggara's flow rates. Until today foggaras irrigates our plans plantation maintains the greenery in the desert. Several constraints seriously disrupting the functioning of foggaras. The drawdown of aquifer affects directly the foggaras'flows rates, several foggaras are dried up despit the big investements made Algerian State to safeguard that system [5]. Need and potential of development of the GIS based foggara management tools to visualize and analyze foggara management data is discussed in detail. This technique can be employed to develop thematic maps, mapping where foggaras are, mapping foggaras' state, you visualize the number of dried up foggaras and where they are located. We can easily shared all information about foggaras with others partners. All those information more and more information come from GIS, are the requirements that will be used by decision-makers. The relevant review literature indicates that GIS is

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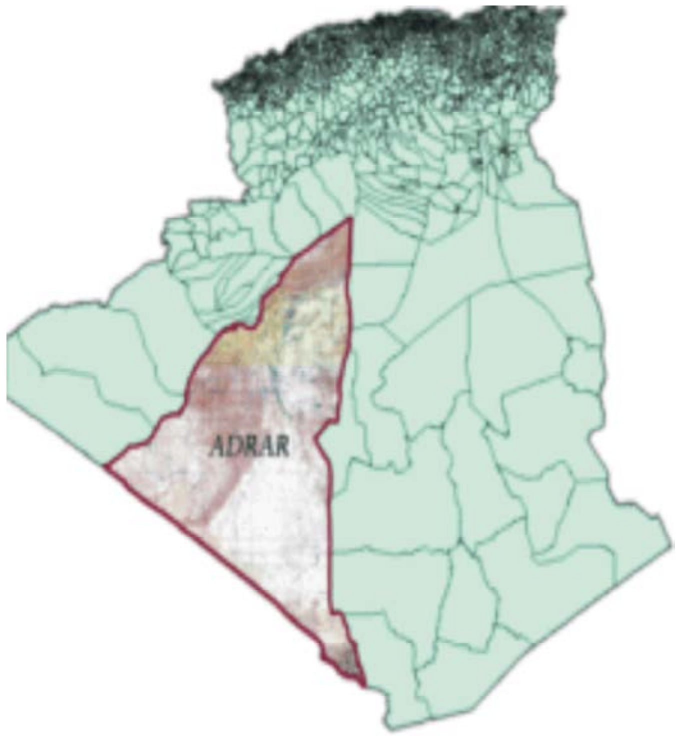

Fig. 1: Location of Adrar province in Algeria.

versatile tool that can be used to provide an appropriate framework for manipulating, analyzing and visualizing spatial data and produce results in the formof map, table and graph to support planning and decision making process in foggaras management [6].

Background of Study Area

Adrar Weather, Geography, Geomorphology and Climate: The study area or the land of foggaras called Adrar. Adrar is a province (wilaya in French), is located in the central part of the Algerian Sahara, Covering an area of 427,968 km^2. Estimated population: 433,000 inhabitants (Figure 1) [5, 7].

It is divided into four regions: Gourara, Tanezrouft (Bordj Badji El Mokhtar andTimiaouine), Taouat and Tidikelt (Figure 2).

Geomorphology: The region of Adrar has three key geomorphological features:

- A vast plain (plateau) with a maximum altitude of about 400 m, bounded by the
- Tademaït Plateau to the east and a depression to the west.
- A 5-10 km wide depression located along the western edge of the plain. This is where the palm groves are located.
- Small sebkhaon the western edge of the depression form the natural outlet of the aquifer. This Sebkhas is depressions that contain brackish water after rainfall, but are dry and covered with salt incrustations in summer.

Climate of Adrar: The region of Adrar is characterizedby high temperatures. The highest records are around 50/52 °C in summer. The average minimum temperature in January is around 5.5°C. The average maximum temperature in July is around 45°C. This is one of the hottest regions in the world (Figure 3 and 4).

The little precipitation and rain that falls in Adrar is usually erratic and varies from year to year. While in Adrar might have an annual average of 50 mm of precipitation. Thus, in arid environments, the annual average tells little about actual rainfall. What does matter in the arid area (Adrar) receives less precipitation than their potential evapotranspiration (Figure 5).

This means that the arid area does not receive enough precipitation to overcome the amount evaporated. This is a problem that must be taken into consideration in water management in oases (Figure 6) wind rose for Adrar shows how many hours per year the wind blows from the indicated direction and shows the wind's speed.

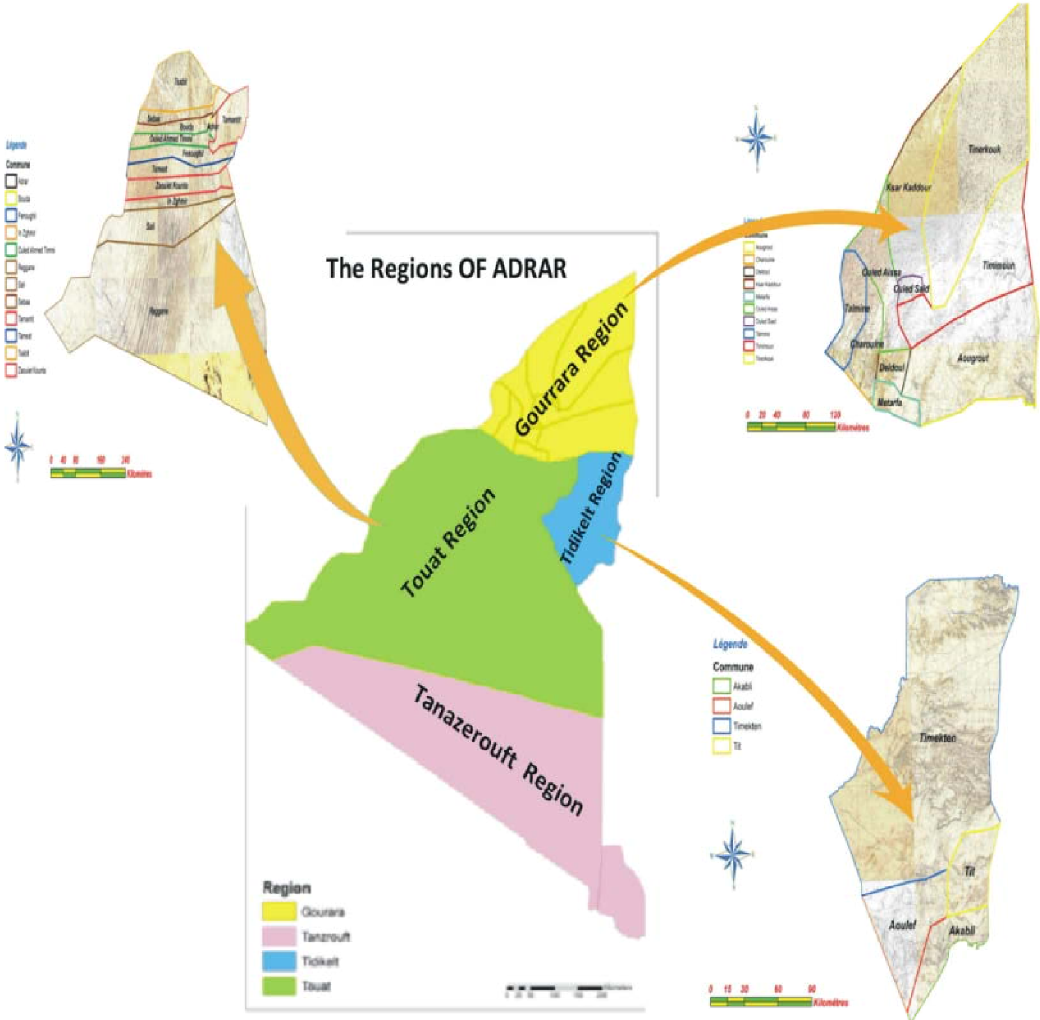

Fig. 2: Adrar Region

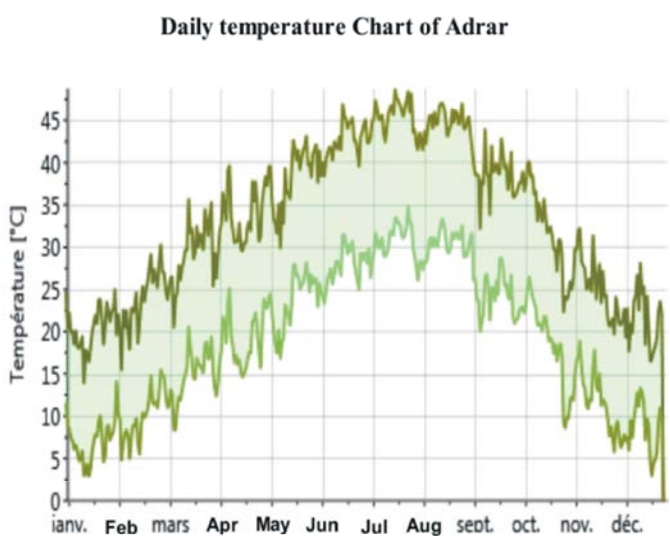

Fig. 3: Daily température chart of study area

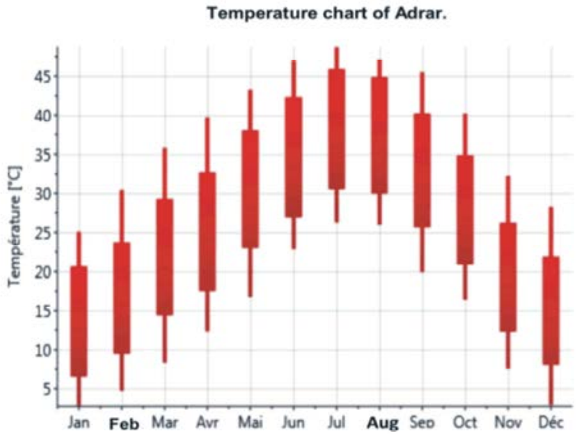

Fig. 4: Temperature chart of Adrar

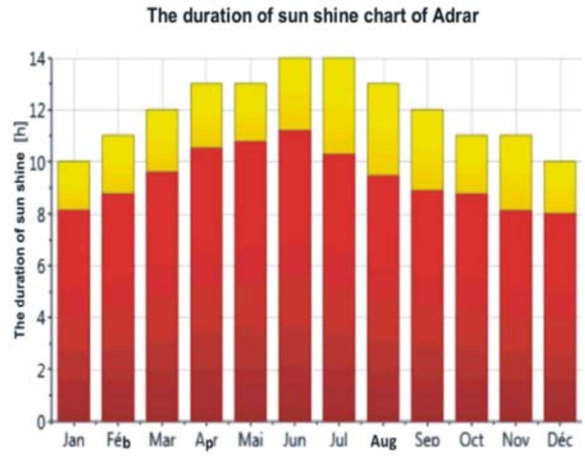

Fig. 5: The duration of sun shine

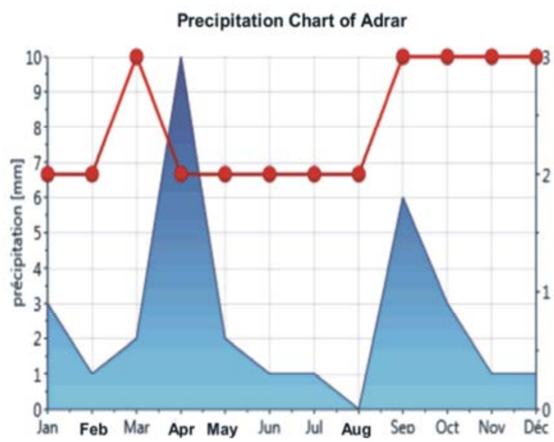

Fig. 6: Monthly precipitation in the study area

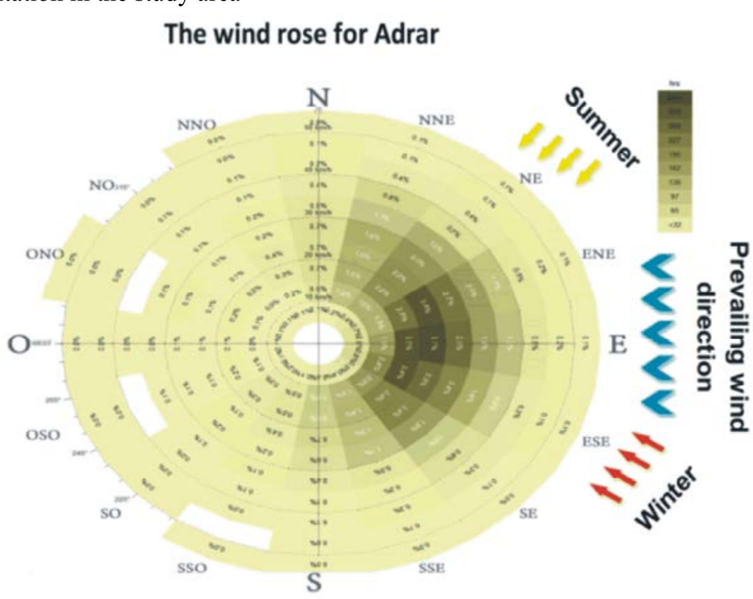

Fig. 7: The wind rose for Adrar

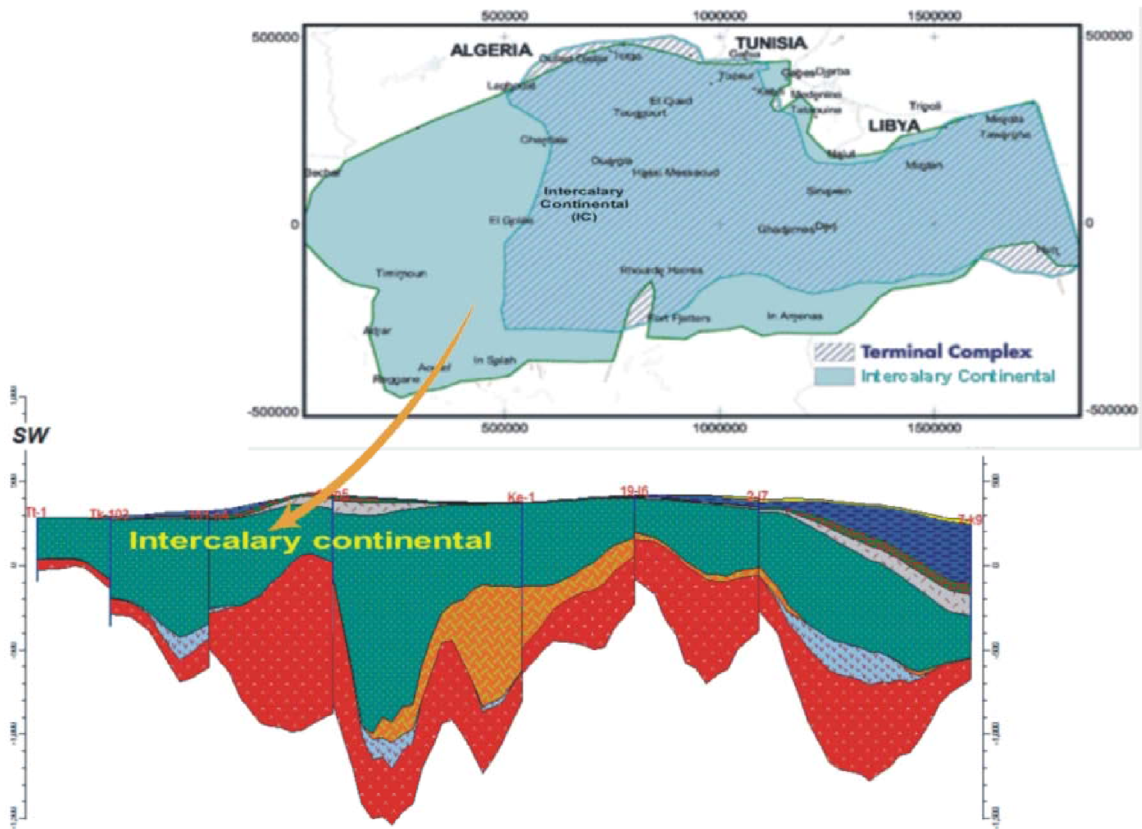

Fig. 8: North Western Sahara Aquifer System (NWSAS)

In summer, Wind is blowing from North East (NE); in winter Wind is blowing from East South East (ESE). The Prevailing wind is blowing from East. (Figure 7).

Hydrogeology: The groundwater used in most of the province of Adrar is commonly called the continental intercalary (CI). It is part of the North Western Sahara Aquifer System (NWSAS). The North-Western Sahara Aquifer System (NWSAS), better known under the acronym (SASS) for its French name "Système Aquifer du Sahara Septentrional" (SASS) and covers a total area of over one million km^2: 700,000 km^2 in Algeria, 80,000 km^2 in Tunisia and 250,000 km^2 in Libya. It contains sedimentary deposits which, from bottom to top, have two main levels of aquifers, the Intercalary Continental (IC) and the Terminal Complex (TC). The thickness of the Continental Intercalary in Adrar, varies from North to Southand from East to West. It oscillates between 150 m and 620 m. The static level of the aquifer is between the 6 m to 30 m. This aquifer is exploited by boreholes, wells and the foggaras (Figure 8) [8, 9].

Foggaras Description: The topography and depth of water of the intercalary continental in some regions of Adrar helped the man of these areas to create the foggaras. These foggaras are located in three regions of Adrar, Touat, Tidikelt and Gourara. All Oases in these regions are irrigated by this system. Each of them is divided into few towns (communes in French). The town is divided into few palms-groves. Most of the palm groves are irrigated by more than one foggara. The foggara is an underground gallery that drains the water from the Intercalary Continental (IC) aquifer to the palm grove. The foggara is composed of several wells with variable depths (Figure 9).

These foggaras are assembled at their bases by a gallery. These galleries serve to drain the water between these wells (Figure 10).

This underground channel is characterised by the geometric dimensions variable from a region to another and ending with a comb, (Kasria) (Figure 11 and 12) [10].

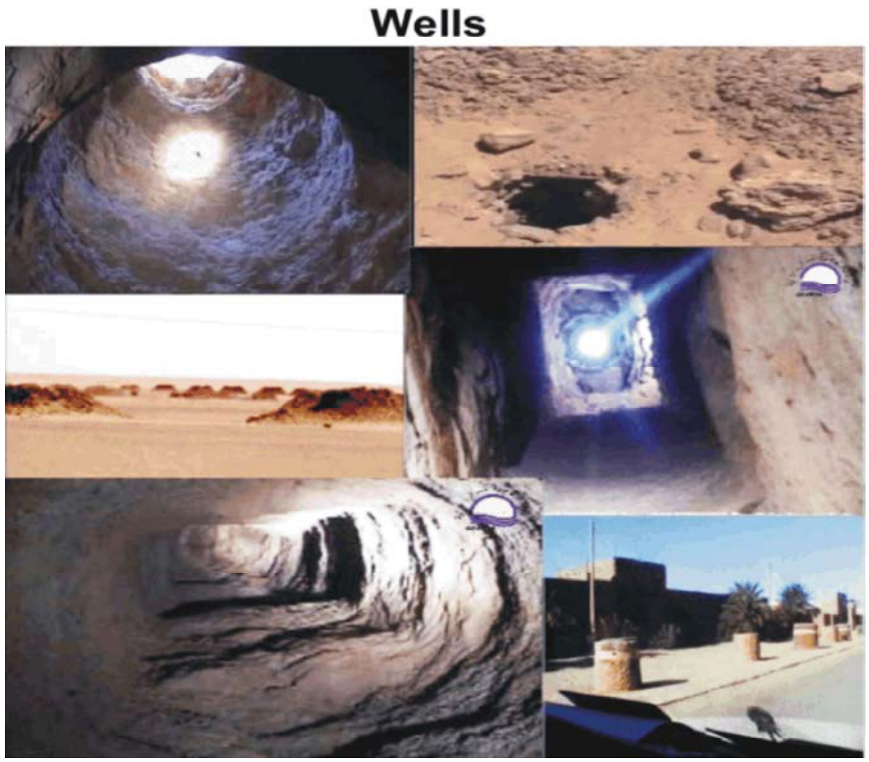

Fig. 9: Wells of foggaras

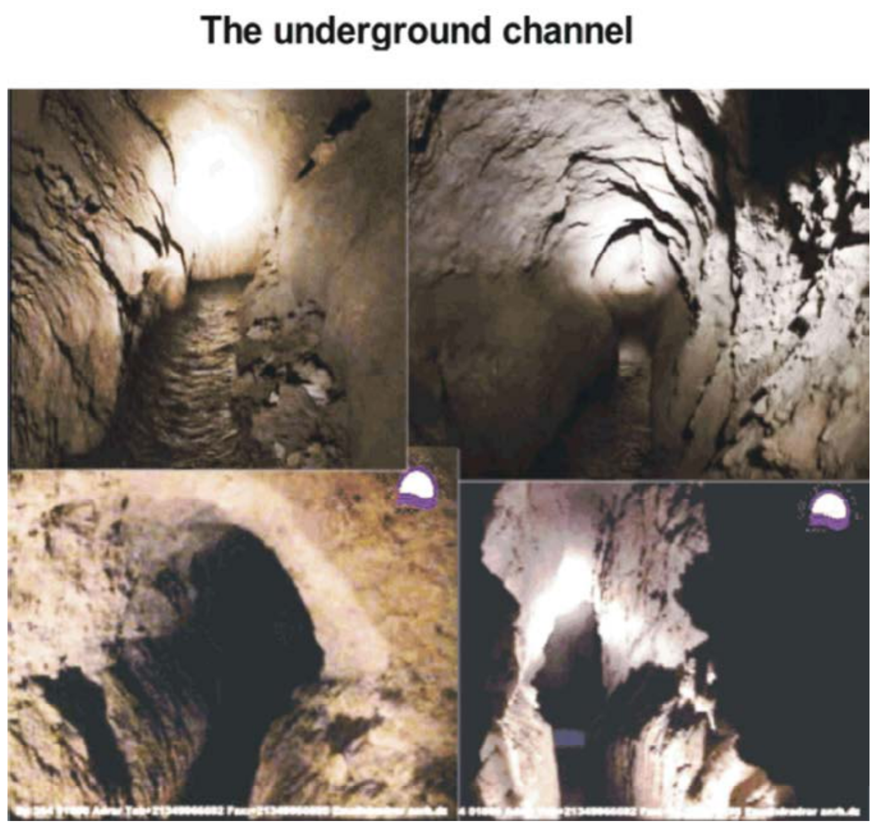

Fig. 10: The underground channel

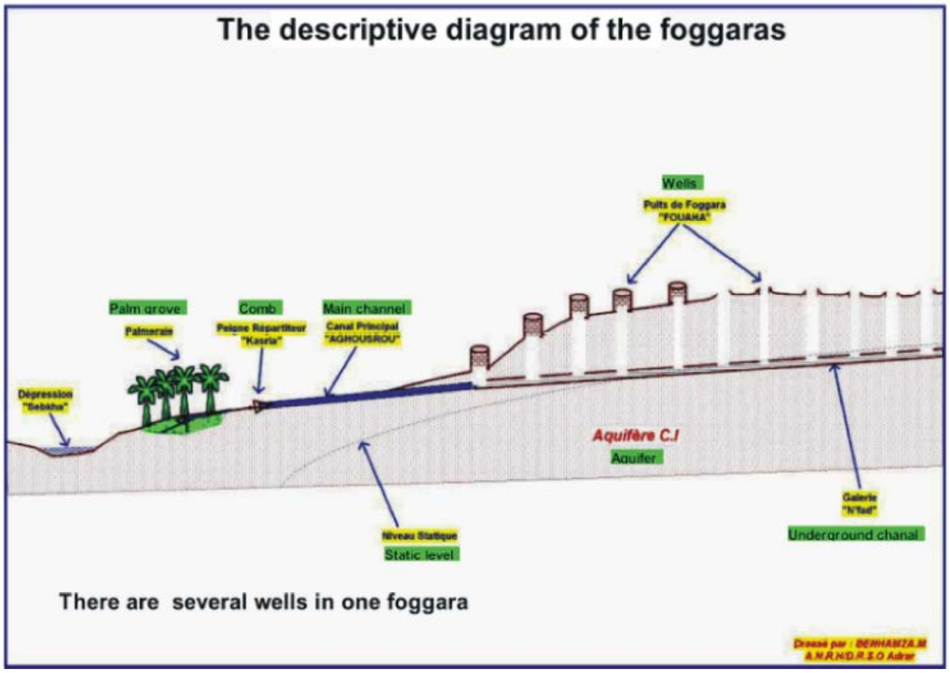

Fig. 11: The descriptive diagram of the foggaras

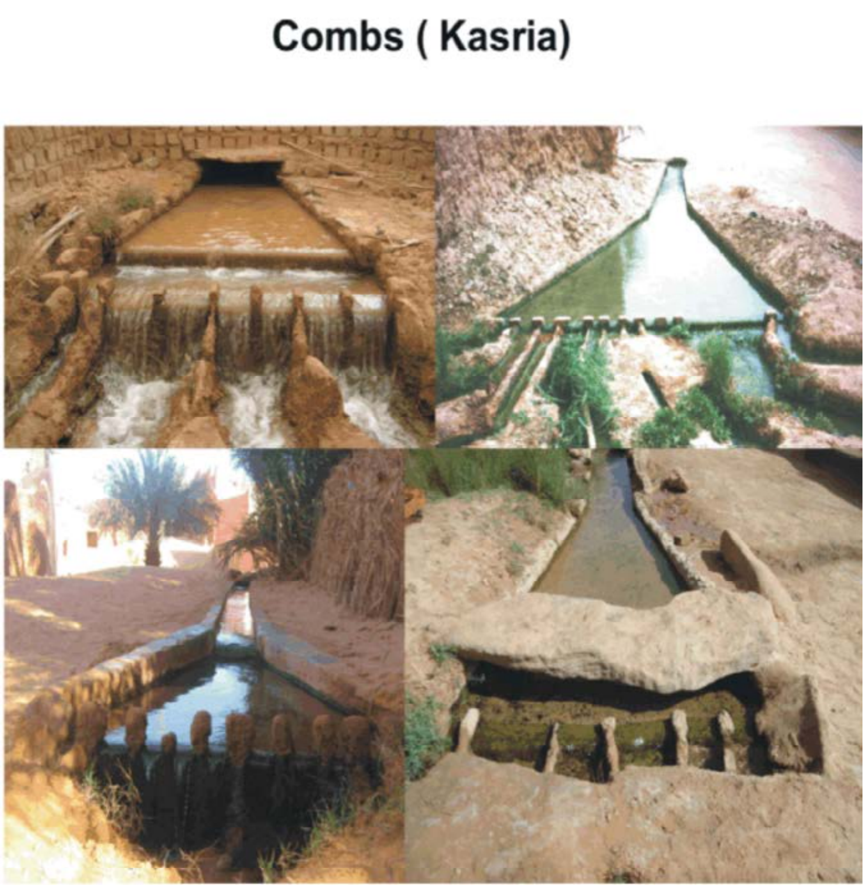

Fig. 12: Combs (Kasria) of foggara

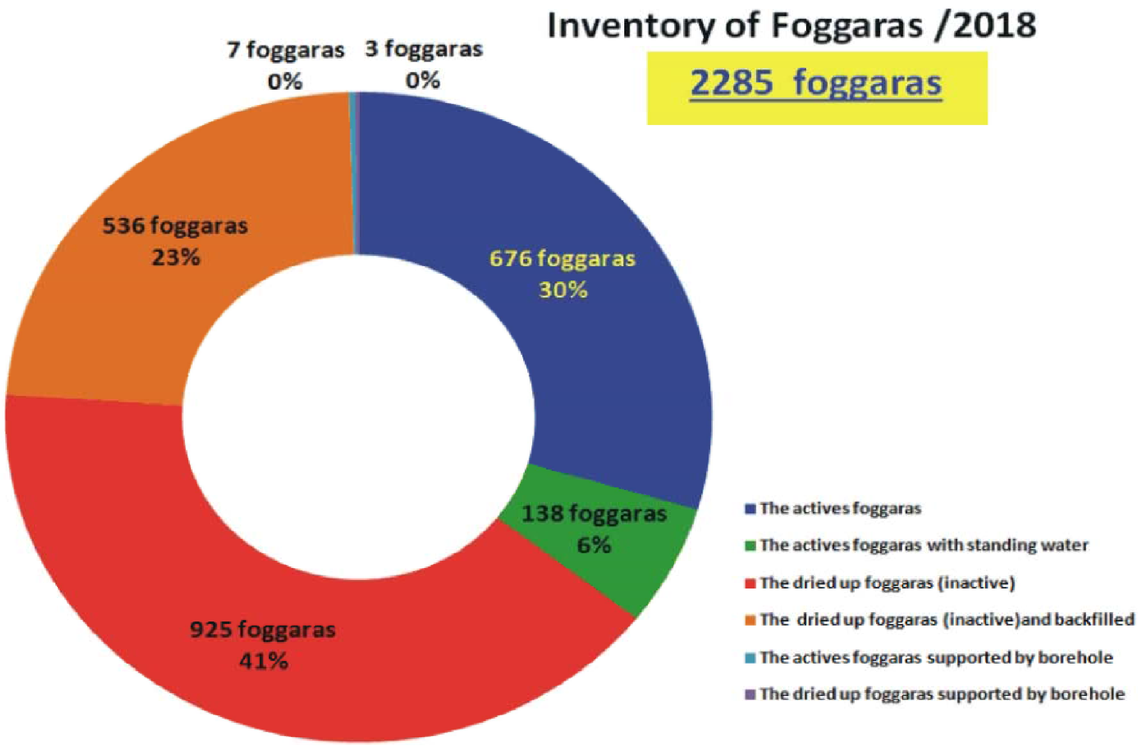

Fig. 13: Inventory of foggaras in Adrar province.

Research Methodology: The perennial foggaras in Adrar province irrigate 176 palm groves, which cover a total area of 17000 ha. A variety of vegetables are cultivated here, including tomatoes, onions, potatoes, garlic, eggplant, carrots and peas. Also, over 100 varieties of date are grown here, serving as a food staple for local 'oasiens'. The dates also contribute to the local economy, with three varieties exported to The Mali and Niger. Despite the long history of foggaras and their use in the Algerian Sahara, they remain complex and fragile systems of water distribution that are sensitive to ecological, hydrogeological and socioeconomic factors and changes. Large-scale ecosystem management involves consideration of many factors for informed decision making [11]. The integration of GIS into foggara's management allows decisions makers from multiple institutions to make a contribution toward protecting foggaras. Because with easy access to all data about foggara and easily share information with all partners become an absolute necessity for the safeguarding of foggaras.

In 1998, National Agency of Hydraulics Resources made an inventory of all foggaras, in Adrar province. The inventory updated in 2011, 2012, 2013, 2014, 2015, 2016, 2017 and 2018.

We have also, a document about the inventory achieved in 1942. The total number of foggaras in Adrar Province is about 2285 foggaras (Figure 13). We have also; positioned 2202 combs by GPS for all foggaras of Touat, Tidikelt and Gourara regions. The total number of actives foggaras is 676+138+7+3 = 824 foggaras. These 824 foggaras irrigates our palm-groves and preserves greenery in this arid area [12].

The total number of foggaras' wells positioned and located by GPS is two hundred and seventy-six thousand eight hundred and thirty-one (276831 wells) in Adrar province. (Figure: 14).

Flow Measurement of Foggara: Flow rate is the volume of water passing through a cross section of the watercourse for one unit of time. It is expressed in m^3/s in the International System (IS) of units. Sometimes for low flows, we use the l / s. Measuring foggara's flow rate with mini current meter consists of measuring the flow velocities over several verticals of the cross-section. The number and position of the verticals depend on the heterogeneity of the section (water level and flow velocities). The verticals are closer to the places where the variation of the velocities is great (generally on the edges), as well as to the right of the

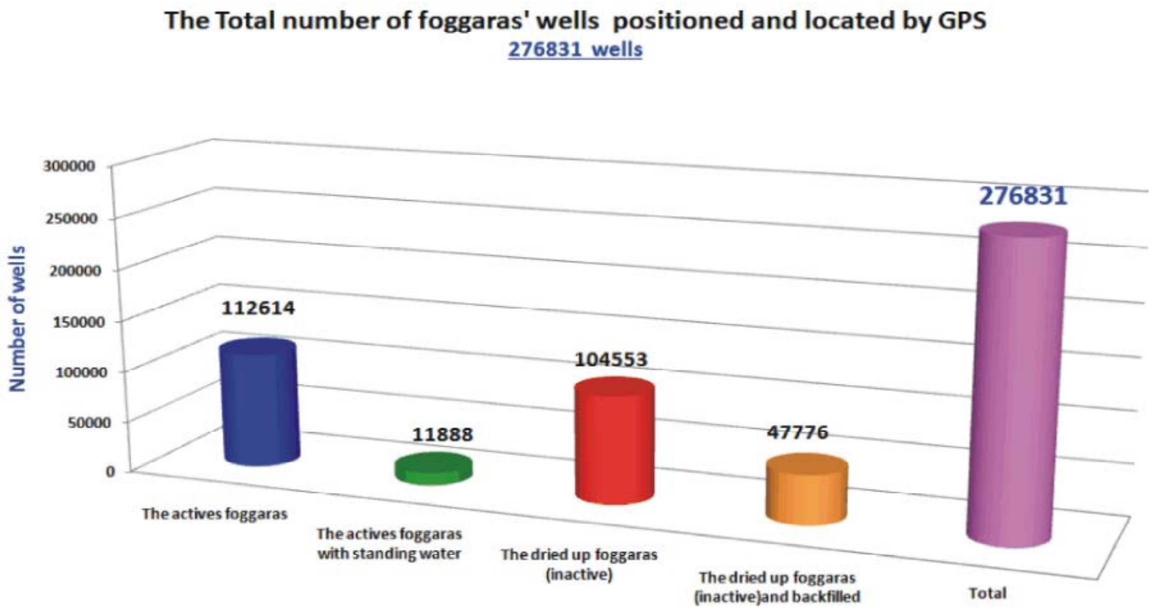

Fig. 14: The total number of foggaras' wells positioned by GPS

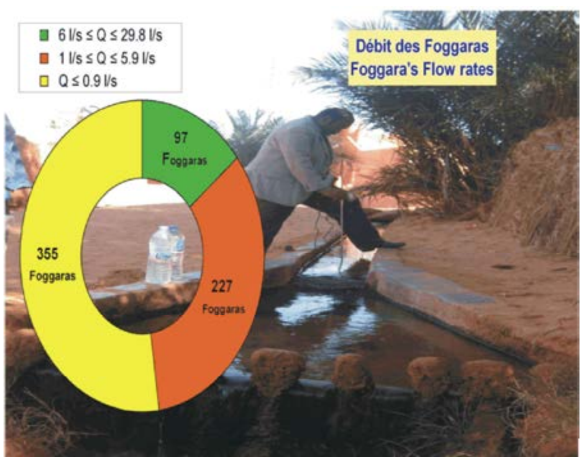

Fig. 15: Mesure de débit de foggaras

important discontinuities of the total depth. The mini current meter immersed in the main outlet of the foggara not far from the principal comb, the propeller pointing upstream of the flow, the speed of rotation of the propeller is linked, by a known relation, to the speed local flow (Figure 15).

A propeller is characterized by its diameter and its hydraulic pitch. The hydraulic pitch is the distance travelled by the water to generate a propeller turn. The relationship between the velocity of the flow and the speed of rotation of the helix is called the "calibration curve" of the propeller. For a determined speed range, the calibration curve is substantially linear. For a given propeller, we will have one or more lines of equation of the form:

$$V = an\ n * nt + bn. \qquad \text{Equation (1)}$$

- V= Flow velocity
- an= hydraulic pitch
- nt= propeller revolution per second
- bn= caracteristic of curent meter m/s

Water Quality of Foggaras: To study the water quality of foggars in Adrar, a total of 681 samples in 2011 and 395 samples in 2015 and 430 samples in 2017, were collected from foggaras wells and combs in the study area, in order to assess the water quality of foggaras; and determining its suitability for agricultural. Physical and chemical parameters of groundwater such as pH, electrical conductivity, total dissolved solids, Na, K, Ca, Mg, Fe, Cl, HCO_3 and SO_4 were determined. Various water quality indices like SAR have been calculated for each foggaras' water sample to identify the irrigational suitability standard. TheTotal dissolved salts TDS (Figure 16) indicates that 64 % of foggaras' water for agriculture is in good category, 36 % of that is used with caution. (Figure17) [13].

The PH indicates that 82 % of foggaras' water for agriculture is in good category (Figure17).

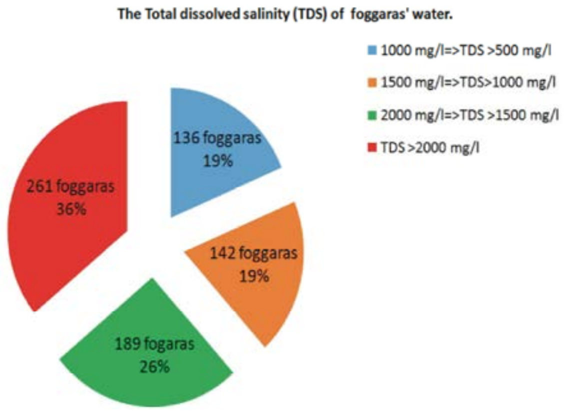

Fig. 16: Total dissolved salinity of foggaras' water

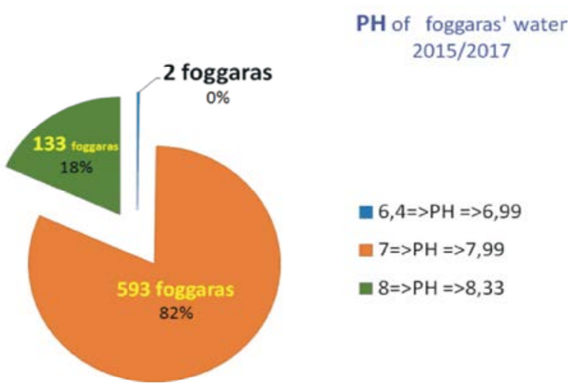

Fig. 17: PH of Foggaras' water

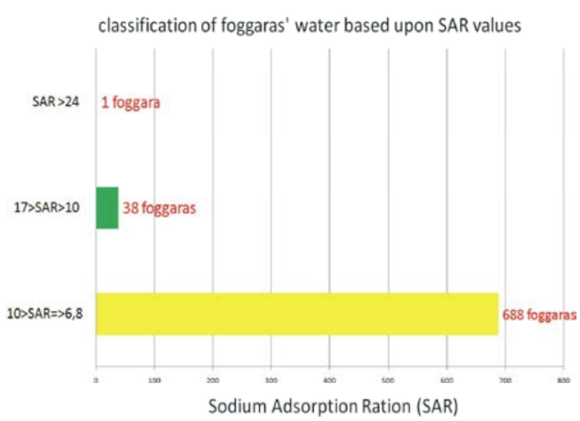

Fig. 18: Classification of foggaras based upon SAR

94.5 % (688 foggaras) of foggaras' water for agriculture is in low Na water (Little danger).

5.21% (38 foggaras) is in medium Na water (Problems on fine texture soils and sodium sensitive plants, especially under low-leaching conditions. Soils should have good permeability), 0.14% (one foggara) of foggaras' water for agriculture is in very high Na water (Unsatisfactory).

Foggara and GIS: In a GIS, you connect data with geography. And you understand what belongs where. Because you don't fully understand your data until you see how it relates to other things in a geographic context. The GIS is associated by a set of tools, which do data management, processing, analysis and presentation of results for information and related geographic locations. The geographical space can be viewed as composed of overlaid planes of information over a wider geographical area like our study area and each plane has specific information or features. One plane may have the positioning of foggars' features, an other plane may have the elevations of foggaras' wells or combs, an other plane may have the depth of wells, an other plane may have foggaras' water quality etc. Tools help among others to combine planes of information do processing with combined planes using map algebra and create thematic maps. Features in a GIS are considered as objects, which are used to build most models of information to help engineers and decisions makers to share easily more and more information. Geographic information systems technology (GIS) offers vital insight for managing and understanding foggaras across the province of Adrar. Understanding precedes action." As Richard Saul Wurman says.

The Components of Foggaras GIS: Generally, the Geographical Information System consists of four basic parts. These are the data itself, the software used to explore the spatial relationships, the hardware used to run and store the software/data and the users. Our GIS is not been created and designed only for foggaras but it designed for water's management in the huge area of south-west of Algeria. Foggara's GIS is part of that big database. It is made up:

- 230 digitized topographic maps.
- 95 digitized geological maps.
- 250 units of digital elevation models (DEM)
- 10 Satellite Photos.
- Database about foggara: wells, combs ; water quality and …… ect.

The Arrangement of the Database in Foggara' GIS: This database is split into two parts, you can only get this information by clicking on the comb,or wells. By clicking on the comb you get this information below (Figure 19).

Add to the information that you have by clicking on the comb, you can have an other information by clicking on the wells (Figure 20).

Fig. 19: Information about foggara by clicking on comb

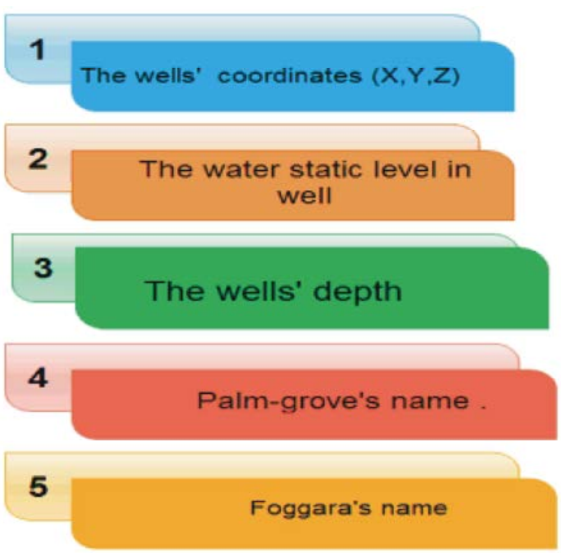

Fig. 20: information about wells

What Can We Do with GIS of Foggaras: GIS can be used as tool in both problem solving and decision making processes, as well as for visualization of data in a spatial environment. Geospatial data can be analyzed to determine:

Mapping Where Foggaras Are: We can map the spatial location of real-world of foggraras and visualize the spatial relationships among them. and you can know any information on any foggara through adrar province. Given that the 2285 foggaras are located over a length of more than 360 km. They are distributed on 260 palm groves (Figure 22). Foggaras' GIS allows you to classify foggaras by state (foggaras actives; foggaras dried up …….ect) (Figure 21 and 22)[14].

Finding What Is Inside?: We can use foggaras' GIS to determine what is happening, inside foggqra or inside palm-grove. We can determine the characteristics of "inside" by creating specific criteria to share with other partners (Figure 23).

Finding What Is Nearby?: We can find out what is happening within a set distance of a foggara by mapping what is nearby using geoprocessing tools. Below foggara and boreholes (Figure 24).

The Protection Foggara from Drying up with Using GIS: Foggaras and boreholes for irrigation or supply water, use the same aquifer (The North-Western Sahara Aquifer System (NWSAS)). Pumping from an aquifer removes water from the void space, leaving there a certain quantity of water that is held against gravity. As a result of pumping, the water table at each point in the vicinity of the well is lowered with respect to its initial position by a vertical distance called drawdown, s(x, y, t). The drawdown surface in the vicinity of a pumping well (also called the cone of depression) shows the variation of drawdown with the distance from a pumping well. As pumping continues, the drawdown at every point increases and the cone of depression expands. The size and shape (slope) of the cone of depression depends on many factors. The pumping rate in the well will affect the size of the cone. Also, the type of aquifer material, such as whether the aquifer is, sand, silt, like NWSAS aquifer, also will affect how far the cone extends. The amount of water in storage and the thickness of the aquifer also will determine the size and shape of the cone of depression.

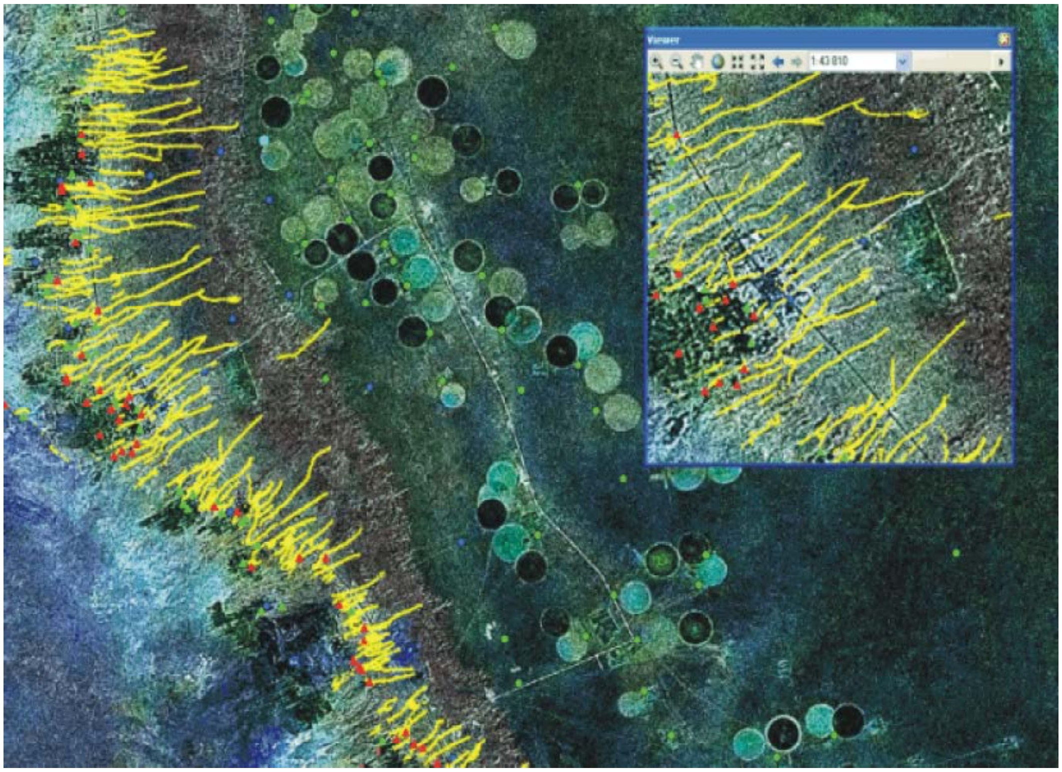

Fig. 21: Map of foggaras in Adrar

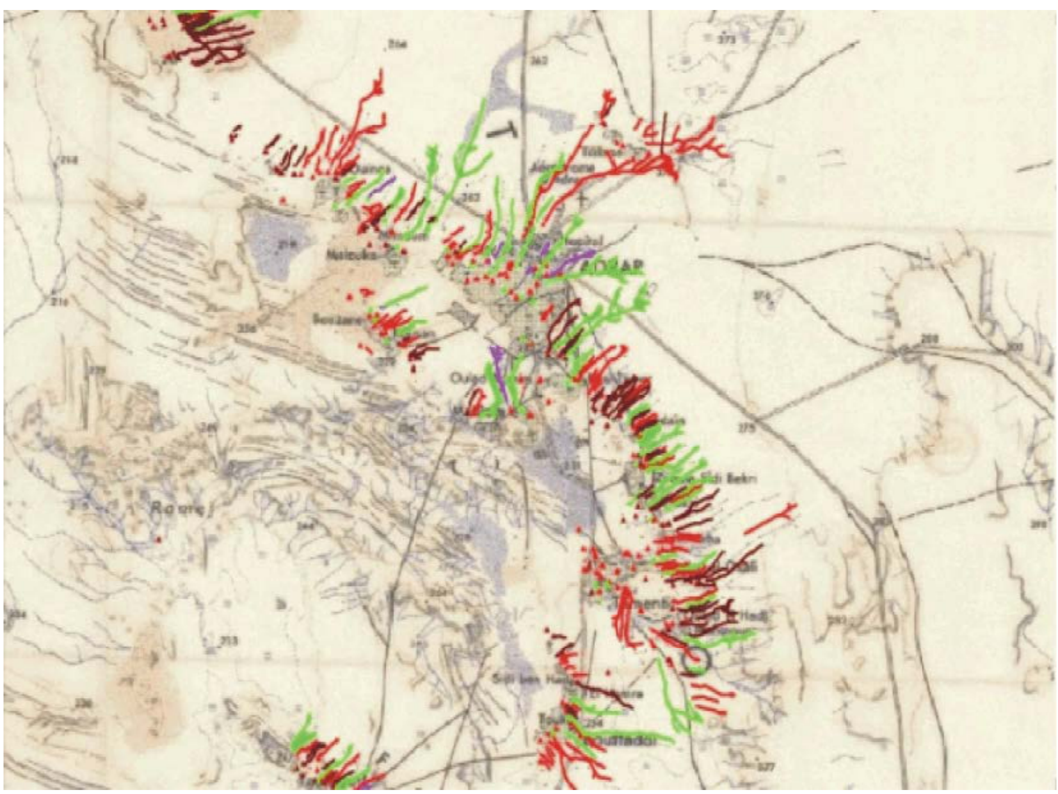

Fig. 22: Classification of foggars by state, green color is foggras actives, red color is foggaras dried up

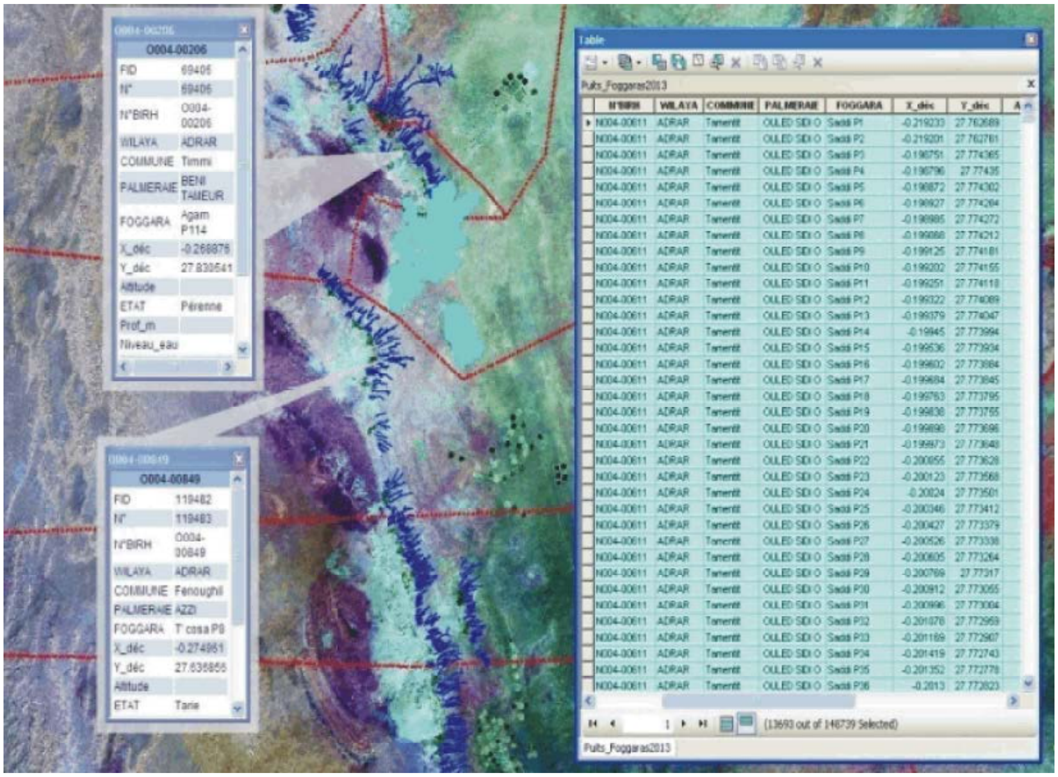

Fig. 23: Information inside Foggara

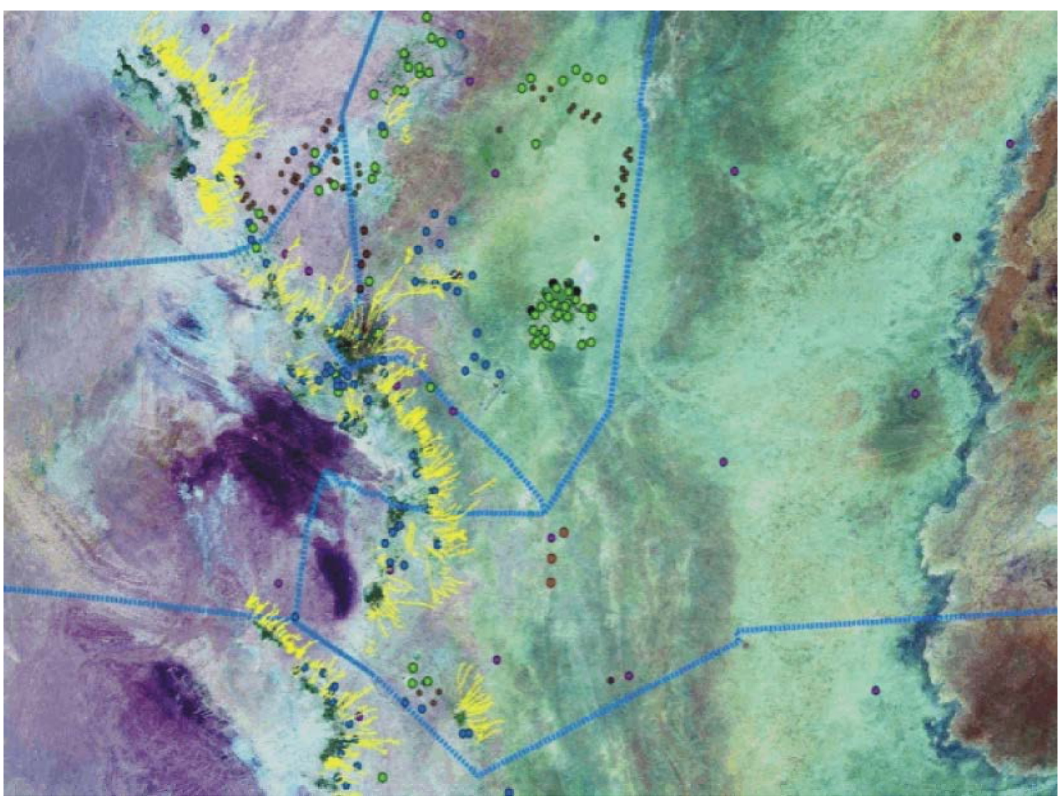

Fig. 24: Finding what is nearby: Boreholes, agricole area

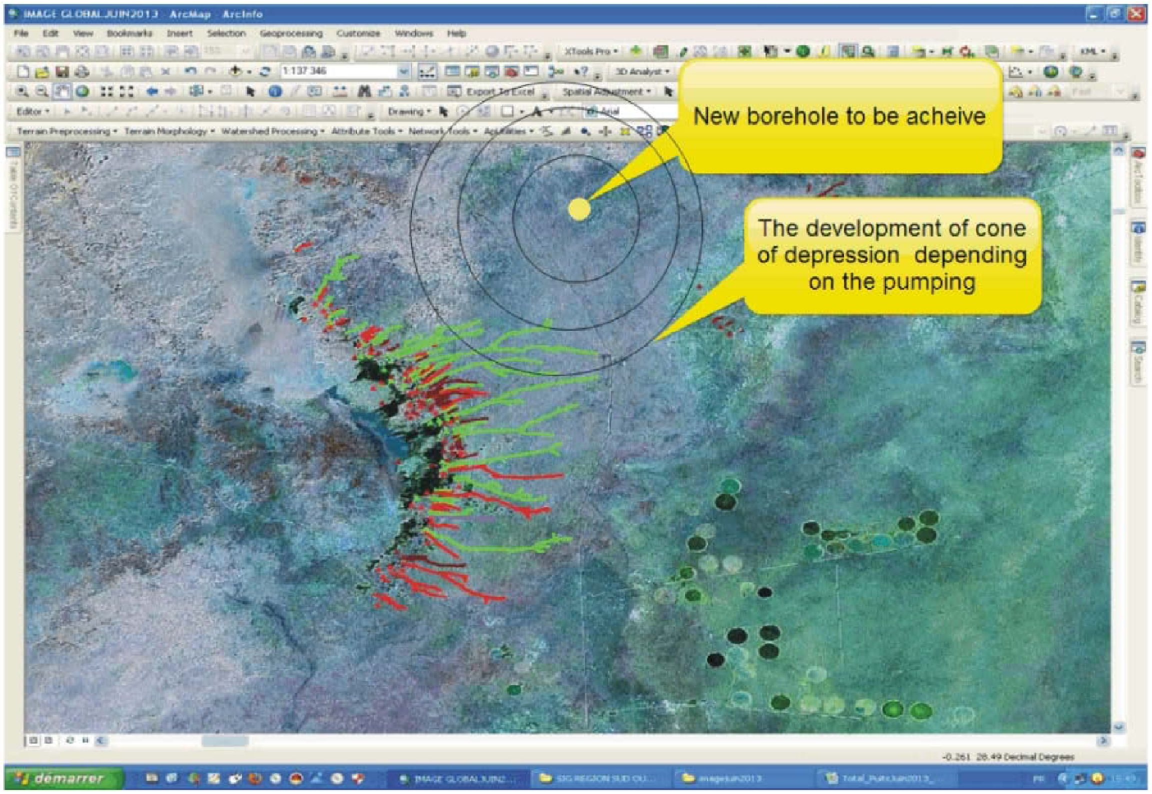

Fig. 25: Protection of Foggara

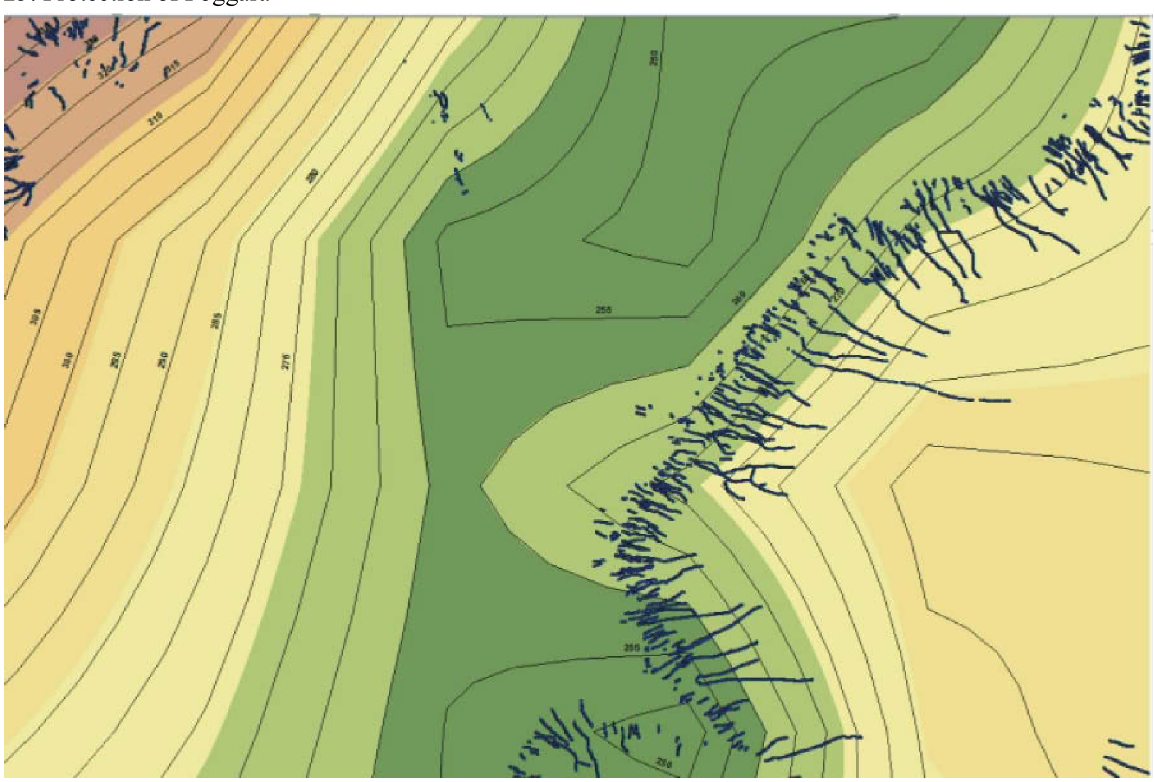

Fig. 26: Map of depth of foggaras' wells

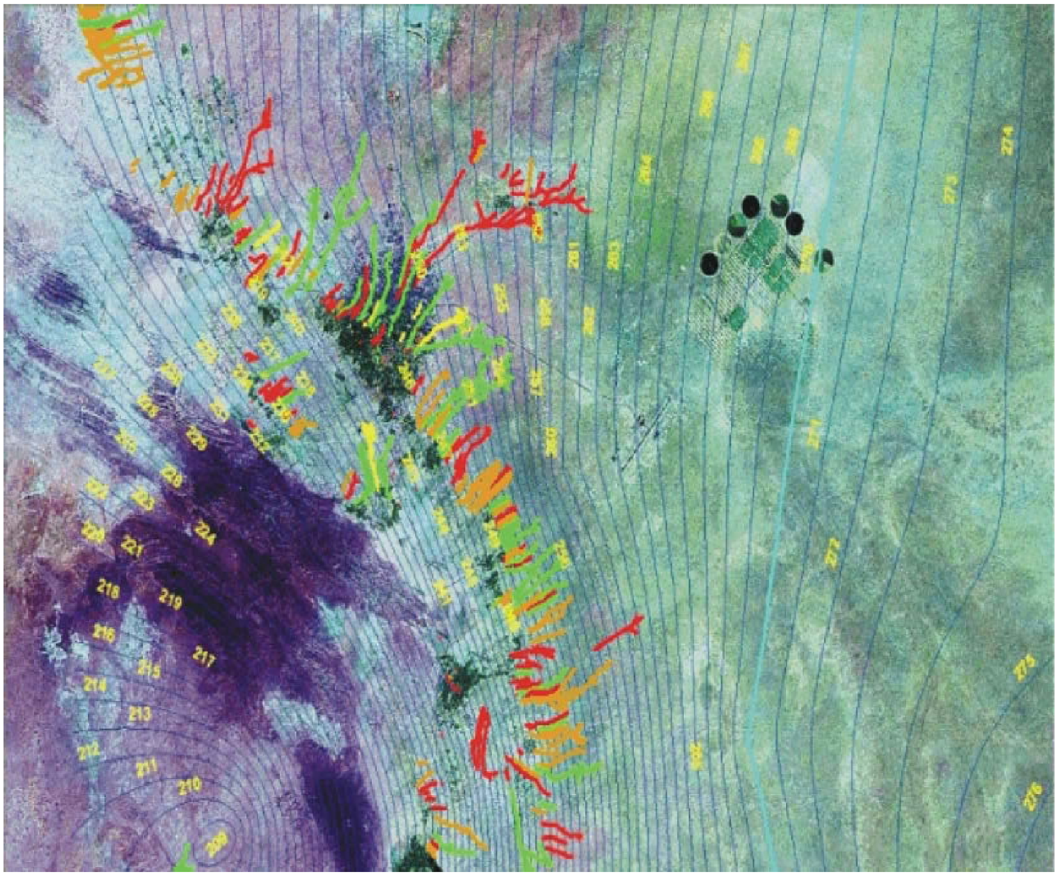

Fig. 27: Foggaras depth destribution

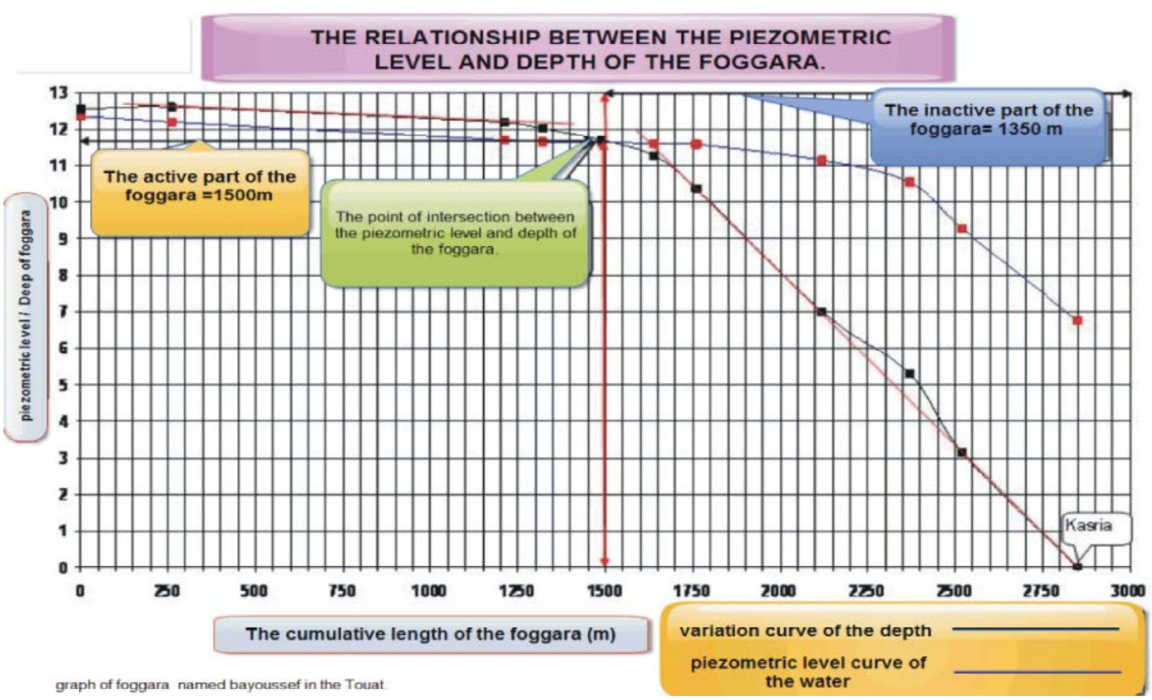

Fig. 28: Relationship between depth map and piezometric map.

A study entitled Water wells' exploitation and its impact on the drying up of foggaras, the case of the foggara of M'ghaer, Timimoune, province of Adrar, Algeria, it carried out by Boualem Remini and Bensaada Mohamed whose results of the study are published in 2014, [15] confirmed that drilling deep water wells near the foggara has a direct impact on it (due to the lowering of the piezometric level of the underground water reserve): the decrease of flow. We have measured the depth of 3718 wells of foggaras. We find that the depth of foggaras wells varies from 2 m to 40 m depending on the region. The foggara uses the first meters of the aquifer, any drawdown of aquifer affects directly foggaras. Foggaras' GIS allows you easily to avoid the drying up of foggara or foggaras because it let you how many foggara will be affected by this new borehole. Also, you can directly measure the distance between new borehole and foggara or foggaras. By estimating the borehole's flow rate you calculate the cone of depression. (Figure 25).

This is a very important data for engneers to chooce easily the best place to achieve borehole and protect foggara.

An Other Purpose of Foggara's GIS: Inventory and measurement of the depth of 3718 wells allow us to draw the map of depth of foggaras' wells (Figure 26 and 27).

We draw a piezometric map. Using the depth map and piezometric map and you combine these two maps. the result of this assemblage is very important information about foggara. you determine the active part and the inactive part of foggara. The GIS allows you to obtain, with an ease that information for any active foggara. This allows you to calculate the spécific flow rate for any foggara (Figure 28).

CONCLUSION

Different water processes have to be understood in relation to each other for implementing integrated water management. At the local scale it is no longer tolerable that different institutions only deal with their separated water system. To improve communication GIS can become a supportive instrument and can act as catalyst. It combines information originating from different sources. We can come closer to integrated water management in a step by step approach where all interested institutions should be involved and all geographical scales should be considered. Foggaras, wells and boreholes uses same water comes from aquifer called the North-Western Sahara Aquifer System (NWSAS) Système Aquifère du Sahara Septentrional (SASS) in French. To understand the functioning the foggaras compared to functioning of boreholes or wells and for safeguarding foggaras also, improve management of this complex system.

You should make all information in GIS Because GIS allows making the technology and data work in a larger context in order to develop effective management strategies of foggaras and a sustainable development of this arid region. Also, GIS of foggara is integreded in huge water database ofAdrar region.

REFERENCES

1. Chehma, A., 2011. Le sahara en Algérie, situation et défis.
2. Pereira, L.S., I. Cordery and I. Iacovides, 2009. Coping with water scarcity: Addressing the challenges. Springer Science & Business Media.
3. Remini, B., B. Achour and R. Kechad, 2010. La foggara en Algérie: un patrimoine hydraulique mondial, Revue des sciences de l'eau/Journal of Water Science, 23(2): 105-117.
4. ANRH, 2011. Étude hydrologique et hydrochimique de la region d'Adrar, Agence Nationale des ressources Hydrauliques, ANRH Adrar, Rapport Interne.
5. Remini, B. and B. Achour, 2013. The foggaras of In Salah (Algeria): the forgotten heritage, LARHYSS Journal ISSN 1112-3680, pp: 15.
6. Acharya, S., A. Pandey and U.C. Chaube, 2014. Use of geographic information systems in irrigation management: A review, Journal of Indian Water Resources Society, 34(2): 32-39.
7. Nasri, B., A. Benatiallah, S. Kaloum and S. Soulimani, 2017. Nitrate Impact on the Groundwater Quality Degradation in Arid Areas (Timiaouine Region South of Algeria), in Euro-Mediterranean Conference for Environmental Integration, pp: 669-672.
8. Benhamza, M., 2013. Aperçu hydrogeologique et hydrochiimique sur le systeme de captage traditionnel des eaux souterraines «foggara» dans la regiion d''adrar," PhD Thesis, Université Badji Mokhtar de Annaba, 2013.
9. CEDARE., 2014. North Western Sahara Aquifer

System (NWSAS) M et E Rapid Assessment Report, Monitoring et Evaluation for Water In North Africa (MEWINA) Project, Water Resources Management Program, CEDARE., Observatoire du Sahel et Sahara, Tunisie, Monitoring & Evaluation for Water In North Africa (MEWINA) 5600155002351.

10. Mohamed, B. and B. Remini, 2017. Water wells' exploitation and its impact on the drying up of foggaras, Applied Water Science, 7(1):. 349-359.
11. Boualem, R. and K. Rabah, 2012. The foggara in the Arab world, Geographia Technica, 1: 1-7.
12. ANRH, Inventories of foggara in Adrar," 2018 1998.
13. N.A. of H.R. ANRH, 2013. Water quality of foggaaras in Adrar area," ANRH, 2013.
14. Nasri, B., A. Benatiallah, S. Kalloum and M. Benhamza, 2018. Caracterisation physico-chimique des eaux sousterraines de la région de Kenadsa et Galbelaousa (Sud-ouest de l'Algérie), Algerian J. Env. Sc. Technology, 4(1): 82-93.
15. Remini, B., R. Kechad and B. Achour, 2014. The collecting of groundwater by the qanats: a millennium technique decaying, LARHYSS Journal ISSN 1112-3680, pp: 20.