# Physico-chemical Characterization of Irrigation Water Foggaras of Aougrout (Southwest of Algeria)

**Boumediene Benaricha, Abdelkader Khaldi and Abdelkader Elouissi**

Laboratoire de Recherche sur les Systèmes Biologiques et la Géomatique. Université de Mascara, BP 305, Mascara, 29000, Algérie

## ABSTRACT

In order to evaluate the underground water physicochemical quality of the Continental Intercalary ply and explain the the mineralization phenomena origin of these waters, physicochemical analyzes were performed on 67 samples of water from Aougrout foggaras (South western Algeria). The aquifer is contained in the Lower Cretaceous formations (Albian and Barremian), made up of sand and sandstone clay. The waters are slightly mineralized with an average value of 1g/l. Piper diagram showed a predominance of the chemical profile-chlorinated sodium and potassium, followed by a sulphated calcic chemical profile depending on the traversed lithology. Saturation indices (SI) calculated show a subsaturation vis-a-vis minerals, such as halite and gypsum. Salinity according Richards diagram is medium to high, and the alkalinity risk is low to high. The Index Base Exchange (IBE) calculated is negative on almost all waters (97%), reflecting the exchange of $Ca^{2+}$ and $Mg^{2+}$ against the $Na^+$ and $K^+$ ions of the surrounding clay formations reflecting the richness of the waters in sodium relative to $Ca^{2+}$ and $Mg^{2+}$. An intrinsic salinity origin supposes sodium salts ion dissolution in contact with groundwater. Statistical analysis by the principal component analysis (C.PA) led us to arrive at 2 points, the first is that variables electrical conductivity (EC), dry residue (R.S), $Na^+$, $Ca^{2+}$, $Cl^-$, $SO_4^{--}$, $Mg^{2+}$, $Na^+$, $K^+$, hydrometric degree (TH), mineralization, are best correlated and responsible for signing the water mineral content, as well as the correlation between bicarbonate ion ($HCO_3^-$) and complete alkalimetric title (C.A.T), the second is that the nitrate ion ($NO_3^-$), opposite to variables above cited, marks its anthropogenic variables. Finally, and in general, the water is good to for irrigation and potable for consumption but under control for the nitrates presence.

**KEY WORDS :** Physico-chemical, Water, Foggaras, Facies, Salinity, PCA, Nitrate

## 1. INTRODUCTION

In the desert areas of the Maghreb (Algeria, Tunisia, Libya), there is a reserve of not very renewable fossil water. It is represented by two large tanks of two sedimentary basins called transboundary aquifers: the Terminal Complex (TC) and the Continental Intercalary (C.I). In the Saharan regions, known for low rainfall, these aquifers are the only water resource for supplying the population and irrigation of gardens Saharan oasis, immutable constellation of green patches on this immense desert of sand and rocks. These totally manmade spaces are representing intensive production systems of great complexity now in almost fragile balance.

In Algeria, oasis occupies an area of 93,000 ha with over 10 million date palms, 11% of the world total. The culture of the date palm and to lesser extent vegetable constitutes the only resources of the population in desert areas.

Aougrout, hyper arid Adrar (Algeria) is part of the oasis which is less supplied by the water of Foggaras system from the underground water of Albian Continental midsole. The fougaras irrigation technique is to install a slightly sloping gallery that drains water from the web to the surface.

This study is part of an extensive research study of hydrochemistry non-renewable fossil water from the entire region of Adrar. Salinity and pollution is a threat of these waters and so to the survival of the Saharan oases populations.

### 1.1 Study area

Aougrout is a town of Adrar Gourara part of the region (southwest of Algeria). It covers 13,736 km2, and is situated in an altitude of 293 meters, latitude 28 ° 45 '00"Nord, longitude 1 ° 25' 00''Est (fig.1). It is limited to the north by the city of Timimoune and south by the city of Adrar. It lies west of the Erg Chech and the northwest of Western erg, Tademaït the tray is in the Northeast. Most of the area around the oasis is a rocky flat plain called reg, with some hills low elevations to the east and southeast. The region has many ksours (traditional villages) and oasis.

**Corresponding Author:** Boumedienne Benaricha, Laboratoire de Recherche sur les Systèmes Biologiques et la Géomatique. Université de Mascara, BP 305, Mascara, 29000, Algérie. Phone: (+213) (7) 80976061 Email: benarichab@yahoo.fr

The climate is hot and desert with very hot summers and mild winters with very low rainfall. Wind is common with 25 km / h, the sirocco reaches 100 km / h. Rainfall does not exceed 10 mm / year, and the humidity rate is around 40%. The vegetation of the oasis consists of date palms and vegetable crops. The agricultural area is about 2491 hectares; 350 hectares are used (photo 1 a & b). It is irrigated by the waters of the Continental Intercalary (Albian) using a hydraulic system called ancestral foggaras (photo.2 a & b).
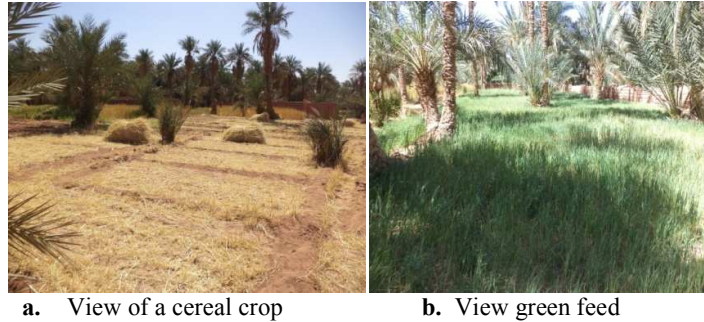


**a.** View of a cereal crop      **b.** View green feed
**Photo.1** view of the plots of the oasis of Aougrout (Benaricha. B, April 2013)
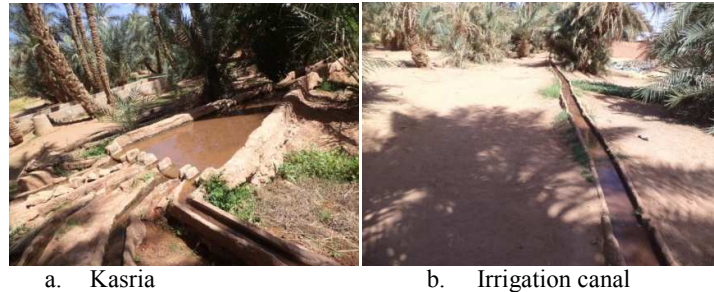


a. Kasria      b. Irrigation canal
**Photo. 2** (a) kasria, triangular basin capturing water foggaras. (b) Water distribution channel in the palm.
(Benaricha. B, April 2013)

### 1.2 Geology and Hydrogeology

On the lithostratigraphic, the paleozoic forms the essential of the sedimentary cover. This coverage is jarring on a Precambrian pedestal or infracambrian whose depth varies between 1800 m in west and around 5500 to 6000 m in the center of the pool. All the paleozoic cycles are either sandstone, or clayey ad clayey-sandstone. Carbonate episodes are only known in Givetian and lower Franien.

The paleozoic is covered by the secondary transgressive depots layers that are generally flat. The Mesozoic average thickness is only of the order of 700 m. The mesozoic cover is represented by the sedimentary series of lower cretaceous, it is constituted from top to bottom with the Albian, and the Barrémien which forms the Continental intercalary. These depots outcrop are: (i) straight in sub-surface, (ii) under a dune recovering of recent age or (iii) under a Pliocene-Quaternary covering [1][2][3][4].

The continental episode is localized between two marine's sedimentary cycles: (i) in base, the paleozoic which completes the Hercynian orogeny, (ii) on the top, the superior cretaceous cycle.

The Barremien of medium thickness of 276 meters, formed of thin sandstone to medium, carbonated, interposed i level of sandstone and dolomitic clays. The Aptien of medium thickness of 24m formed of two dolomitic layers framing a level of clay. The Albien of thick detrital series of the order around 362 m, tie in to an important aquifer horizon, it is represented in its totality by sandstone and silty clay.

The hydraulic pool includes a series of layers, aquifers which have been regrouped in three following types:

**(i)** the artesian aquifer called intercalary continental (or Albian's aquifer), is characterized by continental detrital formation between the paleozoic and the cenomanian marine. The waters of this aquifer flows into a reservoir that stretches over 600 000 km$^2$ from Libya to the west of Algeria [5]. Its capacity is over than 30 000 billions m3, it contain the biggest reservoir of underground water in Saharan zone. The clay-sandstone formations of "C.I." have the average thickness of 200 meters below the post-Albian series Tademait and eroded from this plateau until it is ended in bevel on paleozoic and flushing inside the Gourara-Touat [5];

**(ii)** the aquifer of the terminal complex (T.C) is characterized by the carbonated formations of superior cretaceous and tertiary detrital episodes and mainly the Miocene. The homogeneity of this aquifer waters (T.C) give a thought that these will be issued from the last fresh pluvial, that would be started around 14.500 years [6];

**(iii)** Both aquifers are surmounted by the water table which is presented in all oasis. In the north at the big occidental Erg, this groundwater is situated at Tertiaire continental formations from Saharan atlas to Gourara where it is mixed

with C.I. Waters. The general circulation of waters in the occidental basin is the NNW to the SSE before being recovered in the direction of NE-SW by the depression drain of Gourara-Touat. On the other hand the limestone of Upper Cretaceous and the Eocene Terminal Complex (T.C.) are powered by the flow in the waters of Oueds from the Mzab dorsal [7]. A Sebkha Chaplet makes the underground waters outfall around which the water table has a shallow, is used by wells and fouggaras [8].
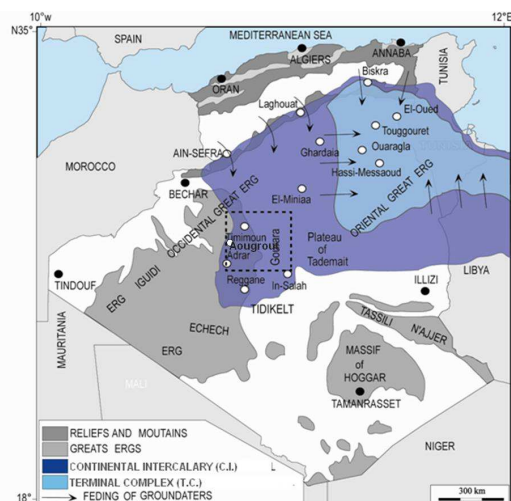


**Fig.1** Map chowing the geographical location of the study area (dotted Square) and geographic extensions of the groundwater of the Continental Intercalary (C.I.) and Terminal Complex (T.C.)

## 2. MATERIALS AND METHODS

The Foggara waters that have been used for the analyzes came from Kasrias, triangular basin used to stock water before being distributed between the part owners of the palm gardens [9]. The samplings were carried out between January-April 2013. The collected water was packaged in opaque bottles and kept cold until arrival at the laboratory [10][11].

Fifty four (67) samples of water were taken from the area of Aougrout (fig.2). The physico-chemical analyzes are presented in two forms:

In situ for organoleptic parameters: color (visual observation), smell (feeling) and flavor (tasting) during the sampling. The physical parameters were determined at the time of taking the samples: a temperature using a field thermometer, pH by a pH meter WTW NOLAB. The electrical conductivity is measured by a ground conductivity type WTW LF 521. A field turbidity (NTU turbidity or nephelometric turbidity unit) to measure turbidity.

Chemical parameters were determined in the laboratory of the National Agency of Hydraulic Resources (N.A.H.R). The hardness or title hydrometric (TH) is determined by a complexometric determination by EDTA at pH 10 using the Black of Eriochrome. The dry residue D.R. is obtained after passing through an oven at 110°C by double weighing. The bivalent cations $Ca^{2+}$ and $Mg^{2+}$ are determined by titration with EDTA (Ethylene diamino tetra acetic acid) the monovalent cations $Na^+$ and $K^+$ were determined by the flame spectrophotometer (PFP7). The $NO_2^-$ anions (nitrite) and nitrate ($NO_3^-$), chloride ($Cl^-$), phosphate ($PO_4^{3-}$) by colorimetry. Carbonates ($CO_3^{2-}$) and bicarbonate ($HCO_3^-$) are determined by titration with sulfuric acid ($H_2SO_4$). The oxidized organic matter is measured by potassium permanganate reduction.

To better visualize and characterize the physico-chemical data of the water, we used two complementary approaches, the charts ranking the water (chemical facies, salinity classes and alkalinities) the diagrams classifying waters. by the Avignon hydrochemistry software (AHS) Version 6 (2014) using diagrams Piper, and Richards, the other, a mathematical description of water by a principal component analysis (PCA) using Statistica version 6 software to study, the spatial distribution of water points in function of the physicochemical variables (variable constant temperature was discarded because it has no variance in the statistical treatment). Multivariate statistical approach allows us to make a comprehensive study of the data involved, to summarize, to represent them, to classify, visualize and define the relationships that may exist between the variables.
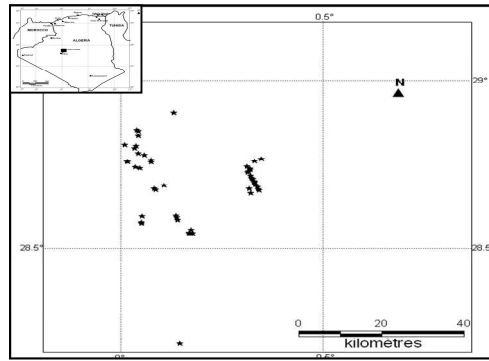
.

**Fig. 2** The geographical location of water sampling points

## 3. RESULTS AND DISCUSSION

### 3.1. Physical parameters

Organoleptic tests revealed no abnormality in the waters of foggaras. The turbidity values (NTU) are less than 5 ranking them as very clear waters. The hydrometric degree (TH) or hardness of water is the sum of the concentrations of calcium and magnesium [12]. According to the World Health Organization [13] hardness standards, water foggaras are 36% hard to very hard (TH> 32 °F), and only 64% hardness levels between 22-32 °F (enough fresh water) and this is related to the lithology of forming acquires and composition of magnesium and calcium. The hardness has consequences more or less harmful as excessive consumption of soap (when the water used is hard (high TH), fatty acids "neutralize" the calcium and magnesium from the water before it can act as agents detergents, hard water requires for the same detergency higher amount of soap a fresh water), poor cooking of pulses and the unacceptable taste.

The temperature of the water is an important factor. It plays a role in the solubility of the gas in the separation of salts, the change in pH, knowledge of the origin of the water and any mixtures, etc. In addition, this measure is important in limnology and in general, it is influenced by the source from which they come superficial or deep [14]. The water temperature is almost constant all values are equal to 21. The pH depends on the origin of water, the geological nature of the substrate through [15][16]. This setting affects many physical and chemical balances, and depends on many factors, including temperature and the source of water. It represents an important indication as regards the aggressiveness of the water (ability to dissolve lime). Hydrogen potential of the values are between 6 and 8.5 in natural waters [17], regarding foggaras water, the pH is between 6.80 and 8.20 with a mean value of 7.60 indicating the presence of bicarbonate ion ($HCO_3^-$). The complete alkalimetric title (C.A.T) in analyzed water samples was mainly due to bicarbonate ion ($HCO_3^-$). CAT varies between 7 and 14° F with an average of 9.80 °F. The CAT is in the range of 75 mg/l 168 mg/l of $HCO_3^-$, with mean values of 118 mg/l $HCO_3^-$, and this results in zero values of the carbonate ion $CO_3^{2-}$. The waters are slightly mineralized. The values range between 691 and 4898 mg / l with an average of 1106 mg / l. The dry residue is between 730 and 5000 mg / l with an average of 1164 mg / l.

### 3.2. Evaluation of water quality

The traditional irrigation system "Foggara" in the Algerian Sahara has allowed the transition from nomadic to sedentary. Uncontrolled irrigation little impact on plants and soils, as can disrupt the development of plants and cause changes in soil structure [18]. To assess the quality of groundwater foggaras of Aougrout used in the oasis, we used the Piper diagram for determining the chemical facies, and diagrams of [19] and [20] Richards - diagram " Riverside ", to understand the risk of salinization and soil sodisation.
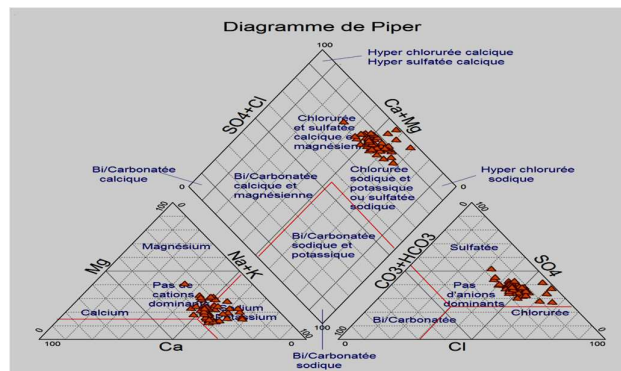


**Fig. 3 Facies of chemical groundwater Aougrout**

### 3.3. Determining the facies of chemical the waters

The representation of the samples on the Piper diagram (Fig. 3) shows the existence in most samples a predominant chemical facies chlorinated sodium and potassium, followed by a calcium sulfatée –chemical facies depending on the lithology traversed. These representative samples of the groundwater table Aougrout to show an alignment of the points that reflects changes between a sodium-chloride-facies of a calcium sulfatée – chemical facies. These are the chlorides predominate in these waters, as well as sodium and potassium cations, resulting in the dissolution of evaporite salt formations.

### 3.4. Origin of mineralization
**The reports Na $^+$ / Cl$^-$ and Ca$^{2+}$ / SO$_4$ $^{2-}$**

The very good correlation between sodium Na$^+$ and Cl$^-$ Chloride ($R^2$ = 0.96) and the alignment points taken around and on the right side of the dissolution of the halite confirms the geological origin of these ions by the dissolution halite (Fig.4a). The correlation between calcium Ca$^{2+}$ and SO$_4^{2-}$ sulphate is good ($R^2$ = 0.88) with a relative enrichment of sulphate with respect to calcium and confirming the dissolution of the gypsum and the geological origin of the mineral (4b). These ions geological origins are from the evaporite salt formations.
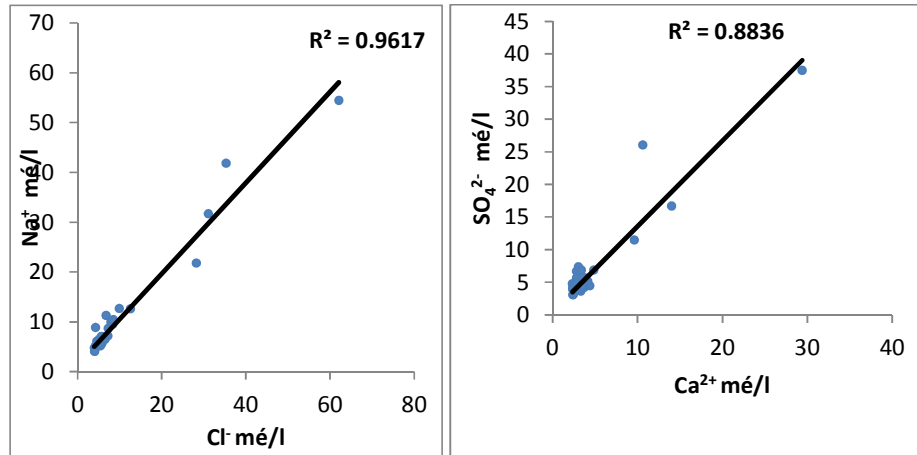
### Saturation Index (SI)

To determine the influence of the chemical elements, we used the thermodynamic tool by calculating the saturation index. According to the law of mass action, to an aqueous solution in equilibrium with a mineral, ion activity product (IAP) of the mineral is equal to the equilibrium constant (KSP) Thermodynamics. The degree of saturation of water can be represented by:

**SI (Saturation index) = Log (IAP/KSP)**

This constant K characterizes the balance established in a reversible system which constantly evolving (for a given temperature). Noting hat SI will be respectively zero, positive and negative to a solution equilibrium with the mineral solid phase considered, for under-saturation water and for over-saturation water towards the ionic elements concerned.

The saturation index calculated on 67 samples, the integrated software PHREEQ in Diagram software (LHA Simlers, 2013) is negative for all water sources, it is groundwater under saturated with halite, promoting the dissolution of this mineral (fig. 5a). the waters of Aougrout are under-saturated with gypsum (fig.5b), indicating the dissolution of this mineral.



a.  Right dissolution of halite                b.  Right dissolution of gypsum

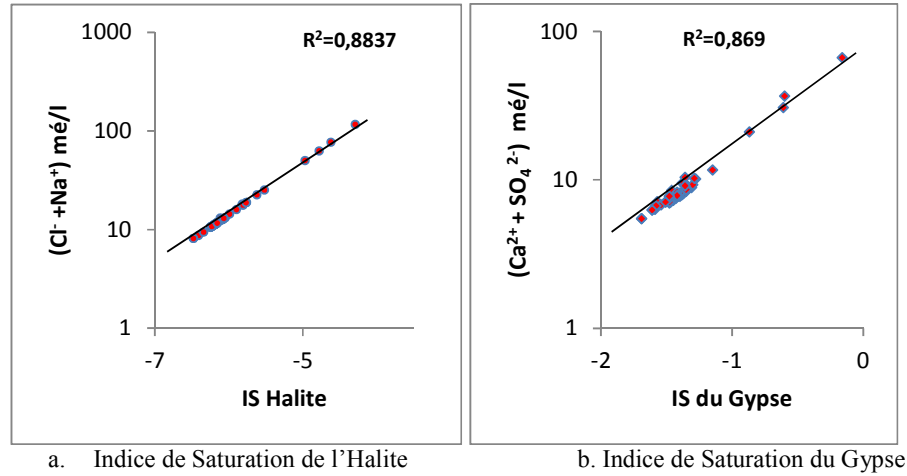**Fig. 4** Relationship of Na$^+$ et Cl$^-$,  Ca$^{2+}$ et SO$_4^{2-}$

a. Indice de Saturation de l'Halite       b. Indice de Saturation du Gypse

**Fig. 5** Correlation of saturation indices water of halite, gypsum, according $Na^+Cl^-$ (a), $Ca^{2+}+SO_4^-$(b) respectively, ($R^2$ coefficient of determination

**Index Base Exchange (I.B.E)**

According to Schoeller, 1934 in [21], the cation exchange is a preferred setting mechanism of certain ions by clay minerals. In principle, and especially $K^+$ $Na^+$ of the solution are exchanged against $Ca^{2+}$ and $Mg^{2+}$ fixed in some mineral sites. Thus, if the contact time with the clay is quite long, the solution tends to become poorer in $Na^+$ and $K^+$, and being enriched by $Ca^{2+}$ and $Mg^{2+}$.

Increasing the concentration of $Na^+$ and $K^+$ cation exchange is evaluated by considering that precipitation water, or recharging, was ions balance between $Cl^-$ and $(Na^+ + K^+)$. The use of index base exchange (I.b.e.) allows to highlight the water chemistry changes during its underground path. This index is the ratio of ion-exchanged and the same kind existing originally ions in water Scholler.H. 1956 in [22], we consider then the ion ratio as index cation exchange obtained by the following relationship:

**I.B.E = [rCl - r (Na + K)] / rCl**

- If I.B.E is negative then $Ca^{2+}$ and $Mg^{2+}$ of water are exchanged against the $K^+$ ions and $Na^+$ of the surrounding formations.
- If I.B.E. is positive then the $Na^+$ and $K^+$ ions of water are replaced by ions $Mg^{2+}$ and $Ca^{2+}$ of the surrounding formations.
- If I.B.E. = 0 then there is a balance between the chemical compositions of the water and that of the surrounding ground.

**Tab.1** Statistical parameters of water for index base exchange

| Stastical parameters | Minimum | Maximum | Average | Standard-deviation |
|---|---|---|---|---|
| Index Base Exchange | 0,199 | -1,194 | -0,202 | 0,147 |

The characterization of ion exchange between the web and the aquifer defined I.b.e index is negative over more than 97% of the water samples, and varies between 0.19 and -1,194 (tab. 1), the ions $Ca^{2+}$ and $Mg^{2+}$ of groundwater are exchanged against the $Na^+$ and $K^+$ ions of the surrounding clay formations. However groundwater of Aougrout reflect well this exchange, as they are richer in $Na^+$ compared to $Ca^{2+}$ and $Mg^{2+}$, this is due to lexiviage of halite in addition the contribution of the base exchange with the clay matrix. None of the index zero was recorded on all studied waters; positive values represent only 3%.
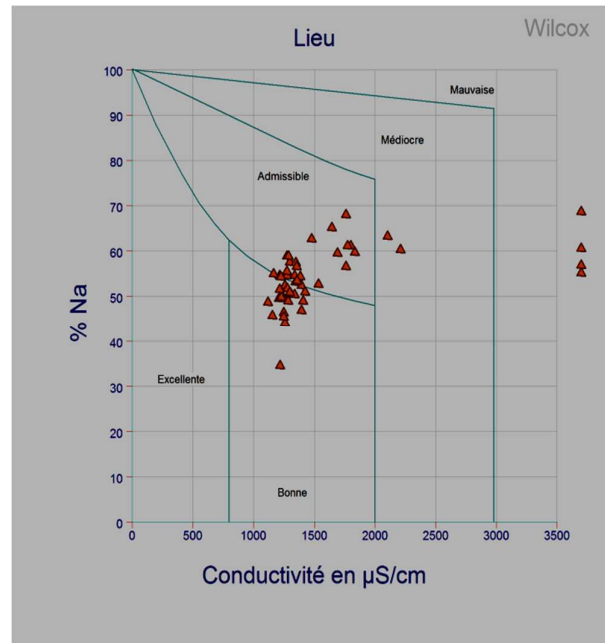
**Fig.6** Representation of water foggaras of Aougrout in Wilcox diagram

### 3.5. Ability of water for irrigation and effects on soil

*Wilcox* diagram (fig.6) shows 91% of groundwater Aougrout are good to qualify and only 9% of the water is poor to bad. The quality of water used for irrigation is an important parameter to consider, not only in the study of the direct impact on agricultural products, but also in that of the indirect impact on them by modifying their physical and chemical properties of soils [23]. High salinity affects plant growth by the osmotic effect, while alkalinity to affect the permeability of the soil.

In order to study the water quality of the aquifer for irrigation, we made recourse of the method of Richards [20]. It highlights different classes of water by the intersection between the electric conductivity and the sodium absorbable (Sodium Absorption Ratio, SAR) defined by the following equation:

$$SAR = [Na^+] / [\sqrt{(Ca^{2+} + Mg^{2+}) / 2}]$$

All ions are in mè / l
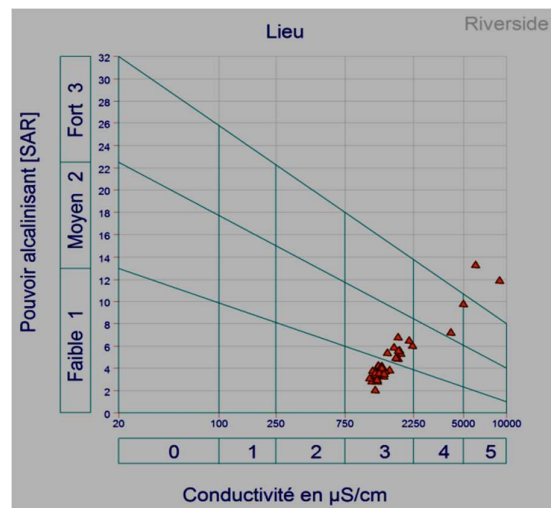


**Fig.7** Distribution of salinity classes of water foggaras of Aougrout in Riverside USSLS diagram

After postponing all water points foggaras of Aougrout on Richards diagram (fig.7) was able to identify the presence of the five classes [C3S1, C3S2, C4-5S3, C5-S4] with a predominance the first 2 classes [C3S1, C3S2] corresponding to the average salinity classes to high and with the risk of low alkalinity high. The other three classes [C4-5S3, C5-S4] are at very high risk of salinity and alkalinity. Similar researches in the Touat,

neighboring Aougrout area, showed that the majority of foggaras waters are in situated in C3-4 S4 classes, corresponding to the high salinity classes and high alkalinity risk [24]. Other works on waters of the intercalary and terminal continental tablecloth, in the Touggourt region, revealed strong salinity classes and a strong to very strong alkalinity risk [25]. Electrical conductivity (E.C.) is a function of the water temperature, it is more important when the temperature increases. According to the standard of the evaluation of the quality of water and the American, Durand [26] in Algeria established in 1958, 93% of waters of high salinity (0.75 <EC <2.25 dS / m or 0.5-1, 5 g / l of salt), 3% of high salt (2.25 <EC <5 ds / m or 1.5-3 g / l of salt), and 1% excessive salinity (5 < EC <20 or 3-7 g / l of salt). The sodisation power (or alkalization), that is to say the SAR of waters are greater than 10 to 99% of water. Acceptable SAR values around 10 have little effect on the properties of the soil as the overall salinity is sufficient (> 0.7 dS / m), but can cause toxicity by sodium [27]. The standard limit of salinity threshold is 3dS/m at 25 °C [27], but given the high evaporation, even the salt concentration of the water sometimes causes severe problems for plants. Thus the salinisation will establish one of the main factors responsible for the wheat yield decrease. Indeed, works on crop yields in Adrar have shown that an increase of 1 dS/m causes a grain yield fall of 4 quintals/ha. In the Aougrout palm, salinity is visible with salts deposits goshawks plants [28]. A depression in the oasis with the accumulation of saline drainage water has created a small sebkha whose progress or lateral seepage has an effect on the surrounding vegetation, leaving place to halophiles plants as Salicornia of salt marshes (fig. 3).



a. Formation of a small sebkha     b. Effect of salinity sebkha vegetation
**Photo.3** View of a small sebkha of Aougrout and effects of salt water on the palms

### 3.6. Principal Components Analysis (PCA)

The principal component analysis (P.C.A) aims to project variables and individuals, from a multidimensional cloud, on planes (two-dimensional). The study was done on 15 variables and 67 individuals. The correlation matrix (tab.2) highlights the strong relationship between electrical conductivity (E.C), the dry residue (RS), $Na^+$, $Ca^{2+}$, $Cl^-$, $SO_4^{--}$, $Mg^{2+}$, $Na^+$, $K^+$, TH, mineralization and the sum ions, as well as the correlation between $HCO_3^-$ and CAT. The first two axes together contribute almost 84% of the information, which is very sufficient and allows us to neglect the use of other axes.

Also, the quantile table at 95% of inertia percentage of the first two dimensions and for variables number equal to 15 and a individuals number equal to 67 gives us about 26%. So our projection quality (83.79%) is considerably good since it far exceeds the minimum requirement (26%). For these reasons, we will simply projecting the plane F1 x F2. The projection of the variables and individuals on F1 x F2 plane is shown in Fig. 8.

Tab. 2 : Correlation matrix between the parameters analyzed groundwater Aougrout

| variables | PH | E.C | R.S | $NO_3^-$ | $Ca^{2+}$ | $Mg^{2+}$ | $Na^+$ | $K^+$ | $Cl^-$ | $SO_4^{2-}$ | $HCO_3^-$ | TH | CAT | Minéra | S ions |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PH | 1 | | | | | | | | | | | | | | |
| E.C | -0.023 | 1 | | | | | | | | | | | | | |
| R. S | 0.011 | 0.956 | 1 | | | | | | | | | | | | |
| $NO_3^-$ | -0.064 | 0.586 | 0.574 | 1 | | | | | | | | | | | |
| $Ca^{2+}$ | 0.069 | 0.922 | 0.874 | 0.459 | 1 | | | | | | | | | | |
| $Mg^{2+}$ | -0.170 | 0.883 | 0.818 | 0.322 | 0.804 | 1 | | | | | | | | | |
| $Na^+$ | 0.029 | 0.994 | 0.959 | 0.576 | 0.918 | 0.859 | 1 | | | | | | | | |
| $K^+$ | -0.161 | 0.902 | 0.887 | 0.681 | 0.706 | 0.761 | 0.899 | 1 | | | | | | | |
| $Cl^-$ | 0.049 | 0.981 | 0.940 | 0.496 | 0.960 | 0.886 | 0.981 | 0.835 | 1 | | | | | | |
| $SO_4^{2-}$ | -0.017 | 0.982 | 0.932 | 0.541 | 0.940 | 0.860 | 0.980 | 0.863 | 0.969 | 1 | | | | | |
| $HCO_3^-$ | -0.005 | 0.249 | 0.293 | 0.248 | 0.201 | 0.185 | 0.246 | 0.206 | 0.218 | 0.190 | 1 | | | | |
| TH | -0.012 | 0.951 | 0.895 | 0.432 | 0.978 | 0.911 | 0.940 | 0.758 | 0.978 | 0.956 | 0.204 | 1 | | | |
| CAT | 0.015 | 0.260 | 0.300 | 0.270 | 0.189 | 0.186 | 0.255 | 0.231 | 0.222 | 0.192 | 0.983 | 0.196 | 1 | | |
| Minéra | -0.036 | 0.987 | 0.942 | 0.581 | 0.919 | 0.874 | 0.978 | 0.883 | 0.967 | 0.973 | 0.262 | 0.945 | 0.267 | 1 | |
| Sum ions | 0.018 | 0.993 | 0.950 | 0.542 | 0.955 | 0.879 | 0.992 | 0.863 | 0.993 | 0.989 | 0.238 | 0.973 | 0.242 | 0.981 | 1 |

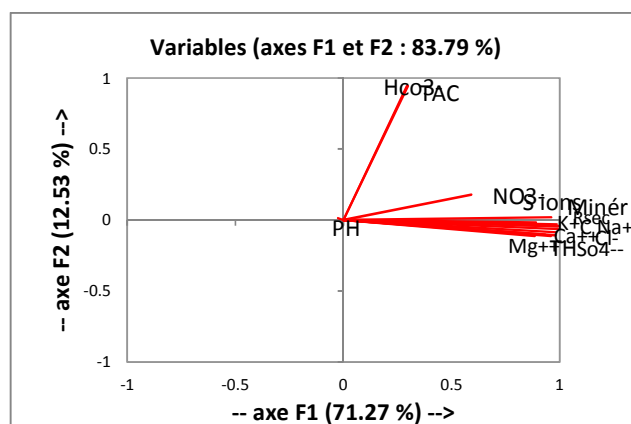Fat, significant values (off-diagonal) at alpha = 0.050 (two-tailed test)

Fig. 8  Projection of variables on the F1 x F2 plane

**Study variables**

Tab. 3 Correlation between variables and axes

| variables | F1 | F2 | F3 |
|---|---|---|---|
| PH | -0.026 | 0.013 | 0.970 |
| E.C | 0.996 | -0.041 | -0.003 |
| Dry Residue (R.S) | 0.962 | 0.019 | 0.024 |
| NO3- | 0.591 | 0.178 | -0.203 |
| $Ca^{2+}$ | 0.934 | -0.103 | 0.151 |
| $Mg^{2+}$ | 0.885 | -0.112 | -0.115 |
| $Na^{+}$ | 0.991 | -0.043 | 0.047 |
| $K^{+}$ | 0.891 | -0.016 | -0.220 |
| $Cl^{-}$ | 0.984 | -0.086 | 0.098 |
| $SO_4^{2-}$ | 0.981 | -0.108 | 0.019 |
| $HCO_3^{-}$ | 0.293 | 0.943 | 0.020 |
| TH | 0.961 | -0.112 | 0.065 |
| CAT | 0.299 | 0.945 | 0.028 |
| Minéralization | 0.987 | -0.028 | -0.013 |
| Sum of ions | 0.994 | -0.063 | 0.056 |

The axis 1 or factor 1 (Fig.8) represents 71.27% of the total information. Table 3 shows that the most correlated variables with this axis are EC, RS, $Na^+$, $Ca^{2+}$, $Cl^-$, $SO_4^{--}$, $Mg^{2+}$, $Na^+$, $K^+$, TH, Mineralization and Sum of ions (> 0.85). It is they who are responsible for the signing of the water mineral charge highlighting the geological natural. Individuals who have high coordinates on the axis 1 have strong values for our above-mentioned variables (and vice versa).

The axis 2 has 12.53% (Fig. 8) of the total information. The CAT and $HCO_3^-$ variables are the only ones that are well correlated with this axis (tab.3), and therefore individuals who have high coordinates on the axis 2 will have high values for these two variables (and vice versa). We note that only well projected variables (coordinates> 0.85) can be interpreted (above mentioned variables). We can also note a slight detachment of nitrate ($NO_3^-$) relative to variables giving the possibility of their anthropogenic origin related to wastewater infiltration from septic tanks in the absence of wastewater sewerage system in the region strengthening this hypothesis [29][ 30], because agriculture is very traditional in oasis Aougrout not using fertilizer.

Natural sources of nitrate ion ($NO_3^-$) are mainly rain and soil-vegetation interactions. The nitrates are anthropogenic contamination by fertilizers, pesticides and household waste. Nitrates are not toxic to humans. However, their conversion to nitrite ($NO_2^-$) in the digestive tract under the bacteria action, can cause the transformation of hemoglobin to "methemoglobin" Blue Baby Syndrome from 50 mg/l [31]. In adults, long-term consumption participle in the nitrosamines formation, a carcinogenic molecule. In natural milieu, concentration rarely exceeds 0.45 mg/l, the water potability standard is 50 mg/l, above 100 mg/l, the water is unfit for consumption. The contents of recorded nitrates greater than 50 mg/l represent only 8% of total foggaras water, 4% are between 40 and 50 mg/l, 88% contents of between 20 and 40 mg/l. The average value

of nitrates (NO$_3^-$) is 35 mg/l; a maximum reported value is 80 mg/l. We can say that the Aougrout foggaras waters are at the potability limit.
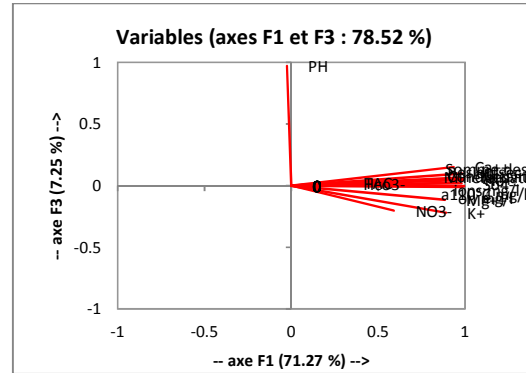


**Fig. 9  Projection of variables on the F1 x F3 plane**

The pH variable is well correlated with the F3 factor (0.97) and therefore it contributes alone to this axis formation. The F1xF3 plane projection seems to provide additional information (Fig. 9). This also indicates that the pH variable, and or the TAC, are correlated with bicarbonate ion (HCO$_3^-$) and anti-correlated with other variables.

## 4. CONCLUSION

The data hydrochemical study showed that foggaras waters, of the sheet infill continental or webs of Aougrout Albian, are characterized by an average pH of 7.60 indicating the presence of the bicarbonate ion or hydrogen carbonate (HCO$_3^-$), an average mineralization of 1 g/l, a chlorinated-sodium and potassium chemical facies predominances followed by a calcium-sulphate chemical facies. They are characterized by high to very high salinity and low to very high alkalizing risk. To highlight the relationship between geology and water chemistry of the aquifer studied, we have directed our research towards geochemical appearance. The waters of the Aougrout Albian table are under-saturated vis-a-vis the evaporite mineral licks. In fact, dissolution of these minerals seems to contribute to the groundwater mineralization. The anthropogenic nitrate (NO$_3^-$) ions origin is confirmed by the statistical study. In general, the water is good to qualify for irrigation and potable for consumption but under control for the nitrates presence.

## 5. REFERENCES

1. Busson, G., 1967. Le Mésozoïque saharien. L'extrême sud tunisien ; CNRS.
2. Deleau, P., 1951. Les bassins Houillers du Sud oranais dans la région de Béchar-Abadla. Bulletin du Service Géologique de l'Algérie, Livre I, Stratigraphie, 275p.
3. Deleau, P., 1952. La région de Colomb-Béchar. Monographie Régionale, Alger, XIXe Congrès de Géologie International, 1 (8): 1-101.
4. Kilian, C., 1931. Des principaux complexes continentaux du Sahara. Comptes Rendus Sommaires des séances de la Société Géologique de France, vol. 9, pp: 109-111.
5. S.A.S.S. (Système Aquifère du Sahara Septentrional)., 2002. Volume 2: Synthèse hydrogéologique, 155p.
6. Gibert, E., 1989. Géochimie et paléohydrologie des bassins lacustres du nord-ouest saharien. Programme Palhydaf, site 2. Thèse de Docteur en Sciences, Université de Paris Sud, Centre d'Orsay.
7. S.A.S.S. (Système Aquifère du Sahara Septentrional  Algérie, Tunisie, Lybie)., 2008. Gestion commune d'un bassin  transfrontalier\ OSS. Collection synthèse n°1. Tunis, 48p.
8. Gonfiantini,G., Conrad, G., Fontes, J-C., Sauzay, G., Payne, B.R., 1974. Etude du Continental Intercalaire et ses relations avec autres nappes du Sahara Sept ; in : Isot techn groundwater hydrology; AIEA.
9. Remini, B., and Achour B.,2008. Les foggaras du grand Erg Occidental Algérien. Larhyss Journal, n° 07, pp: 21-37.
10. Thioulouse, J., Chessel, D., Doledec, S., Olivier, J.M., 1997. ADE-4 : a multivariate analysis and graphical display software. Statistics and Computing Journal 7, pp: 75-83.
11. Rodier, J., 2005. L'analyse de l'eau : Eaux naturelles, eaux résiduaires, eau de mer. 8$^e$ édition. Paris : Dunod.

12. Rosset, R., Ben Amor, M., Ghorbel, A., 1997. Caractérisation du pouvoir incrustant des eaux d'irrigation du Cap Bon par chronoéléctrogravimétrie, Comptes Rendus Académie des sciences Paris, 325, pp: 727-732.
13. World Health Organization (WHO)., 1993. Guidelines for drinking water quality, (2nd edition), Volume 1, Geneva, WHO. 130p.
14. Rodier, J., 1984. L'analyse de l'eau : Eaux naturelles, eaux résiduaires, eaux de mer. Edition Dunod Paris.
15. Dussart, B., 1966. Limnologie : Etude des eaux continentales. Gauthier- Villars, Ed., Paris.
16. Bermond, R., and Vuichaard, R., 1973. Les paramètres de la qualité des eaux. Documentation Française, Paris, 179p.
17. Chapman, D., and Kimstach, V., 1996. Selection of water quality variables. Water quality assessments : a guide to the use of biota, sediments and water in environment monitoring, Chapman edition, 2nd ed. E & FN Spon, London, pp: 59-126.
18. Person, J., 1978. Irrigation et drainage en Tunisie problème posé par la salinité des sols et des eaux. Bulletin du BRGM, 2ème série, section III, n° 2, pp: 143-151.
19. Wilcox, L.V., 1948. The quality of water for agricultural use. U.S. Dept Agriculture Tech. Bull 1962, Washington. DC.
20. Richards L. A. sous la direction U.S.S.L.S. (United State Salinity Laboratory Staff).,1954. Diagnosis and improvement of saline and alkali soils.US Department of Agriculture, Handbook n°60, U. S. Gov. Print. Office, Washington DC (USA), 160p.
21. Bakalowicz, M., 2013. Les eaux souterraines : hydrologie dynamique et chimique, recherche, exploitation et évaluation des ressources. Quoi de neuf ? Dix-neuvièmes journées techniques du Comité Français d'Hydrogéologie de l'Association Internationale des Hydrogéologues Bordeaux 30 mai – 2 juin 2013.
22. Hamzaoui, A.F., Bouhlila, R., Gueddari, M., 2012. Caractérisation de la minéralisation des eaux de la nappe des grèsdu Trias (Sud-Est Tunisien) par les méthodes géochimiques et statistiques. Journal Geo-Eco-Trop., n°36, pp: 49-62.
23. Suarez, D., Wood, J., Lesch, S., 2006. Effect of SAR on water infiltration under a sequential rain-irrigation management system. Agric water Manage; 86, pp: 150-164.
24. Hidaoui, A., and Louannas, A., 2015. Etude du système traditionnel d'irrigation au Sahara, exemple des Foggaras de la région d'Adrar (Touat). Thèse de Master université Abou baker Belaid Tlemcen Algerie. 132p.
25. Belkasier, M-S., Chaab, S., Zeddouri, A., Bouselsad, B., Kechiched, R., 2014. L'irrigation et le risque de la pollution saline. Exemple des eaux de la nappe libre dans la region de Touggourt. International Journal for Environnement and Global Climat Change 2, (3), pp : 32-39.
26. Durand, J.H., 1958. Les sols irrigables. Alger : SES, 190p.
27. Ayers, R.S., and Westcot, D.W., 1976. La qualité de l'eau en agriculture. Bulletin FAO d'irrigation et de drainage 29, 82p.
28. Ziza, F-Z., Daoud, Y., Laboudi, A., Bradi, R., Zouara, A., 2009. Evolution de la salinité dans lesperimetres de mises en valeur et consequence sur la diminution des rendements du blé dans une region saharienn. Cas de la région d'Adrar. Seminaire international « Protection et preservation des ecosystemes sahariens ». Ouargla. pp : 35-36.
29. Settou, D., 2013. Etude hydrogéologique et hydrochimique de la nappe du continentale intercalaire de la région de Touat (Adrar, Algérie). Univ. de Ourgla, mémoire de master, 65p.
30. Djouadi, A., and Oubelaid, A. 2015. Etude hydrochimique des eaux de la région de Gourara (Timimoune, Algérie). Univ, de Khemis Miliana, mémoire de master, 70p.
31. O.M.S., 2011. Guidelines for drinking-water quality - 4th ed. 564p.