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STUDY OF HYDROGEOLOGICAL FUNCTIONING OF COMPLEX TERMINAL (CT) AQUIFER, USING HYDROGEOCHEMICAL AND ISOTOPIC TOOLS: CASE STUDY OF OUED SOUF REGION (SOUTHEAST OF ALGERIA)

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Abstract: *The largest confined aquifers hydraulically continuous from the Algeria Atlas Mountains as a recharge area to the Tunisian Chotts were discharge area. Is being largely used in the valley of Oued Souf, southeastern of Algeria and part of the northeastern Sahara, composed with sedimentary series ranging from the lower Cretaceous to the Quaternary. These formations have favored several aquifer layers with variable hydrodynamic behavior depending on their facies. The high expansion of the agricultural field needs irrigation from groundwater aquifers in this area. The overexploitation of the shallow aquifer causes severe deterioration of groundwater quality and soil suffusion at arid areas. The high salinity (electrical conductivity exceeds 3600 $mS.cm^{-1}$) coupled with groundwater level decline pose serious problems for current irrigation and domestic water supplies. Although, the multi-layers of complex terminal (CT) and continental intercalary (CI) aquifers is used to approve the water supplies. In aim to corroborate the hydrochemical process, and to investigate the water potentialities and mineralization of CT and CI groundwater aquifers, chemical tools namely major elements and trace elements are studied. The isotopic (δ 18O, δ 2H) hydrogeochemical study helps to identify and classify this deep underground water aquifers relationship. The samples isotopic signal shown a current recharge of the CT, according to the regional rainfall signal.*

***Keywords**: aquifer, hydrogeochemical, isotope, Terminal Complex, Oued Souf, Algeria.*

1. Introduction.

In arid provinces, groundwater is the main water supply for populations, economics societies development in MENA region [1], [2]. The Oued Souf valley in the North Est Algeria Sahara is one of the major irrigated agriculture area in Algeria. Most of the agricultural activities use shallow aquifer groundwater through high pumping rates. The regions show a dominant problem of water scarcity, as result of the shallow groundwater overexploitation, climate variability and pollution risks [3], [4]. These acts have not provoked only depletion of the water resources but also the deterioration of the water quality [5], [6]. This poor-quality water can alter soil physicochemical properties causing soil degradation, reducing the productivity as consequence [7], [8], [9]. For permanent water exploitation, deep aquifers hosted in a large sedimentary series which embodies a huge stock of groundwater regard to climate variability and pollution risks [10], [11], [12]. The Continental Intercalaire (CI) aquifer of North Africa is the CI aquifer in Algeria, Tunisia and Libya, is considered as an area with a large artesian basin, from the west (Grand Erg Septentrional) to the east (to the Fezzan of Libya) as well as to the southern Sahara

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basins [13]**.** Although, the overlying aquifer of the Complex Terminal (CT) present a very important and large aquifer worldwide [14], [15]. These aquifers exhibit high vulnerability regards to their unknown proprieties, uncertain boundaries, and unpredictable hydrodynamic interactions with different reservoirs [16], [17].

For this aim, hydrochemical processes were integrated to determine the main factors and mechanisms controlling the chemistry of groundwater in the study area [18]. Though, the stable oxygen and hydrogen isotopic (δ^{18}O and δ^{2}H) ratios properties in different groundwater have become an excellent way to characterize the endmember, of groundwater recharge and discharge, to identify the origins of water bodies, and their migration pathways, [19], [20].

As the first hydrogeological investigation, the mean objectives of this work is to show how isotopic tools and ion elements contribute to the study of water/rock interactions. The extent of any current recharge of these non-renewable water resources in this similar large sedimentary basin.

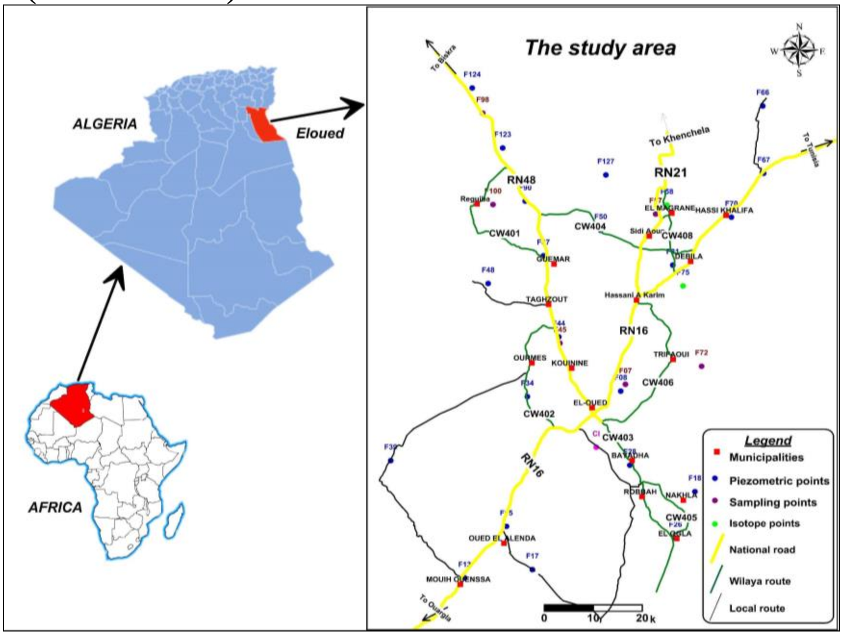


Fig.1. Localization of the study area

1.1. Geographical situation

The study area is located in the Northeast of Algeria. located 700 km southeast of Algiers. The Oued Souf vally extent approximately 10,000 km^2 and lies between the longitudes 5°00´–10°00´E and the latitudes 29°00´–36°00´N. this basin is part of the North-West Sahara Aquifer System (NWSAS), ranging from 700 to 1300 m elevation. The climate presents an alternation of a hot, dry and a cold, wet season. The average annual rainfall is lower than 71 mm, the average annual temperature is (+ 28.4°C) with a minimum of (- 16.3°C) in winter and a maximum of (+ 38°C) in summer. The area corresponds to a synclinal structure limited in the Northeast by the Algero-Tunisian Atlas, in the Northwest with the Algerian Atlas Mountains. The Southern extension of the study area dominated with the sandy dunes of the Oriental Erg part of the great Saharan platform (Fig. 1). The drainage network is dendritic to sub-dendiritic reflecting less permeable bed rocks increasing high concentration of rainwater during flash flood times.

The runoff component during flash flood times is driving its water to the endorhreic depression (Sebkha or Chott Melrhir in Algeria, and Chott Djerid in Tunisia.

1.2. Geological overview

Oued Souf is located in the northeastern part of the Saharan platform. It has been the subject of several geological studies data given in [21]. Completed by geophysical logging [22], in some borehole’s sections, established from the drilling logs of the Albian made by the [23]. These studies show the existence of a sedimentary terrain characterized by detrital facies. The Mio-Pliocene formations are covered by a considerable thickness of Quaternary deposits, they appear in the arrangement of sandy dunes and anti-dunes expanding an immense Erg which is part of the great eastern Erg. It corresponds particularly to sub-horizontal and monotonic layers of Phanerozoic [24]. The multi layers aquifers of CT and CI are hosted in the Lower Cretaceous shaly-sand and sandstone formations (from Barremian to Albian) covered and alternated with clay-rich layers. These layers have a thickness of hundreds of meters and are found in depths ranging from around 400 up to 2000 m below the surface [25].

2. Material and Methods

To study the hydrogeochemical characterization of this large groundwater aquifer, in the mio-pliocene (Pontian), thirty samples from public piezometers and private water wells were collected. Along the flow direction system, the water levels is measured and a multiparametric probe allows as the physicochemical information, pH, temperature (t), electrical conductivity (EC). Other chemical parameters are made in the water and environment laboratory of Tebessa University (Table 1). The cation concentrations were stated and calibrated using atomic adsorption spectrophotometry, appropriate diluted standards. For accuracy the international used tools were checked.

Table 1:

Statistical parameters of chemical elements

Chemical parameter	minimal values (mg/l)	maximal values (mg/l)	arithmetic average	Ecart type	Variation Coefficient
Ca^{2+}	10.600	36.199	16.933	5.965	0.352
Mg^{2+}	5.201	29.686	11.523	6.317	0.548
Na^{+}	4.160	43.230	24.782	5.772	0.232
K^{+}	0.6122	1.444	1.080	0.255	0.236
Cl^{-}	8.364	36.869	25.342	5.067	0.199
SO_4^{-2}	3.908	36.816	18.751	10.177	0.542
HCO_3^{-}	0.820	3.701	2.622	529	0.201
NO_3^{-}	0.067	4.591	1.475	0.821	0.556
Conductivity	3070	7190	4061	679.820	0.167

The stable isotopes were analyzed by the Integrated Laboratory of Water Sciences of the Ministry of Higher Education and Scientific Research (University of Gabes; Higher Institute of Sciences and Techniques of Water). The $\delta\ ^{2}H$ ratio was analyzed using an isotope ratio mass spectrometer. The oxygen of 1 ml. of water sample was equilibrated with commercial CO_2 at a controlled temperature and then the $\delta^{18}O$ water was analyzed by the equilibrated CO_2 using isotope ratio mass spectrometer. The results of the isotopic analyses are reported with the standard notion (δ) in deviations per thousand (‰) with respect to the international standard V-SMOW. The analytical precision is ± 0.15‰ for $\delta^{18}O$ and ± 0.15 ‰ for δ^2H.

3. Results and discussions

3.1. Piezometry

According to the availability and distribution of the sampling water wells in the prone area, a piezometric level campaign was conducted during the period of 2019.

During this field work, the data allows us to draw the piezometric map of this aquifer in this period. This map shows a high piezometric level of the water table, located in Mouih Ouensa 59.25 m and Ogla which marked a value of 58.3 m, a low piezometric level is located in the North-East of Hassi khalifa area with a level of 15 to 20m. Whereas, the piezometric level in the municipality of El-Oued varies between 35 and 40 m, it is noted that the piezometric surface is not regular (Figure 2). The hydrodynamic study and the piezometric map of the terminal complex of the Oued-Souf valley, allowed us to that the groundwater flow direction is oriented in a general direction is South-West to North-East. The spacing of the piezometric curves is a function of the hydraulic gradient, which is stronger as the curves are tighter (I = 7.8×10^{-3}), this is particularly the case in the central part of the region. It has been evaluated at (I = 2.2×10^{-3}) in the S-E and N-E parts of the plain where the iso-piezo curves have a slightly wide spacing. This hydraulic gradient is directly related to the permeability of the environment, the flow velocity, and the flow rate.

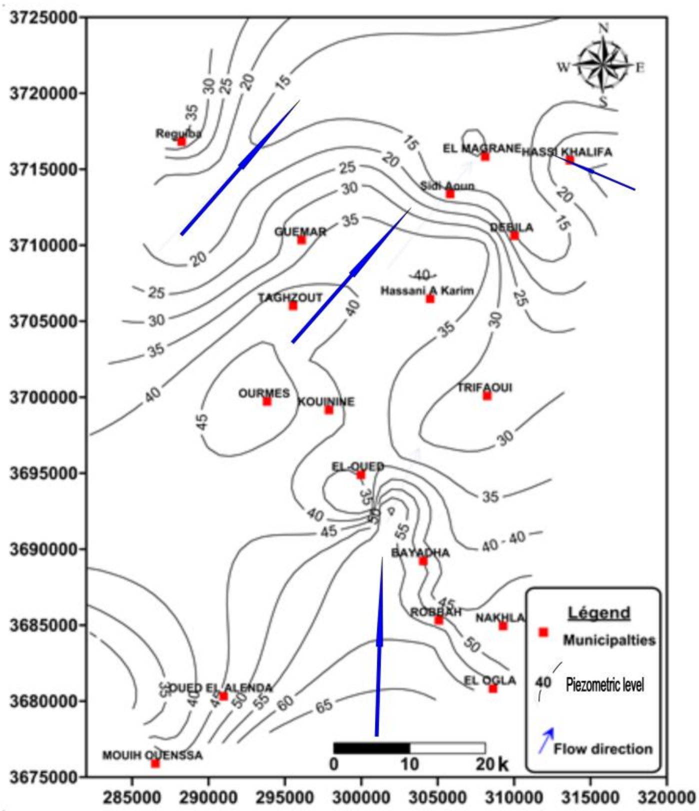


Fig. 2. Piezomeric map

3.2. Hydrogeochemistry

The study of water chemistry aims to identify the chemical facies of water, their quality, potability, as well as their suitability for irrigation. It also allows us to follow the spatial evolution of physico-chemical parameters and to estimate their origin by correlating them with geology and piezometry. Almost all the water wells of the CT aquifer are intended for drinking water supply and for the irrigation of agricultural fields. In order to be used, the water must meet certain standards that vary according to the type of use. For this purpose, a sampling of about thirty water points capturing the Pontian aquifer and evenly distributed throughout the study area was carried out. The chemical analysis of the major elements shows that the CT water aquifer is characterized by the abundance of ions (Na^+, Cl^-, Ca^{2+}, HCO^-_3). This diagram highlights the impact of geological facies in water quality; it also allows estimating the amount of the chemical elements and their classification. The diagram of the cation, we can comprehend that the water samples form essentially one large group, close to the potassium sodium pole (F17, F28, F34....) except for the water wells F100 and F98, which are close to the calcium pole. The wells represented in the middle of the triangle do not show dominance. In the anion diagram, only one group can be distinguished, close to the chloride pole (F13, F17, F18 and so on), except for the water points (F48, F45, F57 and F02) which are close to the sulfate pole. The wells represented in the middle of the triangle do not show dominance.

3.2.1. Study of the ratios characteristic and the origin of the water chemistry

The waters of the studied aquifer show a chloride sodium and sulfate sodium chemical facies, in connection with the lithological formations and a very high salinity, the electrical conductivity is generally high, it oscillates between 3070 µS/cm in the F70 wells and 7190 µS/cm in F28 with an average of 4061 µs/cm (Table 1).

3.2.2. Characteristic ratio

The study of variation of these ratios allows to assess the chemical evolution of the water during its underground journey as well as the contact with the geological environment; to give indications on the zone of supply and the circulation of the groundwater and to explain some of the existing relationships between chemical elements, some graphs have been represented.

a. rMg^{2+} vs rCa^{2+} Ratio

The examination of Figure 3, allows us to notice that all the values of the ratio are lower than 1 for all the samples. Thus, the water is very rich in Calcium, which explains the rapid dissolution of limestone compared to dolomites

b. Ratio $r\ SO_4^{2-}/ r\ Cl^-$

Taking into account the dominance of chloride and sulfate facies, it is important to verify the relationship between these two elements. The graph shows a dispersion of points indicating a proportional evolution of the two elements having thus a common saliferous origin. In addition, the graph shows that some points have an excess of sulfates and others an excess of chlorides. This reflects the dominance of one facies over the other (Figure 4).

c. Ratio $r\ Na^+ / r\ SO_4^{-2}$

The graph shows a scattering of points indicating that the two chemical elements have different origins (Figure 5). This relationship does not also confirm the existence of the sodium sulphate facies. This relationship shows a decrease in sodium while sulfates remain in evolution.

d. Ratio r Na^+ / r Cl^-

Examination of this relationship shows a proportional evolution of chloride and sodium (Figure 6). This relationship reflects the dissolution of a sodium chloride of saliferous origin. This relationship also confirms the existence of the sodium chloride facies.

e. Ratio r Ca^{2+} / r Cl^-

Examination of this relationship shows a proportional evolution of chloride and calcium (Figure 7). This relationship confirms the existence of the chloride-calcium facies. Note that this 'abnormal' facies is the result of a sign of pollution (cases F98 and F100) and/or a mixing of the waters of the superficial and deep aquifers.

f. Ration

(*rHCO_3^- / r (SO_4^{2-} + Cl^-)/conductivity:*

The plot of the water points on this diagram shows a logarithmic decrease in the ratio as a function of electrical conductivity (Figure 8). Two poles are observed. One carbonate is characterized by a dominance of carbonate ions (µ<3000 µS/cm) and the other represents the evaporitic pole and asserts a dominance of sulfate and chloride ions. This pole appears for electrical conductivities above 3000 µS/cm. Examination of the figure thus confirms that the electrical conductivity of the water is due to sulfates and chlorides with a slight dominance of sulfates.

3.3 Origin and recharge mechanisms of groundwaters

The use of stable isotopes is very important in the field evaluation of the water resources, [26], [27], [28]. Stable isotopic oxygen and hydrogen in the groundwater is an active hydrological cycle derive from and reflect the initial isotopic composition of the recharging rainwater. Within the coordinate system of $\delta^{18}O$ and $\delta^{2}H$ is possible to discern a meteoric line, the slope which is characteristic of some hydrological system [29].

In this paper the $\delta^{18}O$ and $\delta^{2}H$ values of precipitation samples, used to establish the local meteoric water lines, are obtained from the Global Network for Isotopes in Precipitation database managed by the AIEA, for a period of 6 years (September 1992- December 1998) for Tunis–Carthage and Sfax meteorological stations (Tunisia). The meteoric water lines defined for Sfax and Tunis (Figure. 9) have been calculated using a least squares regression [30] :

$$\delta^{2}H = (6{,}4 \pm 0{,}5)\ \delta^{18}O + (5{,}2 \pm 1{,}7);\quad \text{Tunis (1992–1998, n= 26)}$$

$$\delta^{2}H = (6{,}7 \pm 0{,}3)\ \delta^{18}O + (3{,}5 \pm 1{,}3);\quad \text{Sfax (1992–1998, n = 45)}$$

The water lines of Tunis and Sfax for the period 1992–1998 are close and seem to be representative of the precipitation isotopic content in Tunisia. The comparison between the Tunisia and the Global Meteoric Water line [31], shows evidence of the evaporation that affects Tunisian precipitation as the rain falls.

3.4 Groundwater isotopic signatures

Stable isotope compositions of the sampling water wells (Table 2). Show that isotope values vary between -4.7291 and -6.2131 for water wells of the CT with a mean of -5.7526 ± 0.2‰ (n = 9) in ^{18}O and from -44.9665 and – 37.2235 with a mean of -42.7555 (n = 9) in ^{2}H. The oxygen-18 and deuterium contents for all the investigated ground waters are plotted both in the classical $O^{18} – H^{2}$ diagram (Fig. 9); in the global meteoric water line ($d\,H^{2}=8d\,O^{18}+10$), defined by [31], and the local meteoric water lines (Tunis and Sfax).

The plot of data points in such diagram provides indication upon the origin and the possible recharge processes of groundwater.

Table.2

The composition of groundwater from the CT and CI aquifers

N°	Sampling code	Altitudes (m)	Raw delta D	Raw delta ^{18}O
1	7	68	-42.0726	-5.5325
2	17	100	-44.9665	-5.7843
3	25	82	-37.2235	-4.7291
4	39	94	-44.3208	-5.6658
5	48	56	-42.6954	-5.9996
6	58	61	-43.1057	-6.1261
7	66	30	-43.8134	-6.1152
8	81	67	-42.2472	-5.6084
9	98	29	-44.3544	-6.2131
10	CI	87	-67.6531	-8.2892

Groundwater samples are plot close to the Tunis and Sfax Meteoric line (Fig. 9), and indicate no significant isotopic modifications by evaporation, which means that the recharge of the aquifer is quit rapid and the recharging meteoric water does not occupy the soil zone of the recharge area for a long time. The similarity of δ^2H versus δ^{18}O for both wells in the CT and CI groundwater samples is not unexpected. in the study area aquifers and suggests the recharge of the both aquifers (CT and CI) correspond to an old end-member in relation with palaeoclimatic recharge, which occurred during the Late Pleistocene and the Early Holocene humid periods. At high elevations (Figure 10) and indicating, that groundwater is homogeneous at the aquifer of CT origin.

The deuterium excess values vary very slightly, indicating that the catchment area of Oued Souf valley wells is not recharged by local originated fossilized water. The total dissolved solid values provide a good indication of the interaction time between the water and the aquifer formation. The ions concentrations increase from wells towards groundwater samples collected from wells of the CT at Oued Souf valley (Fig. 11). Whereas wells samples are represented with high Cduc values, samples well the CI is represented with high δ^{18}O values. It must be emphasized that, although water CI originates in higher recharge areas, their ion concentrations are lower than those of wells because of the interaction time of groundwater with shallow aquifer.

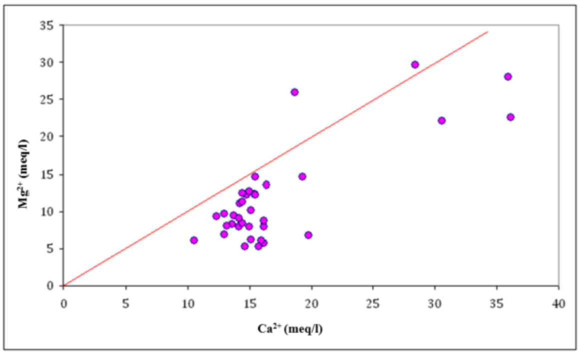


Fig. 3. Ca^{2+} vs Mg^{2+} relationship

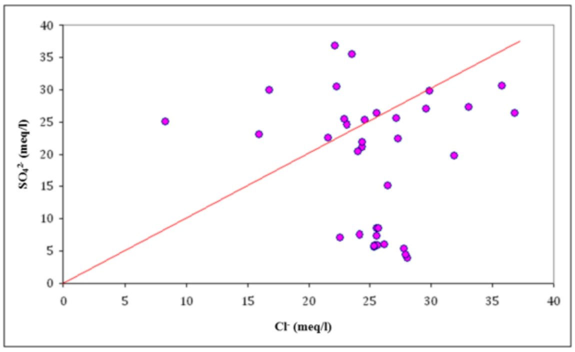


Fig. 4. SO_4^{2-} vs Cl^- relationship

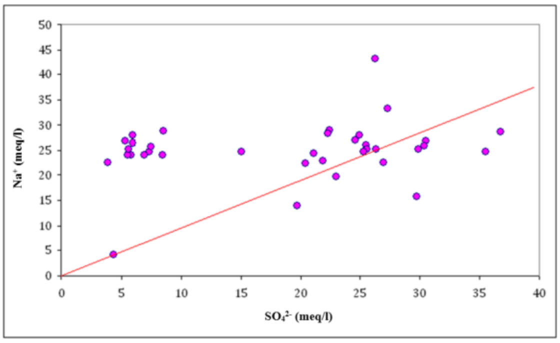


Fig. 5. Na^+/SO_4^{-2} relationship

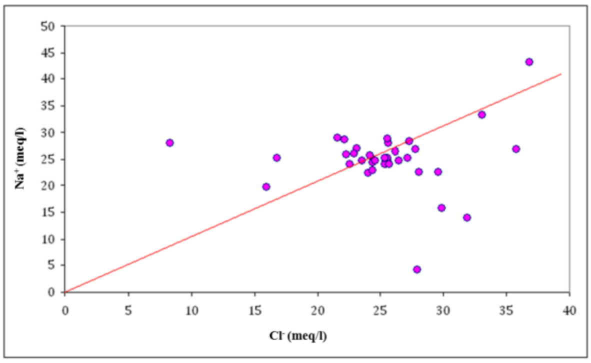


Fig. 6. Na^+ vs Cl^- relationship

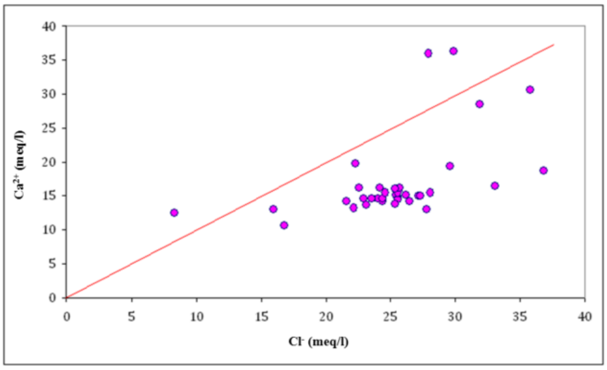


Fig.7. Ca^{2+} vs Cl^- relationship

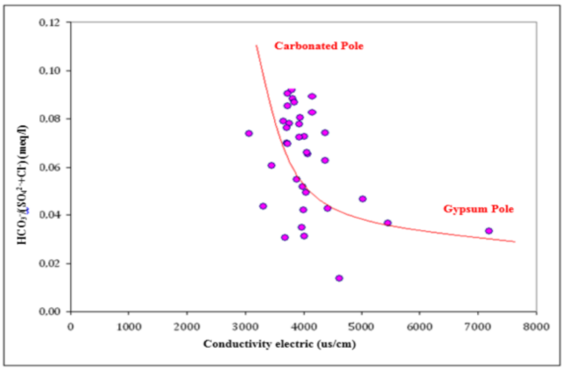
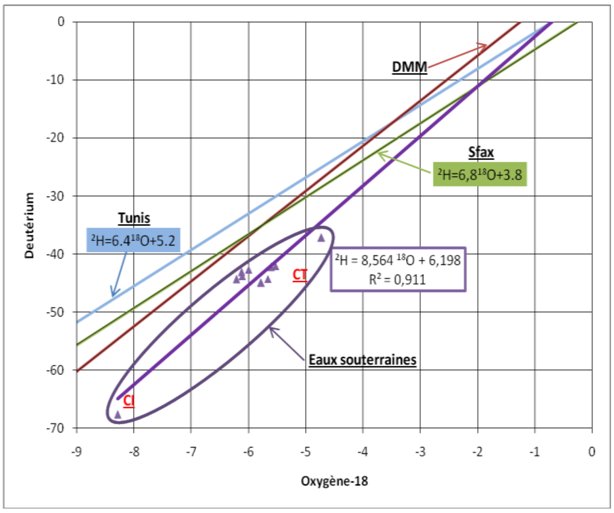


Fig.8. HCO_3^- / (SO_4^{2-} + Cl^-) vs conductivity relationship



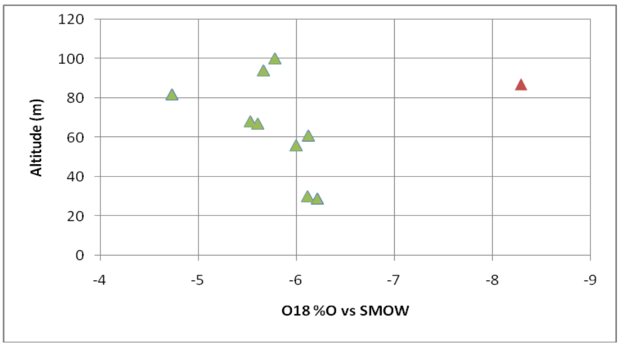


Fig.9. δ ^{2}H vs δ ^{18}O Relationship for groundwater

Fig. 10. δ^{18}O and Zs relationship

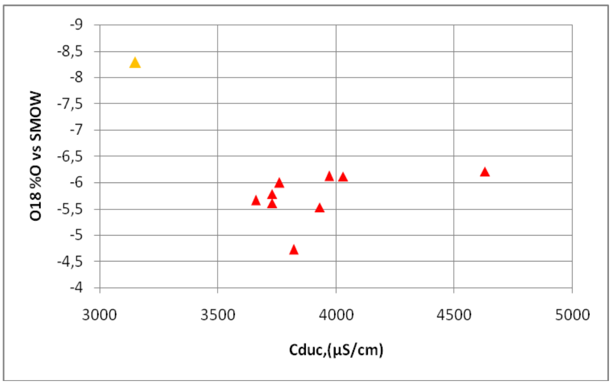


Fig.11: $\delta^{18}O$ and Cduc relationship of water samples

4. Conclusion

The hydrogeochimical and isotopic study of the complex terminal (CT) groundwater shows that mineralization increases with the flow direction. This mineralization is part of the water and aquifer layers interactions. Almost all the water wells of the CT aquifer are intended for drinking water supply and for the irrigation of agricultural fields. In order to be used, the water must meet certain standards that vary according to the type of use. The chemical analysis of the major elements shows that the CT water aquifer is characterized by the abundance of ions (Na^+, Cl^-, Ca^{2+}, $HCO^-{}_3$). The water of the studied aquifer shows a chloride sodium and sulfate sodium chemical facies, in connection with the lithological formations and a very high salinity, the electrical conductivity is generally high, it oscillates between 3070 µS/cm in the F70 wells and 7190 µS/cm in F28 with an average of 4061 µs/cm. However, isotopic signal confirms the fossil nature of the water recharged throw discontinuity during the palaeoclimatic which occurred during the Late Pleistocene and the Early Holocene humid periods.

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