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Hydrochemistry and isotopic geochemistry contribution to the characterization of the aquifers of the upper Plains of Algeria, case of the basin of Chemora, oriental Algeria

N. Belkoum , B. Houha

Department of Ecology and Environment, Abbes Laghrour University, Khenchela , Algeria.

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N Belkoum
nounoueco@gmail.com
+213697446252

Abstract

The upper plains of eastern Algeria are bordered to the south by Aures mountains culminating at 2328 m on Chelia moutain. The water springs of Chelia, initially is weakly mineralized, can become salty by interaction with rocks of Chemora basin and successive evaporation. The salt concentrations can increase until the precipitation of evaporates. The main places of the formation of the solid salts are the irrigated agricultural soils, where evaporation reaches or exceeds the inflow of continental water. Chemical water facies evolved from bicarbonate calcium and magnesium to sulphate calcium. The use of chemical and isotopic tools have shown that the origin of waters mineralization is linked to the interactions water-rock that occur along the flow in the reservoir, by dissolution and mineral precipitations , to the cations exchange and the pollution. The isotopic tool has demonstrated that the aquifer recharge is ensured by meteoric little evaporated waters, with altitudinal influence.

1. Introduction

The aquifers of the steppe upper plains of Algeria have generally a limited and reduced extension from West to East because of their orientation between the both Atlas. They are endoreic basins characterized by the impoverishment of their resources of water and a degradation of their quality induced by both endogenous and exogenous factors such as: semi- arid climate with prolonged and recurrent periods of droughts, evaporation with salt concentrations, leaching of the aquifers evaporitic deposits, interaction water- rocks and pollution. To better preserve and manage these water resources in order to respond to the increase in water needs of the agglomerated populations and the rural zones of the profound Algeria, two dams have been built, one of them is operating dam of Koudiat Lamdouar. The present article aims to identify the origin of the aquifer recharge of the basins of the upper plains, to distinguish the salinity origin of the groundwater masses and to better explore the existence of probable hydraulic links between the dam water and the groundwater, either by losses by infiltration or by feeding by vertical leakance.

2. Experimental details

2.1. *Location and climate*

The endoreic basin of Chemora extends directly to the northern piedmont of the massive of the Aures, which constitutes the oriental extension of the Saharan Atlas, it is drained by Chemora wadi, which rejoins chott Temerganine and sebkha of Eltarf. Located North- east of Algeria, between 35◦15’ and 35◦45’N of latitude North and between 6 and 7° of longitudes, the plain is bordered in the South, the South- east and in the West by the mountains of the Aures, Djebel Amrane and its extension Djebel Bouaarif. In the West, the plain is opened on Chott Temerganine, which constitutes its natural outlet (Fig.1). The general climate is semi-arid marked by dry seasons and weak irregular precipitations, 370 mm/year and a temperature around 16°C.

2.2 *Geological setting*

The endoreic basin of Chemora is an hydrogeological entity of the steppe upper plains, surrounded by landforms having the geological aspects of the Algerian Atlas, formed by a very pleated field, fractured and karstified, having a Cretaceous frame and a very thick tertiary recoverment composed of gypseous red clay and sandstone, and leans directly and discordantly on the lower Cretaceous. The marly cretaceous, marlo-calcareous and sole compact limestone of gypseous and salifere trias recover the powerful series of Miocene sandstone that have a weak hydrogeological interest. The center of the plain is a collapse basin filled by detrital deposits, where conglomerates, gravels, fine sand and red clay have been deposited alternatively in an aquifer multilayer system of a Quaternary age. The South and South-West borders of the basin of Chemora are formed by the mountains of the Aures. These latter are constituted of the karstic formations, that are the bottom of a deep aquifer having a limited extension toward the plain center and that sink slightly to the North, which would favour the flow and drainage of these waters of karstic origin toward the basin of Chemora. Hydrogeologically, the region has two types of aquifers: the multilayer aquifers of the sedimentary basin constituted of the aquifers of the Plio-quaternary, and the aquifers of the carbonate fissured formations of the Cretaceous.

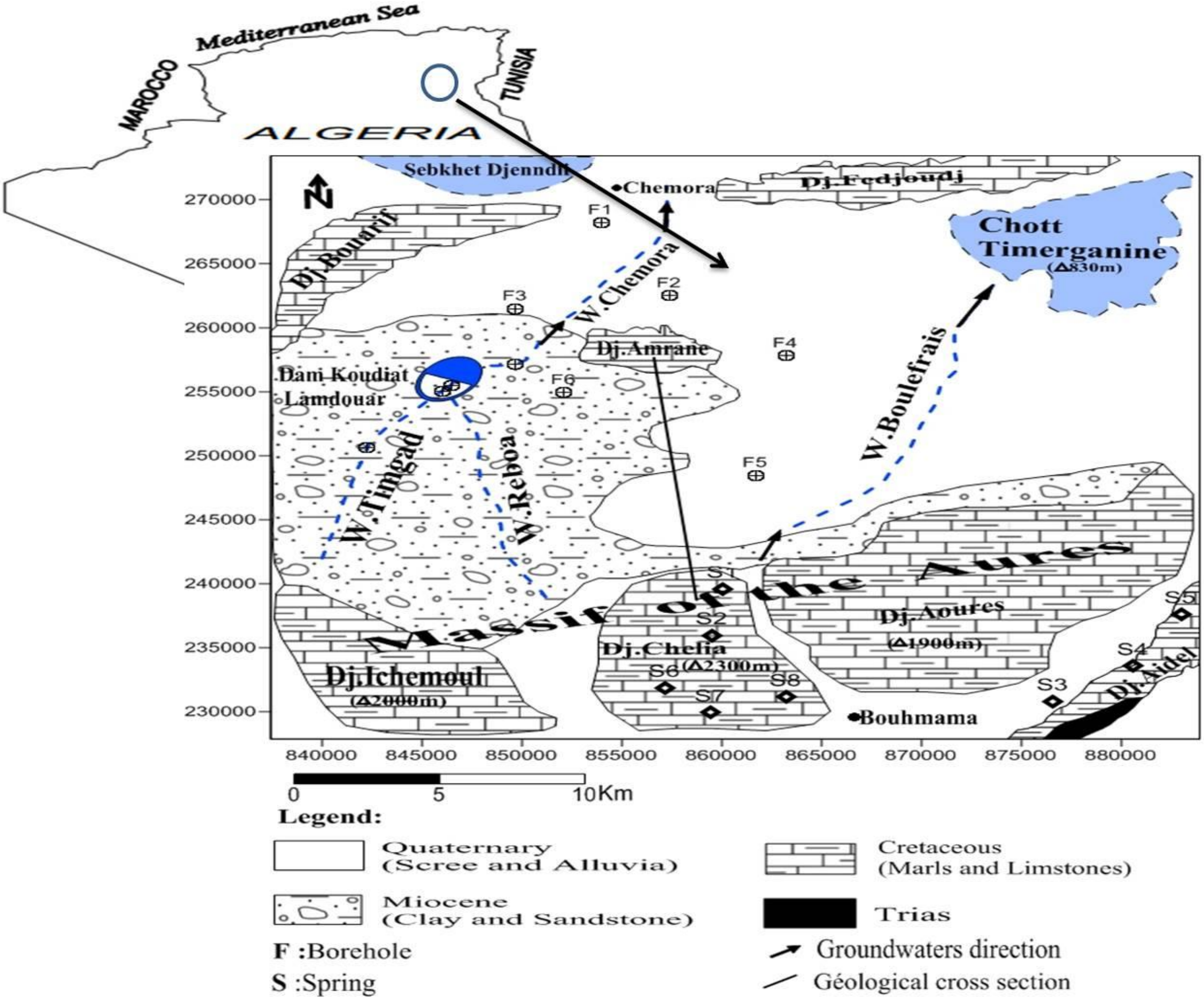

Figure 1: Location and geological features of the study area

2.3 *Materials and methods*

A sampling of eighteen water points related to groundwater: boreholes, springs capturing the Plio-quaternary and the Cretaceous, and surface waters: wadis of Timgad and Chemora and Koudiat Lamdouar dam (Fig.1) has been carried out during the rainy period in April 2015. The electrical conductivity, the temperature and the pH have been measured in the field. The results of the chemical analyses of the major elements and of the ratio of stable isotopes ^{2}H and ^{18}O, carried out in the laboratory of isotopic hydrology of the atomic research center of Algiers (CRNA) are present in table 1 .

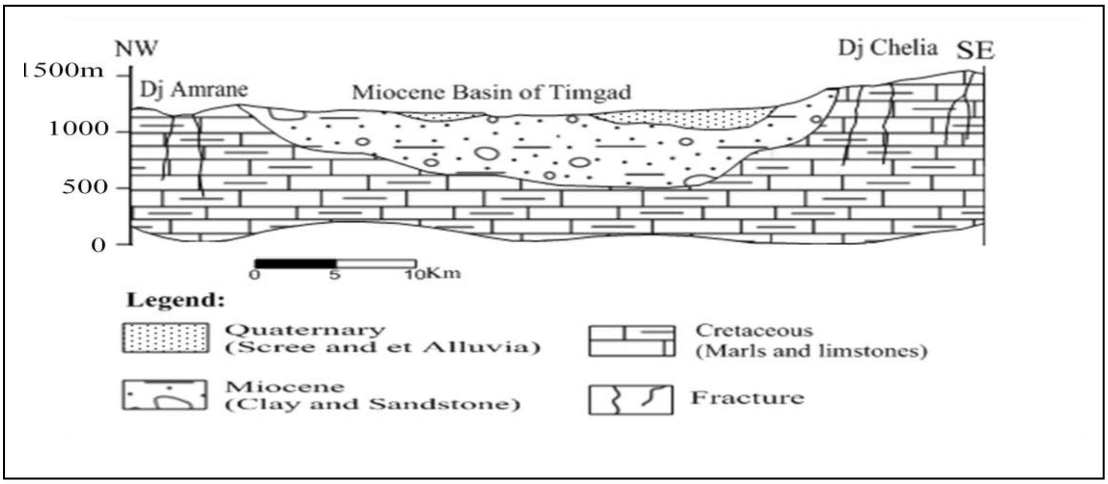

Figure 2: Geological cross section

Table 1: Results of physico-chemical and isotopic analyses of the groundwater and surface waters of the study area

Samples	T (°C)	EC (µs/cm)	pH	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	Na^{+} (mg/l)	K^{+} (mg/l)	HCO_3^{-} (mg/l)	Cl^{-} (mg/l)	SO_4^{2-} (mg/l)	$\delta^{18}O$ ‰	$\delta^{2}H$ ‰
F1	20	1850	6.9	158.1	93.7	126.3	6.3	288.2	158.5	627	-7.34	-48.4
F2	20	1530	6.9	140.1	66.9	148.3	5.2	248.6	138.1	468.3	-6.18	-40.6
F3	22	3020	6.8	287.7	167.3	145.5	19.3	262.3	271.1	750	-6.7	-44.6
F4	24	1690	6.8	100	72.9	137.3	5	314.5	178.3	296.9	-8.16	-52.9
F5	24	1160	8	86.42	35.64	117.3	0.932	695.4	74.8	15	-8.93	-60.1
F6	20	1750	7	209.7	116	119	6.6	320.3	117	718.6	-7.23	-50.6
W.Chemora	24	1999	7.4	145.5	68.5	163.5	8.5	271.5	263	519.5	-3.76	-28.5
Dam	27	1140	7.2	90.3	32.4	93.4	7.7	151	95.8	264.7	-4.12	-29.6
Dam	27	1140	7.2	99.9	31.8	95.1	7.9	149.5	96	289.1	-4.09	-29
W.Timgad	27	1470	7.4	130.7	41.2	117	21.2	332.5	81.6	300	-7.25	-48.6
S1	16	491	6.9	95.4	30.3	15.4	2.6	295.9	16.5	79.9	-7.77	-48.3
S2	14	394	6.8	34.2	36.3	5.6	2.3	308.1	7.7	19.8	-8.88	-55.7
S3	14	492	6.8	91.6	25.1	11.1	1.8	320.3	17.2	50.4	-8.16	-50.2
S4	14	382	6.8	83.6	27.4	5.8	2.1	318.7	10.4	16.9	-8.72	-55.3
S5	12	675	6.67	110.9	51.4	8.5	2.8	536.8	18.4	50	-8.58	-53.4
S6	14	200	7.04	32.7	10.7	3.4	1.6	114.4	5.7	13.1	-9	-55.9
S7	14	288	7	50.4	17.1	3.9	1.7	204.4	6.5	15.5	-9.53	-60.7
S8	15	511	6.8	91.8	36.8	7.5	2.5	382.8	13.9	36.6	-9.33	-58.3

3. Results and discussion

3.1. *Hydrochemistry*

The water temperatures of the multilayer aquifers system of the basin of Chemora vary from 20 to 24 °C for the Mio-plio-quaternary aquifer, with a mean value of 22°C. For the emergences of the Cretaceous aquifer, the temperatures are comprised between 12 and 16°C, with a mean value of 14°C. The groundwater pH values range from 6.67 to 8. The electrical conductivity varies between 200 and 3020 µS.cm^{-1}, with a mean value of

1121 µS.cm^{-1}. The high values of the water conductivity are observed in the North of the basin, with a mean value of 3020µS.cm^{-1}.

3.2. Chemical evaluation of waters

To better characterize and refine the hydrochemical facies interpretation corresponding to different geological formations, and to better distinguish the salinization process of the groundwater, we have taken two procedures.

We have reported the results of the chemical analyses of the sampled waters on the Piper diagram (Fig.3). The report of the contents of the major elements of different sampled points of waters shows that the Cretaceous waters exhibit a bicarbonate-calcium and bicarbonate-magnesium facies at the springs borders South and South-West, whereas the filling waters of the Plio-quaternary show a sulphate-calcium and chloride-calcium facies. These different facies emphasize the importance of the climate aridity and its hydrological effects on the formation and the control of the water salinity in the endoreic basins of the Saharan Atlas [1]. Also, we have employed the cross diagrams of the major elements with the ion of chlorine (Fig.4). This latter is a conserved element, does not participate in the interactions water-rock, characterize the origin of the waters salinity and constitutes a mixing tracer [2]. The disposition of the different points of waters analyzed with respect to mixing line freshwater-saltwater (rainwaters- seawaters) can be of a great interest to identify other phenomena, which are annexed to the mixture process [2].

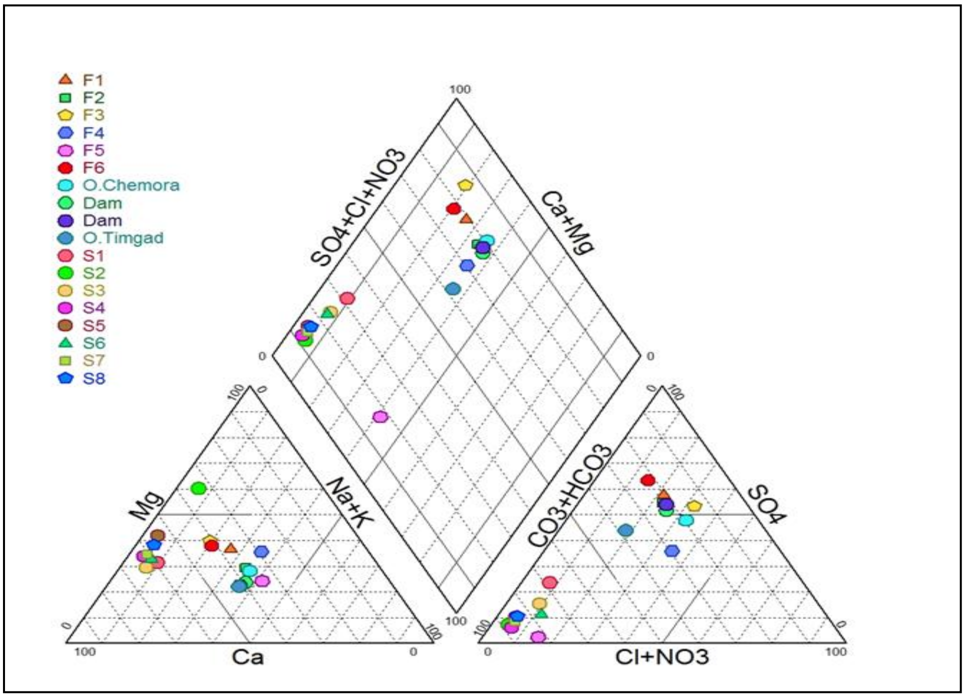

Figure 3: Piper diagram for the waters of the basin of Chemora

The relationship between Na^+ and Cl^- (Fig.4) shows that all the points are below the mixing line. Given that Na^+ content should balance the Cl^- content, the Na^+ deficit is explained by the exchange phenomenon of the ionic base between the water and the aquifer, and is reflected by Na^+ absorption and a Ca^{2+} release. The graph Ca^{2+} against Cl^- illustrates well this, showing that the points are often over the line of the mixture freshwater-saltwater.

The relationship between Mg^{2+} and Cl^- shows that the majority of the points are situated on the line of the mixture with a tendency to the Mg^{2+} enrichment which might be related to the dolomite dissolution [3].

The graph SO_4^{2-} and Cl^- demonstrates that all the points are over the line of the mixture freshwater- saltwater. The sulphate enrichment might be caused by the gypsum dissolution, the leaching of the evaporites and by the infiltration of the irrigation waters loaded in salt and fertilizers [4,5] facilitated by the weak depth of the aquifer and the good permeability of the aquifers terrains [2-6]. The relationship between K^+ and Cl^- emphasizes that the majority of the points are below the mixing line, except some points, which come close to this line, showing that the most probable origin is the pollution.

The study of the geochemical processes which have induced the groundwater salinization in the basin of

Chemora and their saturation vis-a-vis the minerals is based on the ionic activity calculation. The saturation indice expresses the chemical balance degree between the water and the mineral in the aquifer matrix, considered as a measure of the dissolution process and / or the precipitation regarding the interaction water-rock.

The use of the geochemical program of PHREEQ, integrated in the diagram program of the hydrochemical calculations [7], has allowed us to calculate the saturation indice of the calcite, the dolomite, the aragonite, the gypsum, the anhydrite and the halite.

The significant results of all the analyzed water samples (table 2) show that these waters are saturated with respect to calcite, aragonite and dolomite, and are undersaturated with respect to halite, anhydrite and gypsum. The calculation of the saturation indice of minerals in the water points out that only the carbonate minerals tend to precipitate, especially under calcite and dolomite form. Conversely, the evaporitic minerals (gypsum and halite) tend to the dissolution.

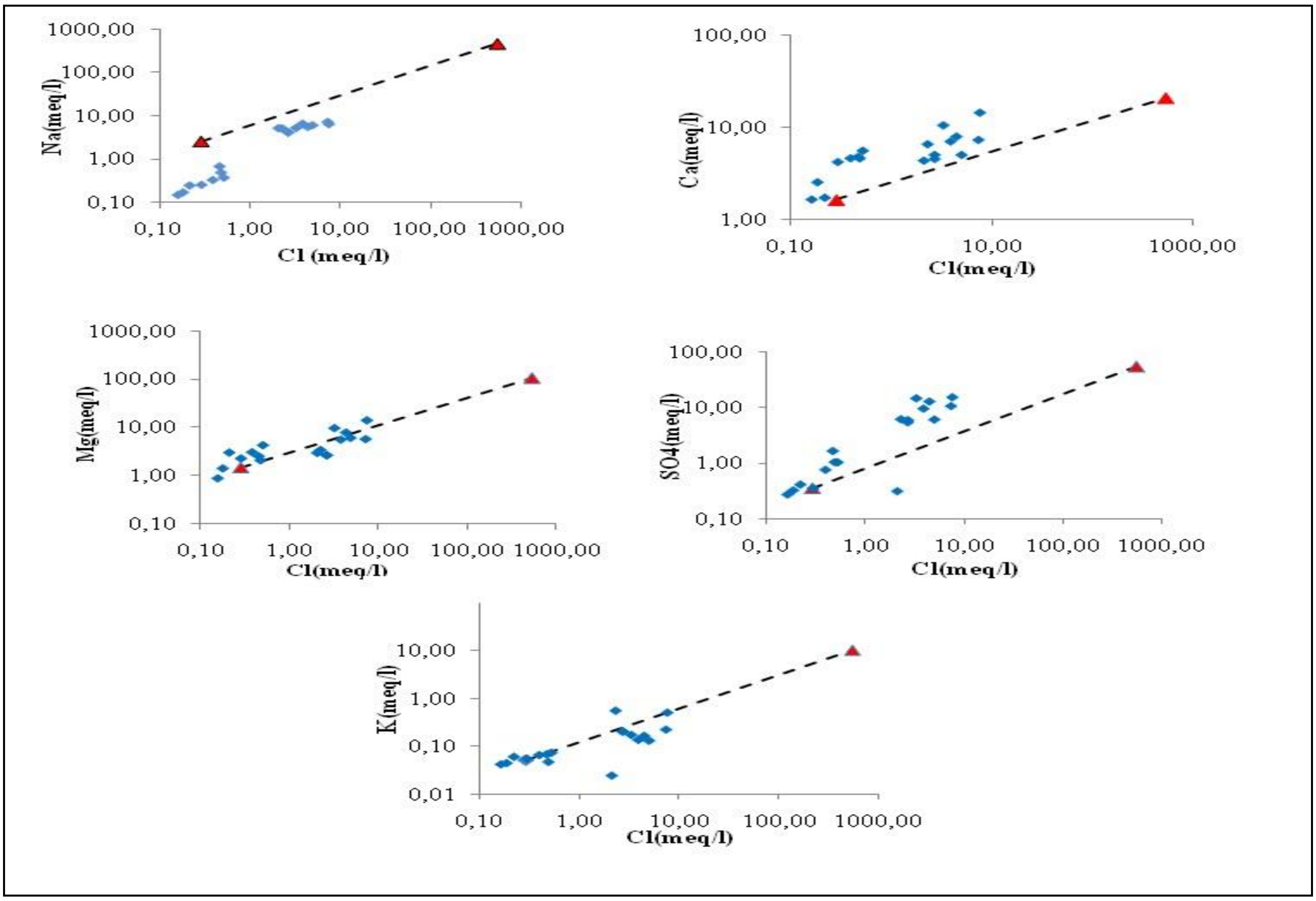

Figure 4: Relationship between major elements and chloride

Table 2: Maximal and minimal calculated values of saturations indices

	SI Calcite	SI Dolomite	SI Aragonite	SI Gypsum	SI Anhydrite	SI Halite
Maximal	0.23	0.48	0.08	-0.59	-0.81	-6
Minimal	- 0.83	-1.78	-0.97	-2.68	-2.9	-9.27

3.3. *Isotopic hydrology*

Measures of stable isotopes contents (oxygen 18 and deuterium) have been carried out on 18 water samples (Fig.1): surface water (wadis Timgad and Chemora and dam Koudiat lamdaouar), groundwater (the aquifer Mio-plio-quaternary (MPQ) and the springs of the Cretaceous aquifer). The stable isotopes contents have been reported on a diagram $\delta^{2}H=f(\delta^{18}O)$ (Fig.5), where also appear:

- The Global Meteoric Water Line (GMWL) of equation $\delta\,^{2}H=8\,\delta^{18}O+10$ [8].
- The Western Mediterranean Meteoric Water Line (WMMWL), of equations $\delta^{2}H=8\,\delta^{18}O+13.7$ [9, 10, 11].

From this graphic representation, three groups of isotopically separate waters have been developed (Fig .5).

The waters of group1 present an impoverished isotopic signature, the mean weighted $\delta^{18}O$ value is -8.70‰ vs-SMOW. According to the diagram $\delta^{18}O/\delta^{2}H$ (Fig.5), the Cretaceous waters are situated near the WMMWL; this indicated that the aquifer recharge of the Cretaceous has been made from the rainwaters of mediterranean origin in high altitudes.

The impoverished feature of the springs waters signifies that the isotopic composition of the precipitations evolves with the altitudes and becomes more and more impoverished in $\delta^{18}O$ and $\delta^{2}H$ when it rises [12, 13, 14,]. The effect of the altitudes agrees well with the massif of the Aures, whose landform is the most marked and culminates at 2300 m [15]. On average, the waters of this group indicate a deuterium excess of 14.5‰, which is nearer to 13.7‰, which characterize the Mediterranean originated waters than 10‰ characterizing the oceanic originated waters.

The waters of group2 present a mean $\delta^{18}O$ value of -6.94‰ vs-SMOW. The study of the diagram $\delta^{18}O/\delta^{2}H$ (Fig.5) shows that the overall groundwater of the MPQ aquifer is aligned on the GMWL, and reflects therefore precipitations of oceanic origin, which have been rapidly infiltrated without having undergone an evaporation phenomenon. The deuterium excess of this group is 8.9‰ on average, showing that the recharge of the Plio-quaternary aquifer is ensured from precipitations which are different from those that have recharged the Cretaceous aquifer. The waters of wadi Timgad, collected during rain seasons, are present in group2.

The group3, the dam and the wadi Chemora present a mean $\delta^{18}O$ value of -3.99‰ vs-SMOW. The study of the relationship ^{2}H versus ^{18}O shows that these surface waters have an evaporated profile for being all situated under the GMWL.

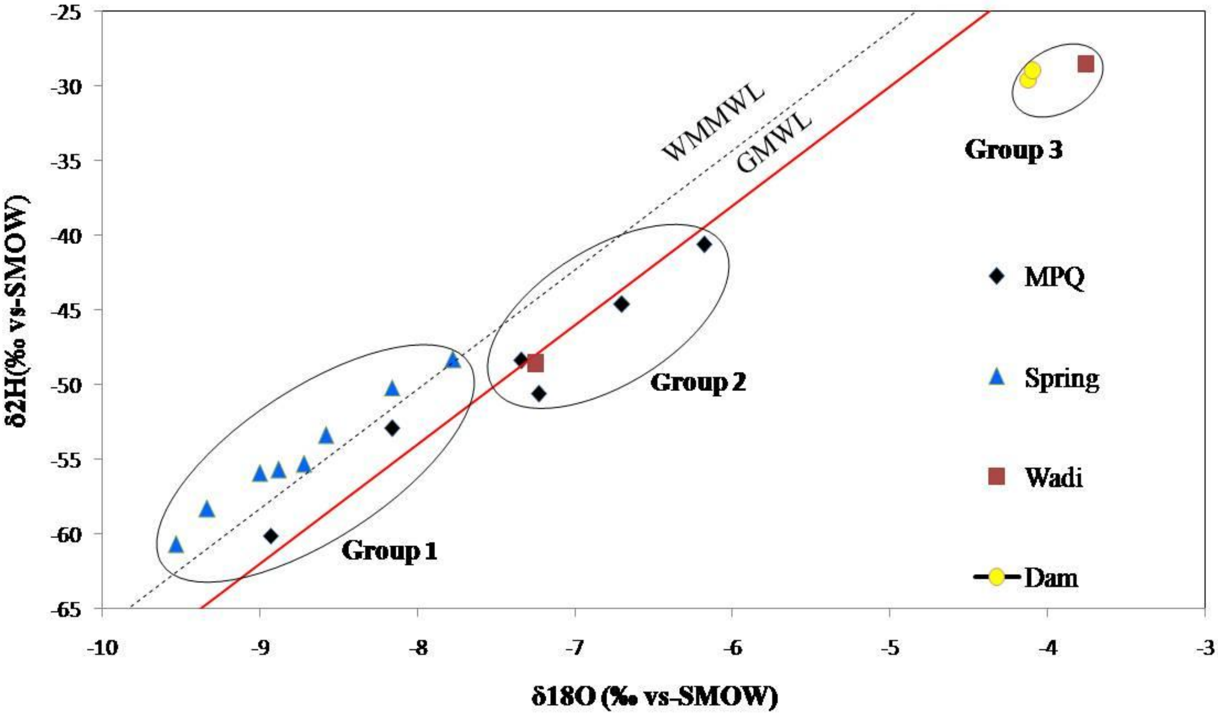

Figure 5: $\delta^{2}H$ vs $\delta^{18}O$ relationship for groundwater and surface waters of the study area

3.3.1. *The dam influence on the aquifer MPQ*

The waters of the dam and the wadi Chemora seem to be the most evaporated. This is explained by the fact that in February and March, the dam has not undergone a renewal of its waters during a dry season. It seems that these surface waters have not undergone an underground feeding by vertical leakance from the deep aquifer. The waters of the sedimentary basin are isotopically impoverished comparatively to the heavy isotopes contents of the surface waters, it might seem that the dam waters does not step in the feeding of the alluvial aquifer, in other words, we would have found evaporated waters in the boreholes situated in the immediate neighbourhood of the lake (Fig.5) and on the bank of the wadi [16]. It seems, according to the topographic structure of the basin and the diagram $\delta^{18}O/\delta^{2}H$ (Fig.5), that the lateral flows of the Cretaceous insure the feeding of the superficial aquifer of Chemora. These lateral flows might be the cause of the impoverished heavy isotopes [17] contents of some boreholes samples of the plain such as boreholes F4 and F5, because the springs water of the mountains summit are of a more negative isotopic composition than the plain waters [18].

Conclusions

The groundwater of the basin of Chemora has important chemical variations mainly induced by the climate dryness, the mineral dissolution and the anthropogenic activity. The Cretaceous aquifer shows bicarbonate-calcium to bicarbonate-magnesium waters, the filling waters of the Plio-quaternary belong to sulphate-calcium and chloride-calcium. The water mineralization is determined by the interactions water-rock, as a primary process, and by the infiltration of the irrigation waters loaded with salt and fertilizers, as a secondary process.
The isotopic tool utilization has shown that the origin recharge of the cretaceous aquifer is ensured by recent rainwaters of Mediterranean origin. This is confirmed by a deuterium excess value of 14.5‰. The impoverished feature of the groundwater in oxygen 18 is attributed to the altitude effect. The feeding waters of the Plio-quaternary are of meteoric oceanic origin, which have been rapidly infiltrated, without having undergone an evaporation phenomenon. The isotopic chemistry has not confirmed an hydraulic link between the dam waters and the superficial aquifer of Chemora.

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