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Hydrogeochemical Characterization of Groundwater in The Plateau of Mellagou (Western Area of Khenchela, East of Algeria).

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ABSTRACT

The study area is a sedimentary basin filled with Quaternary deposit lying on fissured carbonate, calcareous and Marlo-calcareous formations; the marly substratum is of important thickness. The aquifer typology allows the distinction of two water tables, one is superficial contained in the Quaternary filling, and the other is deep within the fissured carbonate formations. Water that appears within the fissured carbonate formations has a bicarbonate-calcium facies in the Mio-Plio-Quaternary; water evolves from sulfate-calcium facies into chloride-sodium water. The thermodynamic analysis has revealed waters saturation with carbonates, calcite and dolomite, because of CO₂ degassing and dissolution of the evaporitic formations, gypsum and halite. Water salinity develops progressively and increases in the flow direction, upstream from the calcareous outcrops, with a conductivity of 589 μ S/cm, to reach a peak of 6440 μ S/cm in the irrigated perimeters. The crossed binary diagrams suggest that the origin of water salinization would be attributing to water-rock interaction through the geochemical process of mineral dissolution-precipitation and ion exchange. The chemical tracing by trace elements and the heavy metals corroborate that the anthropogenic activity contributes, for its part, to increasing water mineralization.

Keywords: hydrochemistry, plateau of Mellagou, salinity, dissolution, pollution and precipitation

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INTRODUCTION

The plateau of Mellagou, with an area of 577 Km² presents itself as a large valley, oriented north-east, and is scattered on the edges with a succession of relief consisting of Kef El Ahmeur-Kef Meda, Djebel Tazrout and Djebel Taafist, oriented north-east and south-ouest. The valley morphology of wadi Mellagou has characterized by two domains: one is of mountainous character, consisting of secondary chains represented by carbonate formations of Cretaceous age, and the other is hilly, developed on Quaternary terrains, in particular. Geology is marked by a sedimentary basin, with a variable texture multi-layer Quaternary filling, and by a summit lying on fissured carbonate formations, and karstified in depth to end with Cenomanian marls as a substratum. Two large aquifers are highlighte: the Mio-Plio-Quaternary superficial aquifer and the deep carbonate aquifer. Water tables typology is describe in the superficial aquifer as a less deep multi-layer alluvial water table and the deep water table of calcareous formations. The chemical composition of Mellagou plateau water is mostly acquire by interaction water-rock, associated with secondary phenomena such as dissolution and mineral precipitation, cation exchanges and anthropogenic pollution. Water contamination by infiltration of chemical pollutants in the irrigated perimeters would be induced by the government action aiming at supporting arboriculture, particularly, the apple tree in the region of Bouhmama, that has become a national and even a Maghreb label.

MATERIALS AND METHODS

Our study area is only located North-East of the department of Khenchela, at the piemont of Djebel Chelia. In fact, the structured models connected to the folds and facies variations system dominate the mountainous domain. It is, mainly, a matter of crests, chevrons and rocky ledges developed in calcareous and calcareous sandstone formations of Djebel Chélia, Djebel Tanout and Kef El Ahmeur. Geology is that of a sedimentary basin represented by a stratigraphic series extending from Trias to Quaternary, characterized, essentially, by the predominance of the secondary terrains, following an anticlinal oriented South West-North East, with, in the center, a Jurassic core topped with Turonienlimstone, characterized by a direction that bends at its northern end to form the axis of Chelia domes. The Quaternary terrains are only present in the valley of wadi Mellagou and in the depressed area of Ziriz. The lithological formations encountered are, in general, silt, pebbles, crusts, calcareous encrustment and landslides of slope bottom in the contacts areas constituting the Mio-Plio-Quaternary filling. The foldings of structures and the structural accidents tend to guide the feeding orientation of the basin. This explains the North East-South East of a large part of the flows. It should also be note that the oldest terrains reported in this area are the Trias facies that, in most cases, are set up thanks to diapirism. Climate is marked by the alternation of hot and dry season and cold and humid season. The mean annual rainfall is weak (400 mm), the mean annual temperature is (+ 15 °C), with a minimum of (- 5 °C) in winter and a maximum reaching (+ 28 °C) in summer. The presence of superficial flows materialized by wadi Mellagou and its different secondary and tertiary tributaries could suggest the existence of groundwater within the underground of the municipality, at least under the form of Quaternary aquifer.

Hydrochemistry will allow an attempt to explain the behavior, the origin and the evolution of the depicted chemical elements to explain the hydraulic functioning of the aquifer system. The study is mainly base on the data of samples taken from 39 boreholes distributed over the terrain. They are private boreholes. The sampling has been performing in Mai 2016. The preliminary findings of the dosed parameters are report in (table 1).

Table 1: Findings of chemical analyses

Variable	C25c	Ph	K	Na	Mg	Ca	HCO3	NO3	Cl	SO4	SiO2
Minimum	589,00	6,92	0,00	15,20	9,37	66,34	101,36	0,00	25,32	26,56	0,14
Maximum	6440,00	7,54	11,26	1029,26	183,63	451,19	390,85	79,91	1764,87	1165,38	30,03
Mean	2001,90	7,16	4,33	178,93	61,16	198,11	264,81	21,48	295,12	417,85	6,05
Std. Deviation	1563,46	0,15	3,14	246,05	43,44	87,09	75,40	17,97	465,90	241,46	5,55

All the analyses have been performed within the laboratories of the University of Montpellier 2 (HSM). Ionic chromatography ICS 1000 Dionex, and trace elements and heavy metals have analyzed major ions

by ICS-MS quadrupole X series 2 thermo-scientific, the multi-elementary analysis of the 39 samples by inductively coupled plasma mass spectrometry, and transient parameters are measure in situ by means of multiparameter type WTW330I.

RESULTS AND DISCUSSION

The study of water chemistry aims to identify the chemical facies of water, their quality of potability, as well as their suitability for irrigation. It also allows for monitoring the spatial evolution of the physico-chemical parameters, and for evaluating their origin by correlating them with geology [1]. The quasi-totality of water points of the aquifer is intended to water supply for drinking and irrigation. To be use, water should meet certain norms that vary in function of the type of use. For this purpose, a sampling on thirty-nine water points capturing the Quaternary aquifer, and regularly distributed over the overall studied area, has been carry out during the period.

The Piper diagram is particularly adapted to the study of facies evolution or is use for comparing groups of samples with each other, and for indicating the dominant cations and anions. The interpretation of the hydrochemical analyses findings has allowed having an idea about the chemical facies of water of our study area. The representation of the physico-chemical data of groundwater of Mellagou plain (39 samples) on Piper diagram has shown the existence of three chemical facies: chloride-sodium, sulfate-calcium and bicarbonate- calcium.

Statistical analysis

Within the framework of our study, 15 variables have been taking into account, represented by the following physico-chemical parameters: HCO₃, Cl, NO₃, SO₄, Ca, Mg, Na, K, SiO₂ and the electrical conductivity (c25°C).

Correlation matrix

The contribution of correlation between the physico-chemical parameters in groundwater helps comprehend certain phenomena originating from the interaction water-rock. It allows for providing an approach on the common origin of certain parameters. It is accepted that a correlation is significant, if the correlation coefficient value « r » is comprised between + 0, 5 and 1 (positive relationship) and -0.5 and -1 (negative relationship) [2]. In our case, many links are significant, but at variable degrees. So, the correlation matrix (table 2) demonstrates that Na⁺ cl⁻ concentrations are very strongly correlated with r=0.993. Ca⁺ calcium is strongly correlated with SO₄ r= 0 .926.The conductivity is related to elements Cl, Na, Ca and K. We can say that the dissolution of the evaporites greatly contributes to water chemistry of Mellagou plateau.

Table 2: Correlation matrix

Variables	C25c	Ph	K	Na	Mg	Ca	HCO3	NO3	Cl	SO4	Sio2
C25c	1										
Ph	-0,4210	1									
K	0,5143	0,0718	1								
Na	0,9538	-0,4026	0,4467	1							
Mg	0,2564	-0,5461	-0,4586	0,3294	1						
Ca	0,6044	-0,6191	-0,0198	0,6387	0,7956	1					
HCO3	0,1289	-0,4528	-0,5536	0,0865	0,6899	0,4694	1				
NO3	-0,3062	0,1506	0,3457	-0,3676	-0,4770	0,3811	-0,4181	1			
Cl	0,9548	-0,3853	0,4591	0,9932	0,3186	0,6270	0,0726	0,3525	1		
SO4	0,3860	-0,5872	-0,2352	0,4294	0,9010	0,9269	0,5281	0,4082	0,3994	1	
Sio2	0,4345	-0,3619	-0,1052	0,5740	0,3948	0,4397	0,3821	0,4753	0,5146	0,3876	1

Table3: factorial axes selected

	F1	F2	F3
Eigenvalue	5,4501	2,7292	1,0676
Variability (%)	49,5460	24,8107	9,7052
Cumulative %	49,5460	74,3567	84,0618

The variables and individuals projection have been performed upon three axes representing 84, 06% of the total variance (**table 3**).

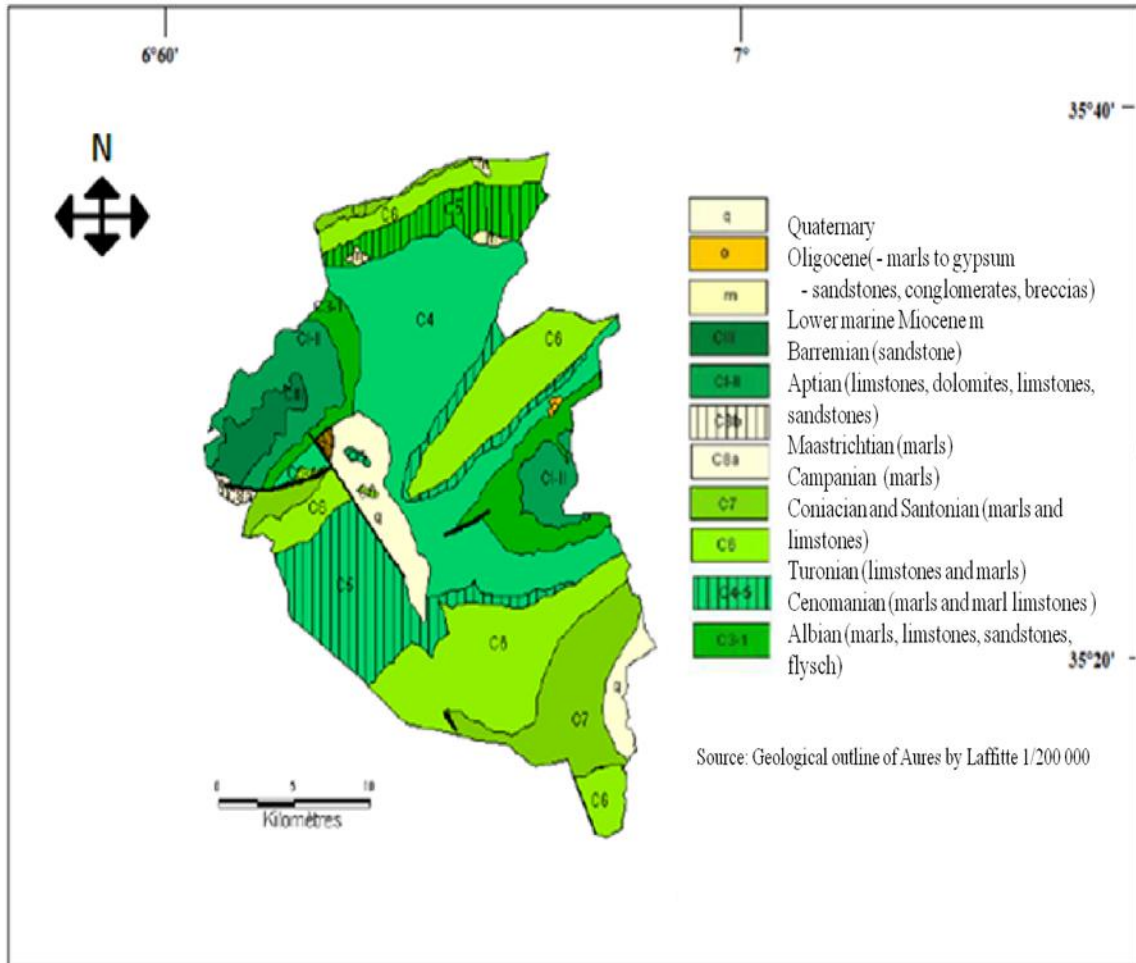


Figure 1: Geology of the study area

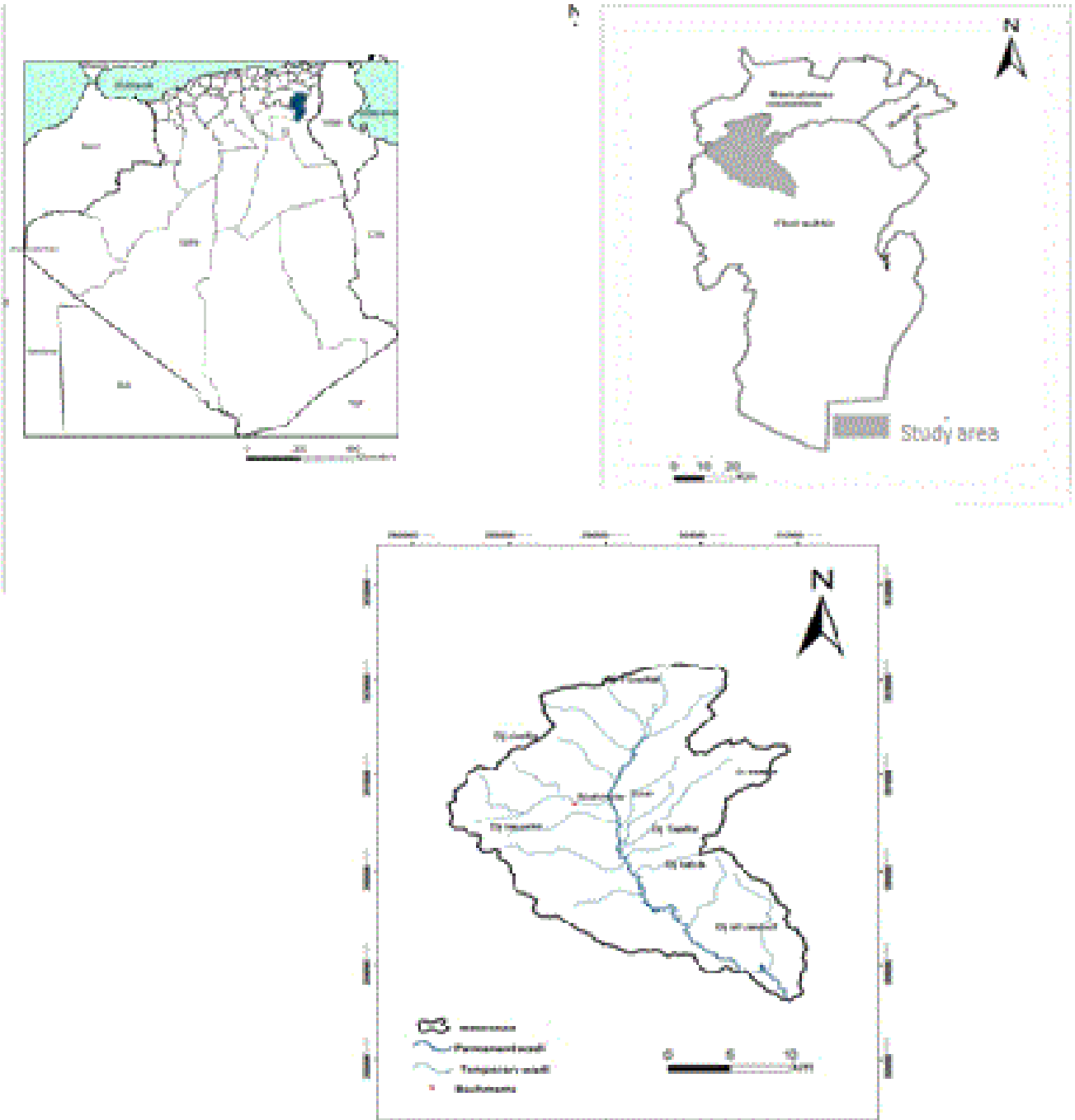


Figure 2: Geographical location of the study area

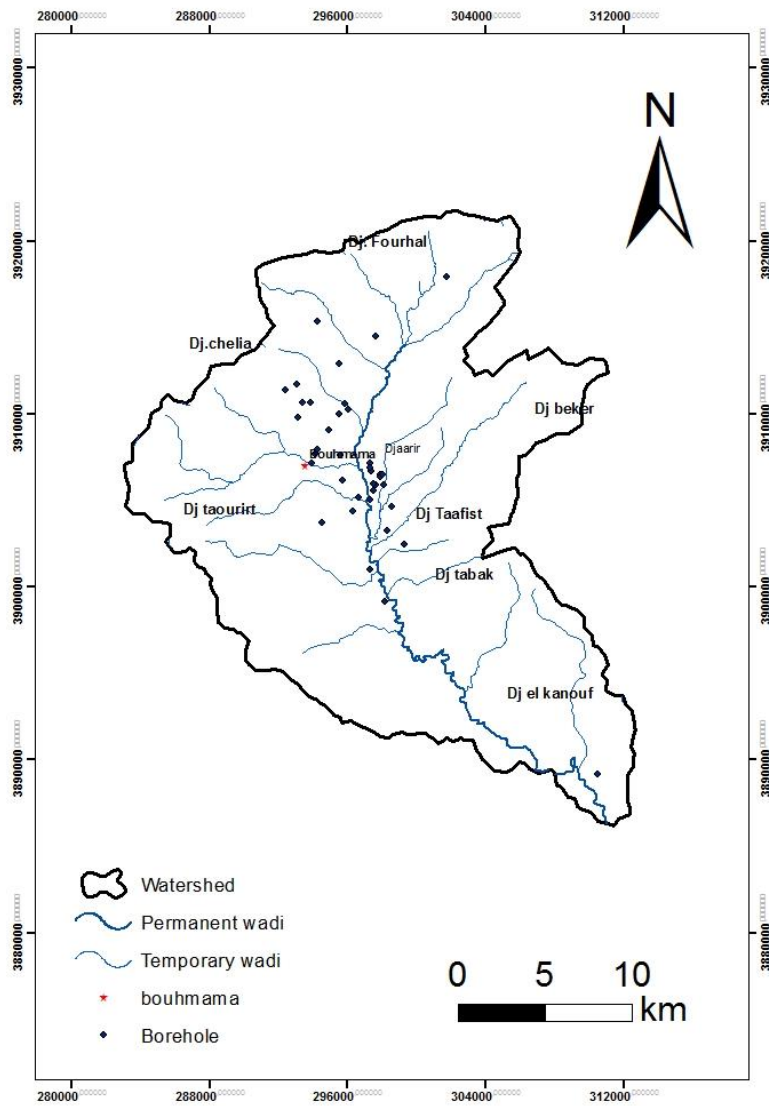


Figure 3: Inventory map

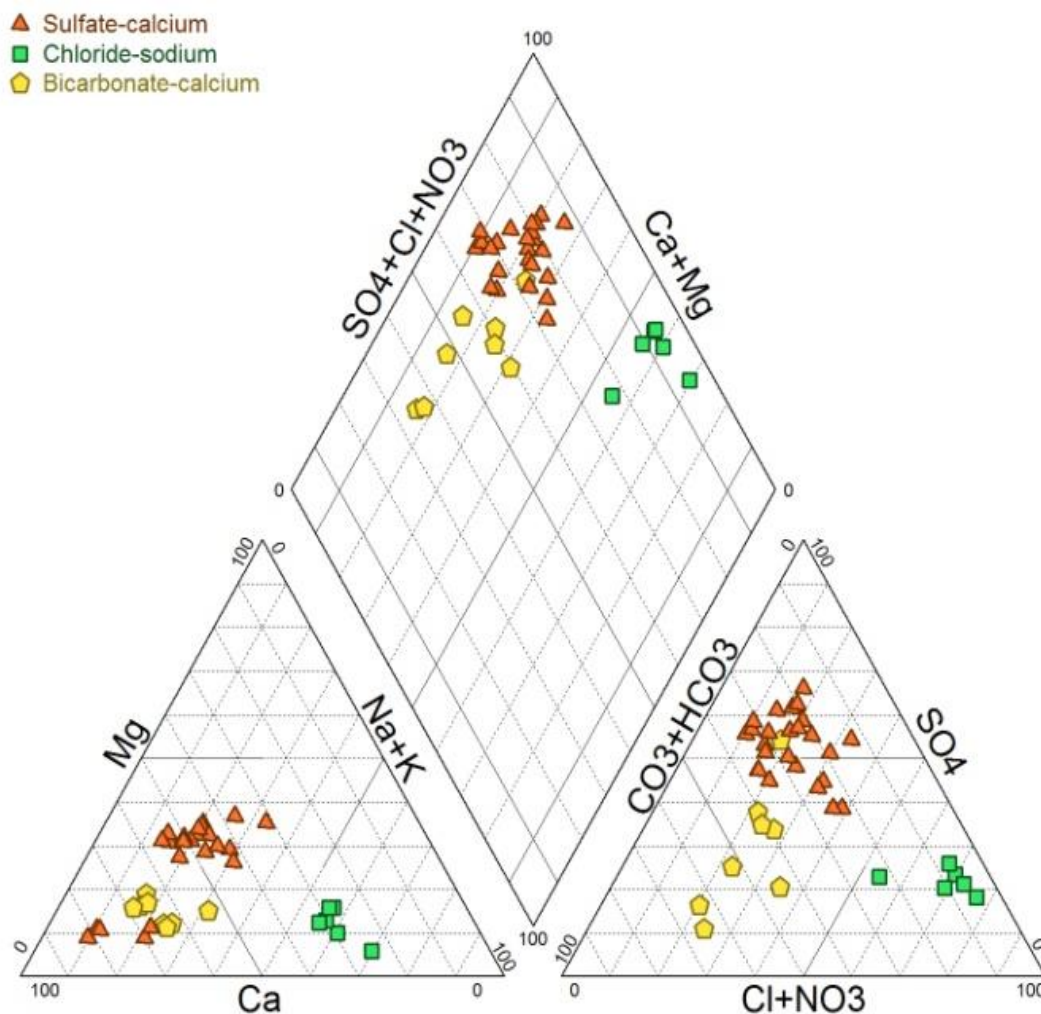


Figure 4: Projection of the samples on Piper diagram

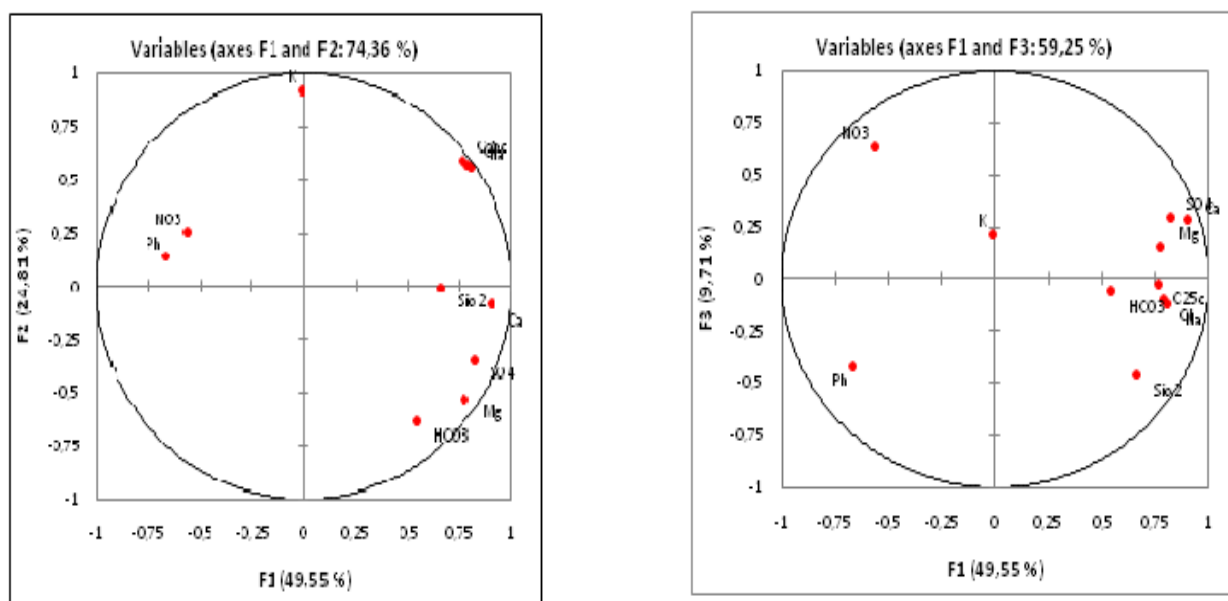


Figure 5: Analysis within the variables space (factorial design F1-F2 and F1-F3)

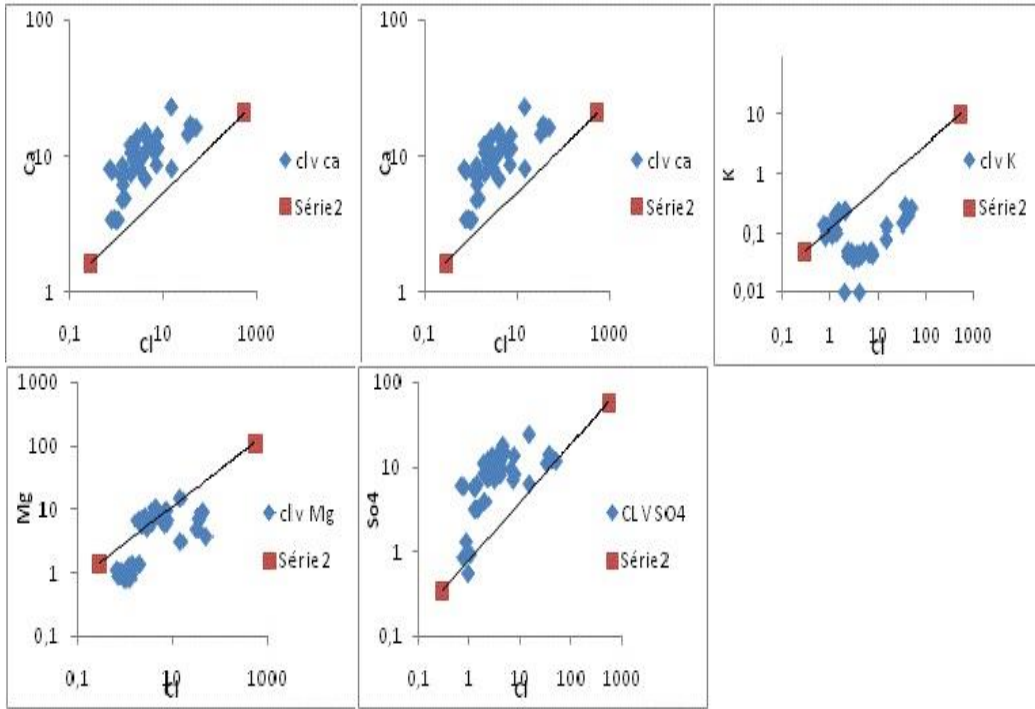


Figure 6: Relationship between Ca, Mg, Na, K, SO4 and Cl of groundwater and rainwater-seawater

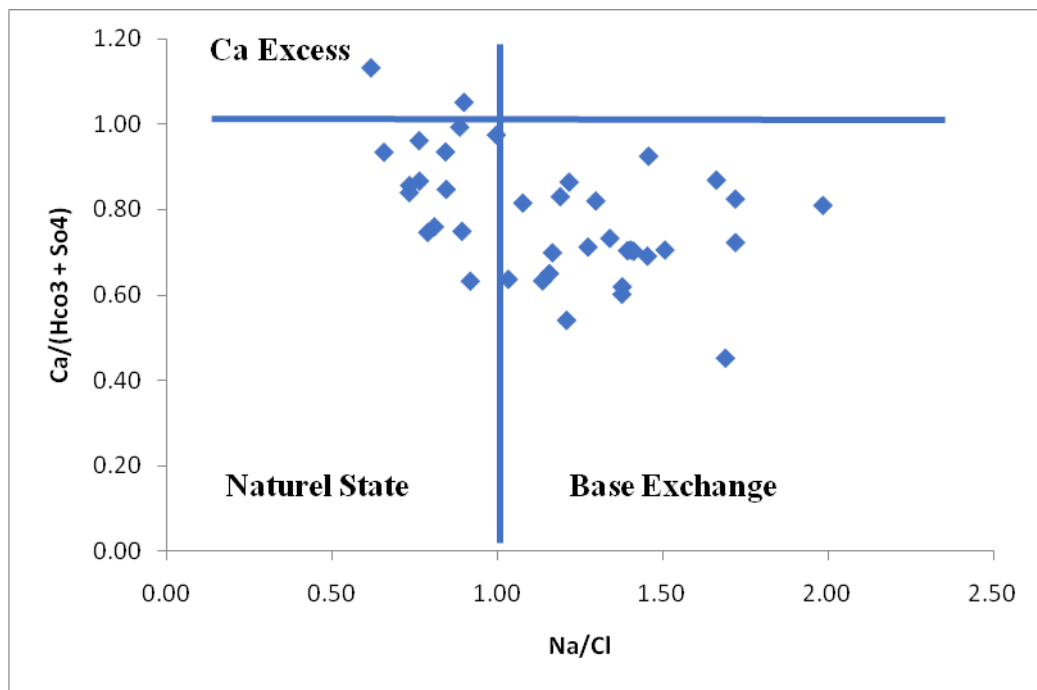


Figure 7: Base Exchange

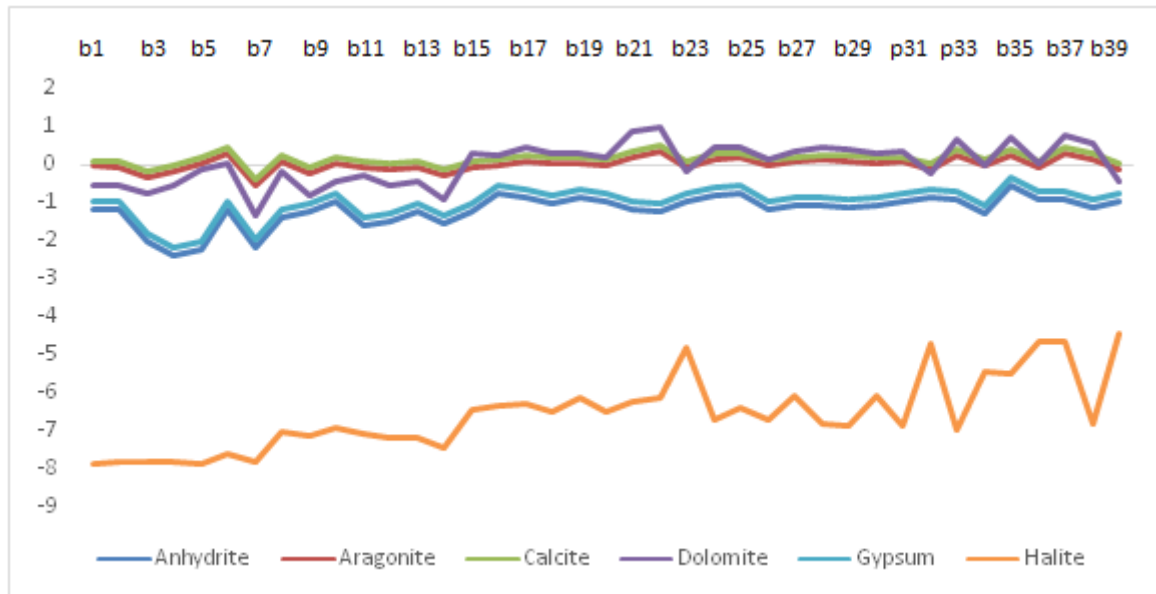


Figure 8: Saturation indice variation of minerals

The variables projection on design F_1 - F_2 (**fig5**) highlights two groups:

The axis F_1 expresses 49.55% of the variance. The positive part of this axis is related to the groups of variables Cl, SO_4 , Mg, Na, SiO_2 , HCO_3 , Ca and to the conductivity, which globally explains waters evaporitic mineralization, with a deep waters circulation and a heavy interaction water-rock. The F_2 axis represents 24.81 % of the explained variance. It is determined by potassium that reflects polluted waters, with the presence of clay fraction.

The axis F_3 defines 10% of the total inertia, and confirms the anthropogenic pollution by nitrates presence.

Salinity origin

To better understanding the mineralization process of groundwater, we have represented the major elements in function of ion chlorides. This latter is a conserved element, does not contribute to interaction water-rock, characterizes the origin of water salinity and constitutes a mixing tracer [3].

The graph Cl^- against Na^+ shows that all the points are situated bellow the mixing line. Considering that Na^+ content should balance Cl^- content, Na^+ deficit is explained by the phenomenon of ionic base exchange between water and the aquifer, and is reflected by the absorption of Na^+ by the clay matrix to desorbs alkaline-earths. So, the figure, of Ca vs. Cl corroborates the enrichment in calcium. This contribution is due to simultaneous dissolution of carbonates and gypsum, associated with Ca contribution through cation exchange that causes calcium to be released to the detriment of sodium and magnesium retention. This latter, after a rapid dissolution, attains the balance with the solution to precipitate under the form of dolomite. The graph of SO_4^{2-} and Cl^- shows that all the points are situating above the mixing line freshwater-saltwater. Sulfates enrichment would be due to contribution through gypsum dissolution, leaching of evaporates and infiltration of irrigation water, loaded with salt and fertilizers, facilitated by the weak depth of the water table and the good permeability of the aquifers terrains [3]. The relationship between K^+ and Cl^- underlines the fact that most of the points are bellow the mixing line, except for some points that get close to this line, showing that the most likely origin would be pollution.

The projection of the different points on diagram $Ca^{+2} / (HCO_3^- + SO_4^{2-}) - Na^+ / Cl^-$ shows that 59 % of the water points undergo a base exchange, 35 % of the points exhibit the natural state, and 05 % (F_7 and F_9) exhibit Ca^{2+} excess with respect to ions HCO_3^- and SO_4^{2-} , surely due to gypseous formations that provide more ions Ca^{2+} .

Saturation Indice (IS)

The water balance with the matrix is often expressed by the saturation indice [$IS = \log (PAI/K_s)$], where PAI is the activity product of the concerned ions, and K_s is the product of dissolubility of the considered mineral [4]. The degree of saturation, subsaturation, where the balance state of a solution toward a mineral is only appreciate, if the solubility product can be compare with the product of the ionic activity of the referential ions within the solution [5]. A zero saturation indice does not signify that water is in balance with the studied mineral. Water will be undersaturated if $IS < 0$ (mineral dissolution), and oversaturated if $IS > 0$ (mineral precipitation)[6]. The significant findings of all the analyzed groundwater samples (fig8) demonstrate that these latter are saturated with respect to the carbonate formations such as calcite, dolomite and aragonite, and are undersaturated with respect to the evaporitic formations that are halite, gypsum and anhydrite. The minerals saturation indice within water points out that only carbonate minerals tend to precipitate, especially under the form of dolomite. Unlike, the evaporitic minerals are in dissolution, which allows the evaporitic elements to appear within water at relatively high concentrations, and explains the dominance of chloride-calcium facies through halite dissolution.

CONCLUSION

Groundwater of Mellagou plateau has significant variations of mineralization that increased from North to South in the direction of flow. The conductivity is generally high, ranging between $589 \mu\text{S cm}^{-1}$ and $6440 \mu\text{S cm}^{-1}$. The most loaded areas are directly connected with salifere Trias. This salinity is, especially controlled by the dissolution of halite, coupled with an anthropogenic pollution. The statistical tool has corroborated that interaction water-rock is responsible for the mineralization of Mellagou basin waters. The thermodynamic analysis confirms that waters geochemistry is determined by mineral dissolution-precipitations phenomena and by ion exchanges. Pollution, for its part, contributes to water mineralization, and remains a secondary factor.

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