

# Multivariate statistical analysis of the alluvial aquifer of Tadjenanet- Chelghoum Laid (Eastern Algeria)

## Analisi statistica multivariata dell'acquifero alluvionale di Tadjenanet - Chelghoum Laid (Algeria orientale)

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### ARTICLE INFO

Ricevuto/Received: 26 January 2023

Accettato/Accepted: 22 June 2023

Pubblicato online/Published online:

30 June 2023

Handling Editor:

Iacopo Borsi

### Citation:

Dib, I., Khedidja, A., Chettah, W. (2023). Multivariate statistical analysis of the alluvial aquifer of Tadjenanet-Chelghoum Laid (Eastern Algeria). *Acque Sotteranee - Italian Journal of Groundwater*, 12(2), 67 - 75  
<https://doi.org/10.7343/as-2023-643>

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**Keywords:** *multivariate analysis, aquifer, salinity, groundwater quality.*

**Parole chiave:** *analisi multivariata; salinità; stato qualitativo delle acque sotterranee.*

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### Riassunto

La regione di Chelghoum Laid – Tadjenanet si trova nell'Algeria orientale. Dal punto di vista geologico è caratterizzata da formazioni di età diverse (Mio-Plio-Quaternarie), ove è presente un acquifero superficiale che è sfruttato per rispondere alla domanda di risorsa idrica per uso potabile e civile. Il sovrasfruttamento di tale acquifero ha comportato negli anni un abbassamento della superficie piezometrica, innescando conseguentemente un crescente problema di salinizzazione. In questo contesto, è stato sviluppato uno studio idrochimico basato su 28 campioni di acqua, utilizzando tecniche di analisi dati come la rappresentazione tramite diagrammi binari o di Piper, PCA (*Principal Component Analysis*), classificazione gerarchica, ecc. L'analisi ha mostrato come le acque che risiedono ai limiti dell'area di studio siano dominate da carbonato di calcio, mentre nella zona centrale vi sia una predominanza di solfato di calcio e cloruro di sodio. La variazione spaziale delle facies idrochimiche che è stata riscontrata nelle acque oggetto dello studio è spiegabile dal fenomeno di dissoluzione e dallo scambio ionico fra metalli alcalini e metalli alcalino terrosi coincidente con la direzione Ovest-Est del flusso di falda.

L'applicazione delle varie tecniche statistiche mostra che la ricarica dell'acquifero è dovuta principalmente all'apporto delle precipitazioni al limite della pianura, dove l'acqua acquisisce la sua originaria mineralizzazione grazie alle formazioni carbonatiche, e diviene poi più mineralizzata in cloruri, sodio e solfati venendo a contatto con le formazioni del Mio-Plio-Quaternario. Inoltre, la salinizzazione delle acque sembra essere dovuta principalmente alla dissoluzione di gesso, salgemma ed epsomite. L'applicazione della classificazione gerarchica ascendente e l'analisi delle componenti principali mostra l'esistenza di due gruppi di acque la cui salinità aumenta dai limiti dell'acquifero verso il centro della pianura, seguendo la direzione principale del flusso di falda.

### Abstract

*The region of Chelghoum Laid - Tadjenanet is located in eastern Algeria, in the high plains. This area is characterized by a varied age (Mio-Plio-Quaternary) formations and the human demand is answered by the groundwater hosted into the superficial aquifer of the Mio-Plio-Quaternary formations. However, the overexploitation of this aquifer leads to a drop in the piezometric surface and an increase in salinity. A hydrochemical study using characteristic ratios and statistical tools such as principal component analysis and hierarchical ascending classification, was performed using 28 water samples. Chemical analyzes show that the waters of this aquifer are of the calcium bicarbonate type on the limits of the study area, and calcium sulphate to sodium chloride in the centre. The spatial evolution of chemical water facies is explained by the phenomenon of dissolution and ion exchange between the alkali metals and alkaline earth metals coinciding with the West-East flow direction.*

*The application of the various tools shows that the aquifer is recharged by precipitation at the plains border, where the water acquires its original mineralization from the carbonate formations, and becomes more mineralized in chlorides, sodium and sulphates concentrations in contact with the salt-bearing terrigenous formations of the Mio-Plio-Quaternary.*

*The salinization of the waters seems to be mainly due to the dissolution of gypsum, halite and epsomite. The application of the ascending hierarchical classification and the principal component analysis shows the existence of two groups of water whose salinity increases from the borders towards the center of the plain following the main flow direction.*

## Introduction

The plain of Tadjanet-Chelghoum Laid, with an agricultural vocation, is located in the North East of Algeria where the various water needs are provided by groundwater from the superficial aquifer of the Mio-Plio-Quaternary formations. The pronounced drought that has raged in recent years has led to a general drop in the piezometry, leading to the drying up of many water sources (Khedidja, 2013, 2016; Bensouilah, 1995; Gao et al., 2022; Sun & Gui, 2015). The past geological, geophysical and hydrogeological studies realized on the research area showed the existence of a shallow aquifer (Khedidja, 2016; Vila, 1980). This aquifer, located within the alluvium, is surrounded by carbonate reliefs of the Eocene-Cretaceous. These carbonate formations constitute boundaries with imposed potential which contribute in an appreciable way to the supply of this aquifer. Groundwater is accessible through shallow wells (from 10 to 15 m). As a result, the exploitation of this aquifer has continued to increase and the withdrawals are becoming higher than the regulating resources (Khedidja, 2019). The overexploitation of this aquifer leads to an average drop in the level of the piezometric surface of 1 to 2 m/year (Khedidja, 2016). This situation makes it difficult to understand the functioning of the Tadjanet-Chelghoum Laid hydrogeological system by conventional hydrodynamic means. Geochemical methods offer an interesting alternative to clarify the functioning of this system (Scanlon et al., 2023). The statistical and cartographic analysis of the hydrochemical data of the waters of the aquifer, have made it possible to contribute to the understanding of the hydrochemical processes and the origin of the salinity of the groundwater.

## Materials and methods

### Study Area

The Tadjanet-Chelghoum Laid basin, with an area of 1000 km<sup>2</sup>, is part of the high plains of eastern Algeria (Fig. 1). It is a relatively flat surface with a very low slope whose average altitude is 830 m a.s.l. and it is surrounded by reliefs culminating at 1170 m a.s.l. This flat-bottomed basin morphology has allowed the installation of a strong exoreic hydrographic network, the main watercourse of which is Oued Rhumel, feeding the Grouz dams in Athmania and Béni Haroun in Mila. The climate of the region is semi-arid, characterized by average annual rainfall of around 372 mm and an average annual temperature of 15.4°C. This semi-aridity condition favors climatic aggressiveness which translates into a water shortage due mainly to the irregularity of rainfall which exposes the region to an increase in temperature and high evapotranspiration. From a geological point of view, the Tadjanet-Chelghoum Laid plain is formed by Mio-Plio-Quaternary alluvium and carbonate formations from the Cretaceous and Jurassic ages (Vila, 1980) which surround the basin. It is a syncline filled with sometimes gypsum red clays topped by lacustrine limestone, conglomerates and alluvium, of Mio-Plio-Quaternary age. This formation is 300 to 500 m thick (Boudoukha et al., 1997). The bedrock of the aquifer is made up of a clay and marl formation, with an irregular morphology and of Miocene age (Issaadi, 1981).

The structure of this southern Setifian unit is disordered by the establishment of diapiric pointings of the Triassic saliferous (Wildi, 1983) occupying extrusive anticlinal positions in connection with the southern Setifian formations;

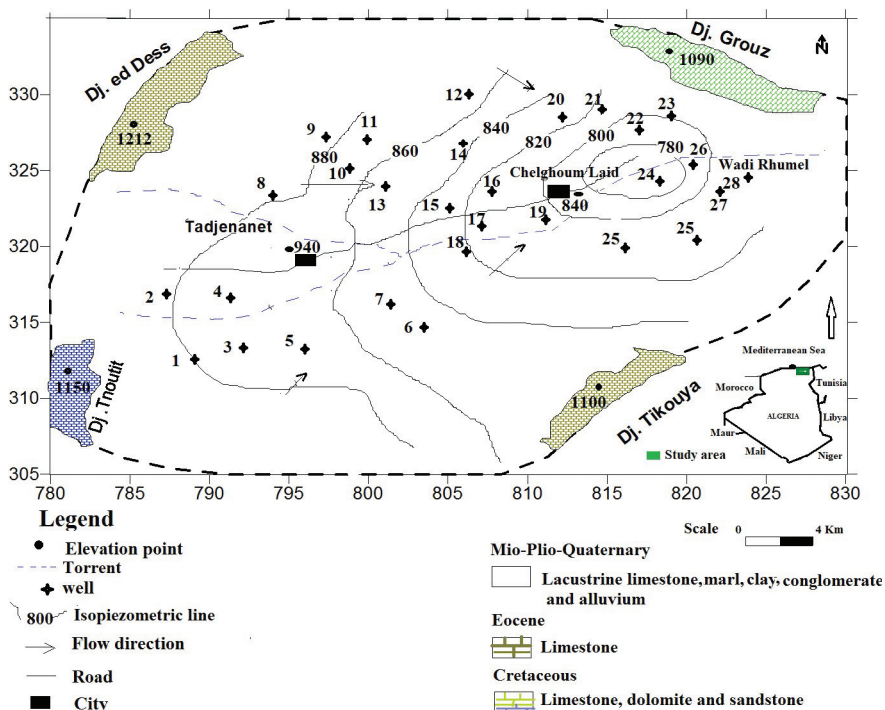


Fig. 1 - Map of the natural conditions of the study area: geology and groundwater level maps (April 2018).

Fig. 1 - Carta dell'area di studio: geologia e piezometria (aprile 2018).

this complex outcrops to the north, south and east. The Triassic formations is composed by a mass of crushed gypsum with small calcareo-dolomitic cubes accompanied by cagneules, greenish sandstone with clay cement and green rocks with an ophitic tendency (Vila, 1980).

Hydrogeological studies have shown the existence of a superficial aquifer in the Tadjnanet-Chelghoum Laid region located in the alluvial formations of the Mio-Plio-Quaternary sediments laying on clays and sometimes gypsum marls. It is an unconfined aquifer whose thickness varies between ten meters on the borders and a hundred meters in the center of the plain. These alluviums have an average permeability of  $10^{-4}$  m/s (Khedidja, 2016). This aquifer is characterized by a flow converging towards East, following closed equipotential lines of West-East direction which coincides with the morphology of the bedrock. The spacing of the equipotential lines reflects an average hydraulic gradient of around 3‰ (Khedidja, 2016) (Fig. 1). This piezometric state suggests a supply by the Secondary limestones outcropping in the western area and a discharge towards the East. The presence of salt formations could have an impact on water quality.

## Methods

The chemical data were analyzed using characteristic molar mass ratios followed by statistical analysis. The salinization mechanism was investigated using a correlation of different chemical elements which is commonly used to estimate the Correlation ( $r$ ) between two variables. It is a simple statistical tool that shows the degree of connection between two variables. A principal component analysis (PCA) was applied to the processing of these chemical data. Although PCA is an exploratory and descriptive method (Dagnélie, 2006), the purpose of this treatment is to determine the main factors that control the chemistry of these waters. This statistical method has been widely applied to investigate environmental phenomena and hydrogeochemical processes (Chiaudani et al., 2017; Deiana et al., 2017; Anazawa et al., 2005; Güler and Thyne, 2004; Belkhiri et al., 2011; Tiri et al., 2011; Ghodbane et al., 2016; Dib et al., 2022). This work therefore focuses on the strength of this technique to characterize the hydrochemical variations in the Tadjnanet-Chelghoum Laid aquifer. The Ascending Hierarchical Classification (AHC) makes it possible to see if samples can be assembled into statistically distinct hydrochemical groups in relation to the geological context. A number of authors have used this technique to classify water samples (Alther, 1979; Williams, 1982; Farnham et al., 2000; Meng and Maynard, 2001; Bencer et al., 2016) and have been able to grouped according to their similarities. This analysis was performed on a table of 9 variables (EC, Ca, Mg, Na, K, Cl,  $\text{SO}_4$ ,  $\text{HCO}_3$  and  $\text{NO}_3$ ) and 28 observations.

All this processing was carried out using Excel 2010 software and STATISTICA® (1998) version Free.

## Results and discussion

### Salinity and chemical facies

The examination of the chemical analyses (Tab. 1), shows pH varies between 6.6 and 7.6, which indicates a low alkalinity of groundwater. The Electrical Conductivity (EC) increases from West to East, it goes from 660  $\mu\text{S}/\text{cm}$  near to the edges to 3960  $\mu\text{S}/\text{cm}$  in the center of the plain at the level of Rhumel Wadi, where the water table is close to the surface from 0 to 3 m in the northeast part which makes it exposed to the phenomenon of evaporation leading to a concentration of chemical elements. The ratio  $(\text{Ca}+\text{Mg}+\text{HCO}_3)/(\text{Na}+\text{Cl}+\text{SO}_4)$  vs EC shows that low salinity is linked to the effect of dissolution of carbonates for the 65% of the analysed cases, while high salinities are linked to the dissolution effect of evaporitic salt formations, and it corresponds to the 35% of the analysed cases (Fig. 2).

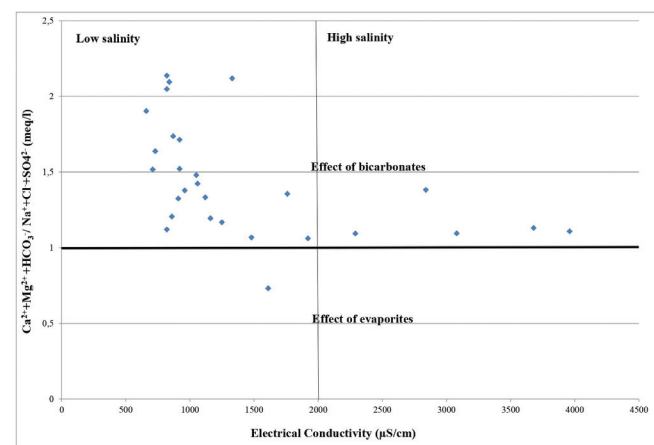


Fig. 2 - Effect of water rock interaction on the groundwater salinity.

Fig. 2 - Effetti dell'interazione acqua/roccia sulla salinità delle acque sotterranee.

The presentation of the chemical analysis results on the Piper diagram made it possible to reveal that most groundwater samples are characterized by mixed water type with a tendency to  $\text{SO}_4$ , Cl and Ca water-types (Fig.3).

The presence of fissured and karstified limestone formations at the border of the aquifer

suggests an infiltration of precipitation waters where they acquire their original calcium bicarbonate mineralization, which explains the low salinity of the waters on these limits. These waters become more mineralized in chlorides, sodium and sulphates in contact with the saliferous terrigenous formations by dissolution of the salty minerals, by base exchange with the clays and by concentration of the waters in chemical elements along the underground flow (Said et al., 2020; Dib et al., 2022; Elango & Kannan, 2007). They thus acquire their final saliferous mineralization (calcium sulphate then sodium chloride). This concentration is also favored by the low flow velocity, being the hydraulic gradient relatively low.

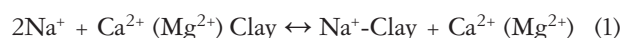
Tab. 1 - Physico-chemical features of the Tadjanet-Chelghoum Laid alluvial plain Groundwater.

Tab. 1 - Caratteristiche fisico-chimiche delle acque sotterranee della pianura alluvionale di Tadjanet-Chelghoum Laid

N° Well	T (°C)	EC (µS/cm)	pH	Ca <sup>2+</sup> (mg/L)	Mg <sup>2+</sup> (mg/L)	Na <sup>+</sup> (mg/L)	K <sup>+</sup> (mg/L)	HCO <sub>3</sub> <sup>-</sup> (mg/L)	Cl <sup>-</sup> (mg/L)	SO <sub>4</sub> <sup>2-</sup> (mg/L)	NO <sub>3</sub> <sup>-</sup> (mg/L)
1	16.5	1120	7.1	147.49	31.56	20.64	8.8	150.06	177.50	165	20
2	16.3	910	7.1	112.22	33.48	27.88	7.9	122	134.90	135	26
3	16.5	1250	6.8	144.28	34.44	47.03	7.8	183	177.50	198	24
4	16.5	870	7.3	80.16	57.50	9.80	6.1	219.60	101.25	184	43.5
5	16.5	820	6.8	145.89	32.52	18.11	7.3	286.70	49.70	225	23
6	16.4	860	7.3	148.29	29.16	45.54	7.5	190.32	92.50	295	37.5
7	16.5	1610	6.8	128.25	49.80	135.9	6	186.70	266.25	247	9.5
8	16.6	660	7.1	69.25	60.48	12.60	4.8	190.32	97.50	134	11
9	16.5	840	7.1	93.78	44.64	13.20	4.9	175.68	95	102	36
10	17.5	1480	7.1	176.35	71.88	24.61	5.9	101	266.25	325	80
11	16.8	1050	6.9	133.86	45.32	19.50	5	176.90	149.75	190	48
12	16.6	960	7.2	77.75	78.24	20.12	7	164.70	149.10	210	42
13	17.5	1920	7.6	202.80	108.72	94.30	6.8	298.90	305.30	475	26
14	17.5	3080	7.2	136.27	211.08	76.82	4.5	286.70	337.25	650	44
15	17.4	1760	6.6	259.71	20.50	41.40	5.8	237.90	248.50	235	88
16	17.5	820	6.9	256.51	124.56	68.08	6.9	275.72	323.05	602	40.5
17	17.4	920	7.2	124.24	31.08	11.4	9.2	151.28	113.60	178	49.5
18	17.5	3960	6.7	396.38	101.30	79.60	5.3	251.32	333.70	780	82
19	17.5	730	6.8	125.85	16.68	34.73	6.9	228.40	60.35	180	20.5
20	18	710	6.9	120.24	43.08	52.9	9.9	292.80	17.75	320	5
21	17.5	820	7.2	92.98	37.44	17.76	6.8	226.9	71	135	31.5
22	17.5	3680	6.9	336.67	129.24	35.65	10.2	207.40	333.70	785	48
23	17.5	2840	6.8	318.23	82.68	19.32	11.3	289.14	337.70	457	45
24	17.5	2290	7.1	274.14	52.56	30.36	5.5	134.20	330.50	378	81
25	16.8	1060	6.9	125.04	71.40	42.78	9	265.90	63.90	380	11.5
26	17.5	1330	7.3	204.40	98.16	23.3	11.2	488	39.03	495	4
27	16.9	1160	6.9	155.51	36.36	28.69	8.9	131.70	184.60	210	42
28	17	920	6.9	116.23	40.68	44.85	12	298.90	85.20	185	9
<b>Min</b>	16.3	660	6.6	69.25	16.68	9.8	4.5	101	17.75	102	4
<b>Max</b>	18	3960	7.6	396.38	211.08	135.9	12	488	337.7	785	88
<b>Average</b>	17.06	1443.93	7.02	167.96	63.38	39.17	7.47	221.86	176.51	316.25	36.71
<b>SD</b>	0.50	912.88	0.22	83.76	42.43	29.08	2.11	79.26	109.37	194.89	23.73
<b>CV%</b>	0.03	0.63	0.03	0.50	0.67	0.74	0.28	0.36	0.62	0.62	0.65
CV coefficient of variation, SD standard deviation											

The Ca<sup>2+</sup>/Mg<sup>2+</sup> molar ratio provides information on the origin of these elements from the dissolution of calcite and dolomite. If ratio Ca<sup>2+</sup>/Mg<sup>2+</sup> ≤ 1, there is a dissolution of dolomite, on the other hand a higher ratio testifies to the dissolution of calcite (Maya and Loucks, 1995), when it is greater than 2, it indicates the dissolution of silicate minerals (Katz et al., 1998). The waters of the Tadjanet Chelghoum Laid aquifer are characterized for the majority of cases (46%), by ratios between 1 and 2, reflecting a dissolution of calcite and secondarily (40%) of silicate minerals (terrigenous) (Fig. 4).

The origin of these major elements was also investigated using the Ca<sup>2+</sup> + Mg<sup>2+</sup> vs SO<sub>4</sub><sup>2-</sup> + HCO<sub>3</sub><sup>-</sup> diagram. If the analytical points align around the straight line with slope 1, the dominant reactions are due to the dissolution of calcite, dolomite and gypsum. Base exchange tends to move the dots down due to excess Ca<sup>2+</sup> + Mg<sup>2+</sup> or up due to excess SO<sub>4</sub><sup>2-</sup> + HCO<sub>3</sub><sup>-</sup> (Cerling et al., 1989; Fisher and Mulican, 1997). This process is done according to reaction (1).





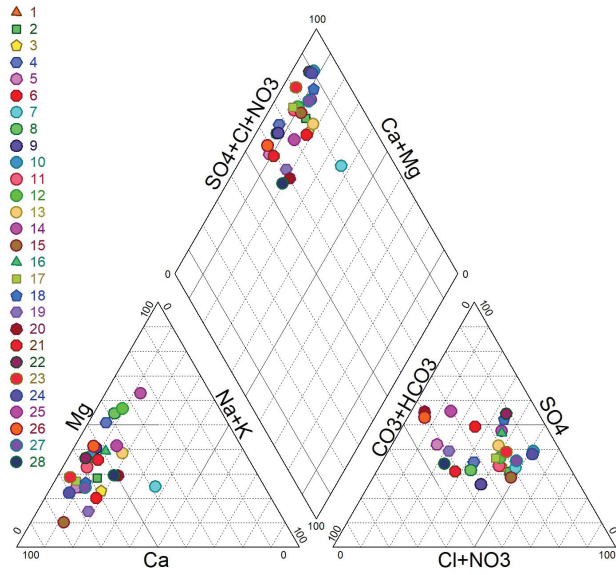


Fig. 3 - Piper diagram of the groundwater sampling points.

Fig. 3 - Diagramma di Piper relativo ai campioni analizzati.

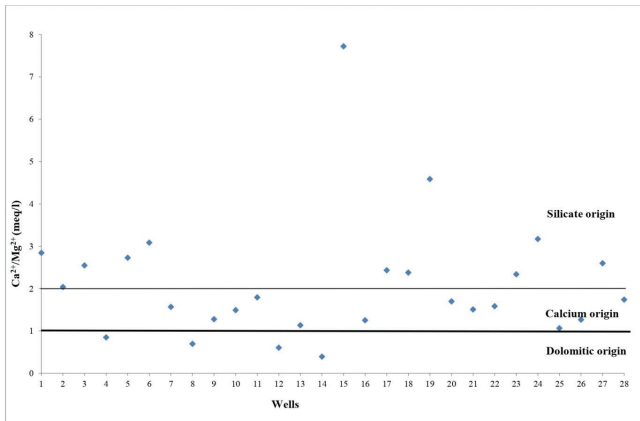
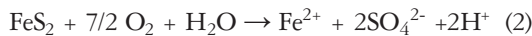


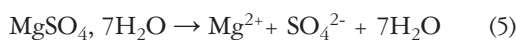
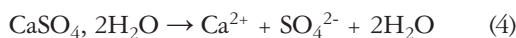
Fig. 4 - Origin of calcium of the Tadjenanet-Chelghoum Laid aquifer.

Fig. 4 - Origine del contenuto in calcio dell'acquifero di Tadjenanet-Chelghoum Laid.

The presence of sulphates in large quantities in groundwater (up to 400 mg/L) could also be attributed to the dissolution of anhydrite, pyrite or marcasite according to the formula proposed by Appelo and Postma (1993) and Droubi et al. (1976) according to the same formula (2).



The Na-Cl and Ca-SO<sub>4</sub> diagrams reflect a dissolution of halite, anhydrite and/or gypsum and epsomite according to formulas (3), (4) and (5). (Fig. 6 and 7).



Nevertheless, the excess recorded in Cl and SO<sub>4</sub> may be due to anthropogenic action, Oued Rhumel constitutes the main outlet for waste water in the region, which allows contamination of the water table given that the static level is very close to the ground surface (< 3 m) (Khedidja, 2016).

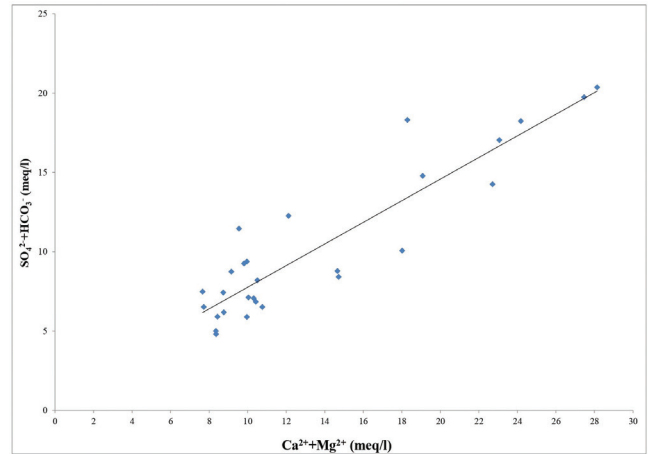


Fig. 5 - SO<sub>4</sub>+HCO<sub>3</sub> - Ca+Mg relationship in groundwater samples.

Fig. 5 - Relazione fra SO<sub>4</sub>+HCO<sub>3</sub> - Ca+Mg nei campioni di acque sotterranee.

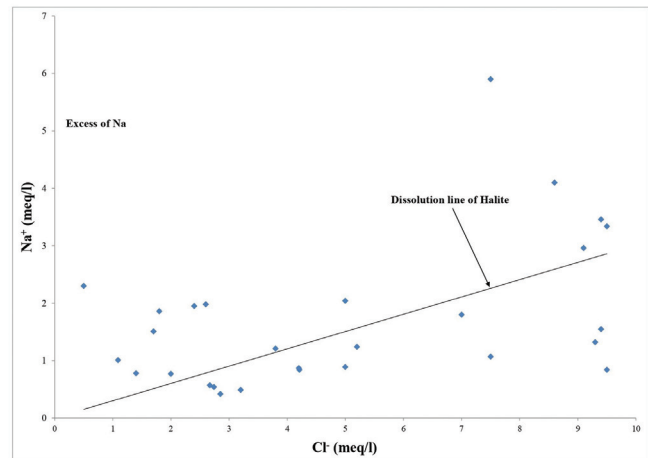


Fig. 6 - Na-Cl relationship in groundwater samples.

Fig. 6 - Relazione fra Na e Cl nei campioni di acque sotterranee.

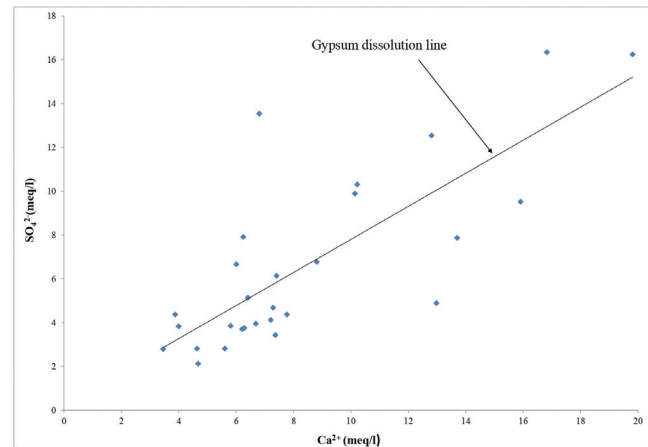


Fig. 7 - Ca- SO<sub>4</sub> relationship in groundwater samples.

Fig. 7 - Relazione fra Ca e SO<sub>4</sub> nei campioni di acque sotterranee.

## Statistical analysis

### Correlation between variables

For a better characterization of the chemical parameters and their evolution, a correlation was made between the different variables analyzed. The different relationships between the chemical parameters can be determined by estimating the correlation coefficient on the basis of the theoretical critical coefficient taken from the Bravais-Pearson table as a function of the number of pairs involved between two variables. On this basis, the critical coefficient is equal to 0.37 for a number of pairs of 28 (Tab. 2). This shows that salinity is linked to almost all the elements. Salinity is therefore due both to carbonated elements and to evaporitic elements. The carbonated elements ( $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$  and  $\text{HCO}_3^-$ ) are well correlated with each other, which testifies to the dissolution of calcite ( $\text{CaCO}_3$ ) and dolomite ( $\text{CaMg}(\text{CO}_3)_2$ ). The evaporitic elements are also well correlated with each other, which testifies the influence of evaporitic minerals such as halite ( $\text{NaCl}$ ), sylvite ( $\text{KCl}$ ), anhydrite ( $\text{CaSO}_4$ ) and gypsum ( $\text{CaSO}_4 \cdot \text{H}_2\text{O}$ ) in the chemical composition of these waters. Therefore, the water-rock interaction is well highlighted using this coefficient.

### Principal component analysis (PCA)

The analysis performed is a reduced centered PCA that was performed on an array of 9 variables ( $\text{EC}$ ,  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{HCO}_3^-$ ,  $\text{Cl}^-$ ,  $\text{SO}_4^{2-}$  and  $\text{NO}_3^-$ ) and 28 individuals, water samples taken from the aquifer in question. Kaiser's (1960) criterion was applied to determine the total number of significant factors. The eigenvalues measure the amount of variance explained by each principal axis. They are large for the first axes and small for the following axes. It allowed us to determine the number of principal components to be considered (Kaiser, 1960 ; Voudouris et al., 1997; Ugbaja et al., 2012). According to this criterion, only factors (F) with an eigenvalue greater than or equal to 1 will be accepted as possible sources of variance in the data. This is because a

factor with an eigenvalue of 1 accounts for as much variance as a single variable, and the logic is that only factors that explain at least the same amount of variance as a single variable is worth keeping. But often a cut-off of 1 results in more factors than the user bargained for or leaving out a theoretically important factor whose eigenvalue is just below 1. Therefore, F1 and F2 are assumed to be representative of the process of acquiring the water chemistry related to the water – rock interaction and agricultural pollution (Ghodbane et al., 2016). The analysis of our results shows that two principal components (PC) have been retained and represent 63.444% of the total variance, which is quite good and can be used to identify the main variations in the hydrochemistry (Tab. 3). PC1, which represents 43.311% of the variance, is determined positively by ( $\text{EC}$ ,  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^+$ ,  $\text{HCO}_3^-$ ,  $\text{Cl}^-$ ,  $\text{SO}_4^{2-}$ ). It is therefore the factor of mineralization and contamination by evaporitic and carbonated elements. PC2, which represents 20.132% of the total variance, is positively determined by K and  $\text{NO}_3^-$ . This last factor is therefore that of agricultural pollution (Tab. 4). Therefore, PC1 and PC2 are assumed to be representative of the process of acquiring water chemistry linked to water-rock interaction and pollution by agricultural activity (Khedidja and Boudoukha, 2013).

Tab. 3 - Characteristics of the PCA applied to the physico-chemical data of the waters of the Tadjanet-Chelghoum Laid aquifer.

Tab. 3 - Caratteristiche della PCA applicata ai dati dell'acquifero di Tadjanet-Chelghoum Laid.

CP	Eigenvalues	% of variance of PC	Variance Cumulative (%)
1	4.331	43.311	43.311
2	2.013	20.132	63.444

Tab. 2 - Correlation matrix of physico-chemical parameters of the Tadjanet-Chelghoum Laid aquifer.

Tab. 2 - Matrice di correlazione fra i parametri chimico-fisici dell'acquifero di Tadjanet-Chelghoum Laid.

Variables	EC	pH	$\text{Ca}^{2+}$	$\text{Mg}^{2+}$	$\text{Na}^+$	$\text{K}^+$	$\text{HCO}_3^-$	$\text{Cl}^-$	$\text{SO}_4^{2-}$	$\text{NO}_3^-$
EC	1									
pH	-0.19	1								
$\text{Ca}^{2+}$	<b>0.80</b>	-0.35	1							
$\text{Mg}^{2+}$	<b>0.62</b>	0.23	0.36	1						
$\text{Na}^+$	0.36	-0.12	0.25	<b>0.37</b>	1					
$\text{K}^+$	-0.04	-0.07	0.12	-0.10	-0.16	1				
$\text{HCO}_3^-$	0.12	0.04	0.20	<b>0.38</b>	0.19	<b>0.39</b>	1			
$\text{Cl}^-$	<b>0.78</b>	-0.13	<b>0.72</b>	<b>0.58</b>	<b>0.46</b>	-0.24	-0.15	1		
$\text{SO}_4^{2-}$	<b>0.81</b>	-0.07	<b>0.78</b>	<b>0.81</b>	<b>0.44</b>	0.08	<b>0.42</b>	<b>0.65</b>	1	
$\text{NO}_3^-$	<b>0.50</b>	-0.16	<b>0.56</b>	0.12	-0.09	-0.42	-0.39	<b>0.60</b>	0.29	1

Significant correlations are indicated in Bold

Tab. 4 - Variable correlations – factors.

Tab. 4 - Relazione fra fattori e variabili di correlazione.

Variable	PC1	PC2
EC	0.923	-0.033
pH	-0.184	0.189
Ca <sup>2+</sup>	0.858	-0.031
Mg <sup>2+</sup>	0.727	0.335
Na <sup>+</sup>	0.494	0.205
K <sup>+</sup>	-0.106	0.637
HCO <sub>3</sub> <sup>-</sup>	0.197	0.851
SO <sub>4</sub> <sup>2-</sup>	0.910	0.307
Cl <sup>-</sup>	0.877	-0.287
NO <sub>3</sub> <sup>-</sup>	0.534	-0.715

### Ascending Hierarchical Classification

The hydrochemical data were classified by the AHC according to the method of Ward (1963) in a space with 9 variables (EC, Ca<sup>2+</sup>, Mg<sup>2+</sup>, Na<sup>+</sup>, K<sup>+</sup>, HCO<sub>3</sub><sup>-</sup>, Cl<sup>-</sup>, SO<sub>4</sub><sup>2-</sup> and NO<sub>3</sub><sup>-</sup>) and 28 individuals. The result of such a treatment showed that the waters of the region can be classified according to the flow direction into two groups, where the electrical conductivity seems to be a major distinguishing factor (Fig. 8).

- Group 1 formed by the carbonated elements (Ca<sup>2+</sup>, Mg<sup>2+</sup> and HCO<sub>3</sub><sup>-</sup>).
- Group 2 formed by the rest of the elements and which can be divided into two subgroups. The first subgroup is represented by elements related to agricultural activity (K<sup>+</sup>, SO<sub>4</sub><sup>2-</sup> and NO<sub>3</sub><sup>-</sup>) while the second subgroup is made up of elements resulting from the dissolution of evaporitic minerals (Na<sup>+</sup> and Cl<sup>-</sup>).

Group 1 is formed by the samples with weak mineralization and which are found on the edge of the plain in connection with the carbonate formations. On the other hand, Group 2 is formed by samples taken from the center of the plain and they are characterized by strong mineralization

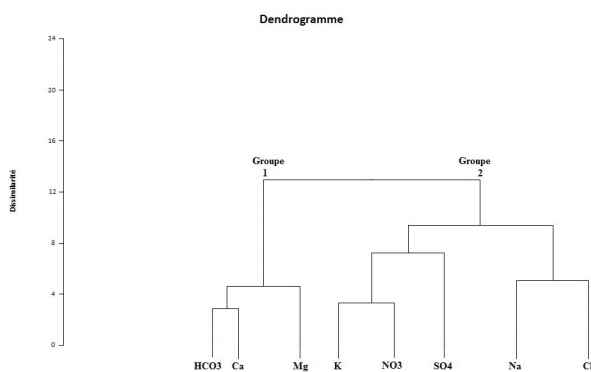


Fig. 8 - Analysis by Ascending Hierarchical Classification.

Fig. 8 - Analisi basata sulla classificazione gerarchica ascendente.

### Evolution of the chemistry of the two groups of water

Water-rock interactions and fluid circulations are recognized as the main agents of rock dissolution and the immigration of dissolved matter. Thus, the chemical composition of groundwater reflects the mineralogical composition of host rocks and can be used to identify recharge areas, the origin of groundwater and different chemical ions (carbonate, sulfate, nitrate and ammonium).

Accordingly, the groundwater facies the chemical results indicate natural mineralization is probably the result of the influence of aquifer mineralogical composition (such as clay, carbonate, marl and gypsum. The presence of fractured limestone formations at the boundaries indicates infiltration of precipitation waters, where they acquire their initial bicarbonate-calcium mineralization, which explains the low salinity of waters at these boundaries. These waters are more mineralized with chlorides, sodium and sulfates on contact with terrigenous saliferous formations due to the dissolution of evaporate minerals. Furthermore, the groundwater chemical evolution is highlighted by the Ca<sup>2+</sup> – Na<sup>+</sup> ionic exchange due to the presence of clay minerals along the groundwater flowpath. However, the anthropogenic origin of chlorides, sulfates and calcium is not excluded. Elevated nitrates concentrations in the analyzed water are caused by the excessive use of chemical fertilizers, and infiltration of irrigation water. This made it possible to classify the water into two groups, with increasingly high salinity depending on the direction of flow.

### Conclusion

The application of hydrochemical and statistical tools in the study of groundwater in the superficial aquifer of Tadjanet-Chelghoum Laid, made it possible to clarify its dynamics. The infiltration of precipitation waters at the level of the karstic aquifers at the plain borders where the groundwater acquires its original mineralization (carbonate), mineralize more in chlorides, sodium and sulphates in contact with the salt-bearing terrigenous sediments of the Mio-Plio-Quaternary formations. Chemical analyses show that the waters of this aquifer are of the calcium bicarbonate facies on the borders of area, calcium sulphate and sodium chloride in the centre. The salinization of the waters seems to be mainly due to the dissolution of gypsum, halite and epsomite. The application the statistical tools, made it possible to show significant connections between the electrical conductivity and the various chemical elements, which the groundwater aquifer is characterized by mixed water type

with a tendency to SO<sub>4</sub>, Cl and Ca water-types. The application of principal component analysis showed that two factors explain nearly 63% of the variance. Factor 1 is that of mineralization, while factor 2 is that of agricultural pollution. The application of the ascending hierarchical classification showed the existence of two groups of water whose salinity increases from the limits towards the center of the plain along the direction of flow. The hydrochemical and statistical tools

have shown that the salinity of groundwater is controlled by salt minerals in connection with the salt-bearing terrigenous formations and carbonate minerals, which is explained by the existence of two origins of water salinity. One is natural conditioned by the dissolution of carbonated and evaporitic formations, and an anthropic origin, relating to the agricultural vocation of the study area with excessive use of nitrogenous products

### Acknowledgments

This work was overseen by the Laboratory of mobilization and resources management, Department of Geology, Earth Sciences and universe Institute, University of Batna 2, Algeria. Acknowledgments to the General Directorate of Scientific Research and Technological Development (DGRSDT-MESRS) for the technical support. Tribute to the editor and reviewers for their valuable improvement on the manuscript.

### Funding source

This work was self-funded by the authors.

### Competing interest

The authors declare no competing interest.

### Author contributions

The authors Imane Dib and Abdelhamid Khedidja contributed to the design and implementation of the research, to the analysis of the results, and to the writing of the manuscript.

The author Wahid Chattah contributed to design of the figures.

All authors read and approved the final manuscript.

### Additional information

Supplementary information is available for this paper at <https://doi.org/10.7343/as-2023-643>

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## REFERENCES

- Appelo, C., & Postma, D. (1993). Geochemistry, groundwater and pollution. *Journal of Hydrology*, 155(1-2), 295-296.
- APHA. (1995). American Public Health Association, AWWA (American Water Works Association), and WPCF (Water Pollution Control Federation). Standard methods for the examination of water and wastewater (19th ed.). New York, USA.
- Alther, G.A. (1979). A simplified statistical sequence applied to routine water quality analysis: a case history. *Ground Water* 17, 556–561.
- Anazawa, K., & Ohmori, H. (2005). The hydrochemistry of surface waters in Andesitic Volcanic area, Norikura volcano, central Japan. *Chemosphere*, 59(5), 605-615.
- Bencer, S., Boudoukha, A., & Mouni, L. (2016). Multivariate statistical analysis of the groundwater of Ain Djacer area (Eastern of Algeria). *Arab J Geosci* (2016) 9:248 <https://doi.org/10.1007/s12517-015-2277-6>
- Belkhir, L., Boudoukha, A., & Mouni, L. (2011). A multivariate Statistical Analysis of Groundwater Chemistry Data. *Journal Environemental Reserch*. 5(2), 537-544.
- Bensouilah, S. (1995). Contribution à l'étude hydrogéologique des hautes plaines sétifiennes dans le cadre de la haute vallée de l'oued Rhumel en amont d'oued Athménia "Contribution to the hydrogeological study of the high plains of Setif in the upper valley of the Rhumel wadi upstream of the Athmenia wadi". Th. Magi. Univ. Constantine. 184p.
- Boudoukha, A., Kowalsky, W.M., Pharissat, A. (1997). Evolution des sédiments lacustres Plio-Villafranchiens des dépressions fermées d'El Eulma. Est algérien. "Evolution of the Plio-Villafranchian lacustrine sediments of the closed depressions of El Eulma. Eastern Algerian". Bulletin de la Société des Sciences Naturelles du Pays Montbéliard, 187-200.
- Cerling, T.E., Pederson, B.L., Damm, K.L.V. (1989). Sodium–calcium ion exchange in the weathering of shales: implications for global weathering budgets. *Geology* 17, 552–554.
- Chiaudani, A., Di Curzio, D., Palmucci, W., Pasculli, A., Polemio, M., & Rusi, S. (2017). Statistical and fractal approaches on long time-series to surface-water/groundwater relationship assessment: A central Italy alluvial plain case study. *Water*, 9(11), 850.
- Dib, I., Khedidja, A., Chattah, W., Hadji, R. (2022). Multivariate statistical-based approach to the physical-chemical behavior of shallow groundwater in a semiarid dry climate: The case study of the Gadaïne-Ain Yaghout plain NE Algeria. *Mining of Mineral Deposits* Volume 16 (2022), Issue 3, 38-47. <https://doi.org/10.33271/mining16.03.038>.
- Dagnelie, P. (2006). Statistique théorique et appliquée "Theoretical and applied statistics". Tome 2 : Inférences à une et à deux dimensions. Bruxelles-université DE Boeck et Larcier.
- Deiana, M., Mussi, M., & Ronchetti, F. (2017). Discharge and environmental isotope behaviours of adjacent fractured and porous aquifers. *Environmental Earth Sciences*, 76, 1-15.
- Droubi, A., Cheverry, C., Fritz, B., & Tardy Y. (1976). Géochimie des eaux et des sels dans les sols des polders du lac Tchad: Application d'un modèle thermodynamique de simulation de l'évaporation "Geochemistry of water and salts in the polders soils of TChad lake: Application of a thermodynamic model for simulating evaporation". *Chemical Geology*. 17, 165-177.
- Elango, L., & Kannan, R. (2007). Rock–water interaction and its control on chemical composition of groundwater. *Developments in environmental science*, 5, 229-243.
- Farnham, I.M., Stetzenbach, K.J., Singh, A.K., Johannesson, K.H. (2000). Deciphering groundwater flow systems in Oasis Valley, Nevada, using trace element chemistry, multivariate statistics, and geographical information system. *Mathematical. Geology*. 32, 943–968.
- Fisher, R.S., Mulican, W.F. (1997). Hydrochemical evolution of sodium-sulfate and sodium-chloride groundwater beneath the northern Chihuahuan desert, Trans-Pecos, Texas, USA. *Hydrogeology Journal*, 10(4) 455–474.



- Gao, Y., Chen, J., Qian, H., Wang, H., Ren, W., & Qu, W. (2022). Hydrogeochemical characteristics and processes of groundwater in an over 2260 year irrigation district: a comparison between irrigated and nonirrigated areas. *Journal of hydrology*, 606, 127437.
- Ghodbane, M., Boudoukha, A., & Benaabidate, L. (2016). Hydrochemical and statistical characterization of groundwater in the Chemora area, Northeastern Algeria. *Desalination and Water Treatment*, 57(32), 14858-14868.
- Guler, C., & Thyne, G.D. (2004). Hydrologic and geologic factors controlling surface and Groundwater chemistry in Indian wells-Owens Valley area, southeastern California, USA. *J. Hydrol.*, 285: 177-198.
- Issaadi, A. (1981). Etude hydrogéologique des massifs du Guerion et Fortars "Hydrogeological study of the Guerion and Fortars massifs". Thèse, 3ème cycle, Univ. Haouari Boumediene, Alger.
- Kaiser, H.F. (1960). The application of electronic computers to factor analysis. *Educ. Psychol.Meas.*, 20: 141-151.
- Katz, B.G., Coplen, T.B., Bullen, T.D., Davis, J.H. (1998). Use of chemical and isotopic tracers to characterize the interaction between groundwater and surface water in mantled Karst. *Groundwater*, 35(6) 1014-1028.
- Khedidja, A., & Dib, I. (2022). Effect of the agriculture on the quality of groundwater in the alluvial aquifer of the tadjenanet area (eastern algeria). *Geomatics, Landmanagement and Landscape No. 3 2022*, 45-57. <http://dx.doi.org/10.15576/GLL/2022.3.45>.
- Khedidja, A., Boudoukha, A. (2019). Quality assessment of shallow groundwater for irrigation purposes in Tadjenanet – Chelghoum Laid area (Eastern Algeria). *International Journal of River Basin Management*, 19:2, 141-148, <https://doi.org/10.1080/15715124.2019.1628031>.
- Khedidja, A. (2016). Caractérisation des paramètres hydrodynamiques de l'aquifère de Tadjanet – Chelghoum Laid et impact de la pollution des eaux de surface sur les eaux souterraines "Characterization of the hydrodynamic parameters of the Tadjanet Chelghoum Laid aquifer and the impact of surface water pollution on groundwater". Thèse de Doctorat en Sciences. Univ. Batna 2.
- Khedidja, A., Boudoukha, A. (2013). Risk assessment of agricultural pollution on groundwater quality in the high valley of Tadjenanet – Chelghoum Laid (Eastern Algeria). Publication au Journal International. Science and engineering. *Desalination and water treatment /Vol.51, January 2013*, pp.292- 301.
- Maya, A.L., & Loucks, M.D. (1995). Solute and isotopic geochemistry and groundwater flow in the Central Wasatch Range. *Journal of Hydrology*, 172, 31-59.
- Meng, S.X., & Maynard, J.B. (2001). Use of statistical analysis to formulate conceptual models of geochemical behavior: water chemical data from the Botucatu aquifer in Sao Paulo state. *Br. Journal of Hydrology*. 250, 78-97.
- Said, I., Merz, C., Salman, A., Schneider, M., & Winkler, A. (2020). Identification of hydrochemical processes using multivariate statistics in a complex aquifer system of Sohag region, Egypt. *Environmental Earth Sciences*, 79. <https://doi.org/10.1007/s12665-020-08913-8>.
- Scanlon, B. R., Fakhreddine, S., Rateb, A., de Graaf, I., Famiglietti, J., Gleeson, T., ... & Zheng, C. (2023). Global water resources and the role of groundwater in a resilient water future. *Nature Reviews Earth & Environment*, 1-15.
- Sun, L., & Gui, H. (2015). Hydro-chemical evolution of groundwater and mixing between aquifers: a statistical approach based on major ions. *Applied Water Science*, 5, 97-104.
- Tiri, A., Belkhir, L., Boudoukha, A., Lahbari, N. (2011). Characterization and evaluation of the factors affecting the geomistry of surface water of Koudiat Medouar basin. Algéria. *African Journal of environmental Science and Technology*. 5(5). 355-362.
- Ugbaja, A., Edet, A., & Offiong, O. (2012). Application of statistical methods in evaluating groundwater in parts of Mamfe Embayment, Southeastern Nigeria. *Journal of Geography and Geology*, 4(3), 1.
- Ward, J.H. (1963). Hierarchical grouping to optimize an objective function. *Journal of the American Statistical Association*. 69, 236-244.
- Wildi, W. (1983). La chaîne tello-rifaine (Algérie, Maroc, Tunisie) : structure, stratigraphie et évolution du Trias au Miocène, *Revue de géologie dynamique et de géographie physique "The Tello-Rif chain (Algeria, Morocco, Tunisia): structure, stratigraphy and evolution from the Triassic to the Miocene"*. Paris. 24, 201-297.
- Williams, R.E. (1982). Statistical identification of hydraulic connections between the surface of a mountain and internal mineralized sources. *Ground Water* 20, 466-478.
- Vila, J.M. (1980). La chaîne alpine de l'Algérie orientale et des confins Algéro-Tunisiens "The alpine chain of eastern Algeria and the Algerian-Tunisian borders. Doctorate thesis in science, Pierre and Marie Curie". Thèse de Doctorat- es -sciences, Université Pierre et Marie curie, Paris VI.
- Voudouris, K. S., Lambrakis, N. J., Papatheothorou, G., & Daskalaki, P. (1997). An application of factor analysis for the study of the hydrogeological conditions in Plio-Pleistocene aquifers of NW Achaia (NW Peloponnesus, Greece). *Mathematical Geology*, 29, 43-59.