CONTRIBUTION TO THE HYDROCHEMICAL STUDY OF GROUNDWATER IN THE PLAIN OF MELLAGOU - BOUHMAMA (NORTHEAST ALGERIA)

Noureddine BELKOUM*[1], Zouhir ZEGHDANI[2], & Horiya BOUALI[1]

[1]*Department of Ecology and Environment, Faculty of Natural and Life Sciences, Biotechnology, Water, Environment and Health Laboratory, Abbes Laghrour University, BP 1252 Road of Batna, Khenchela -40004- Algeria,*
**Corresponding author: noureddine.belkoum@univ-khenchela.dz*
[2]*Laboratoire de Zoologie Appliquée et d'Ecophysiologie Animale, Faculté des Sciences de la Nature et de la Vie, Université de Bejaia, Algérie.*

Abstract: The groundwater of Bouhmama shows important chemical variations induced by the aridity of the climate, mineral dissolution and agricultural activity. The use of geochemical techniques has identified that the evolution of the chemical facies takes place from the calcium bicarbonate pole in the limestone outcrops in the West towards a major facies of calcium sulfate type in the center and downstream of the plain. These chemical facies are determined by the water-rock interaction, dissolution and mineral precipitations, through cationic exchanges along the water flow towards its outlet and the infiltration of irrigation waters loaded with salts and fertilizers in the irrigated perimeters. PCA (Principal Component Analysis) explaining 85.64% of the variance shows that except for bicarbonates all elements are responsible for the mineralization of groundwater.

Keywords: Bouhmama, groundwater, chemical facies, irrigation, fertilizers.

1. INTRODUCTION

In Algeria, the demand for drinking water continues to increase alongside population growth. In addition to water quality, especially groundwater, which poses serious problems. However, the successive drought years accompanying the scarcity and irregularity of annual inputs both in surface water and groundwater delay development and pose a problem of managing these resources especially in the agricultural sector (Belhadj et al., 2017; Houha, 2007).

Irrigation water, whether from rivers or pumped from aquifers, is never pure, it contains dissolved salts which depending on their concentration can affect soils and crops. It is then important to adopt agricultural practices adapted to the water available knowing that behaviors will be different depending on the nature of the salts involved (Baali et al., 2007).

The chemical composition of water must therefore be examined in relation to its impact on land and plants.

Bouhmama region is one of the areas affected by the problem of water stress. This area is known for its agricultural vocation which exerts pressure on the aquifer through overexploitation and intensive use of agricultural inputs (fertilizers and pesticides) (Carrard et al., 2019).

The objective of our study is to assess the physicochemical characteristics of the groundwater in the study area, to follow their evolution in space and time through mapping of their chemical composition, to define their degree of pollution and their subsequent use to provide answers to the needs expressed by the public authorities in order to lay the foundations for sustainable development.

2. GENERAL AND GEOLOGICAL FRAMEWORK

The Mellagou basin (Bouhmama) is an entity of the high steppe plains, it is located between the Tellian Atlas in the North and the Saharan Atlas in the South, between 35°-10'-25" and 35°-42'-25" N latitude and between 6°-61'-10 "and 7°-1'-75" longitudes (Figure 1). The study area is almost completely surrounded by a mountain range (Houbib, 2013), it is limited to the North by Djebel Kef elahmeur and Djebel Guern elkabch, to the South by Djebel Kef Mdaouer and Djebel Tanout, to the East by Djebel Taafist and to the West by Djebel Chelia (2328m) (Gaagai et al., 2022).

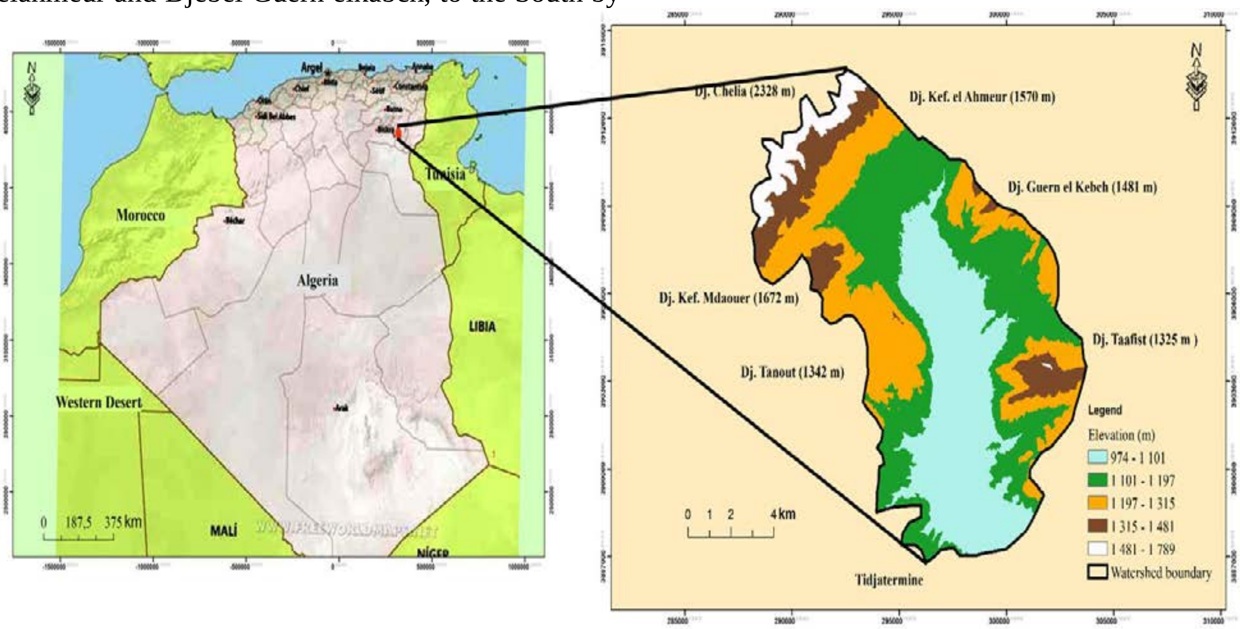

Figure 1. Geographical map of the Mellagou basin (Bouhmama)

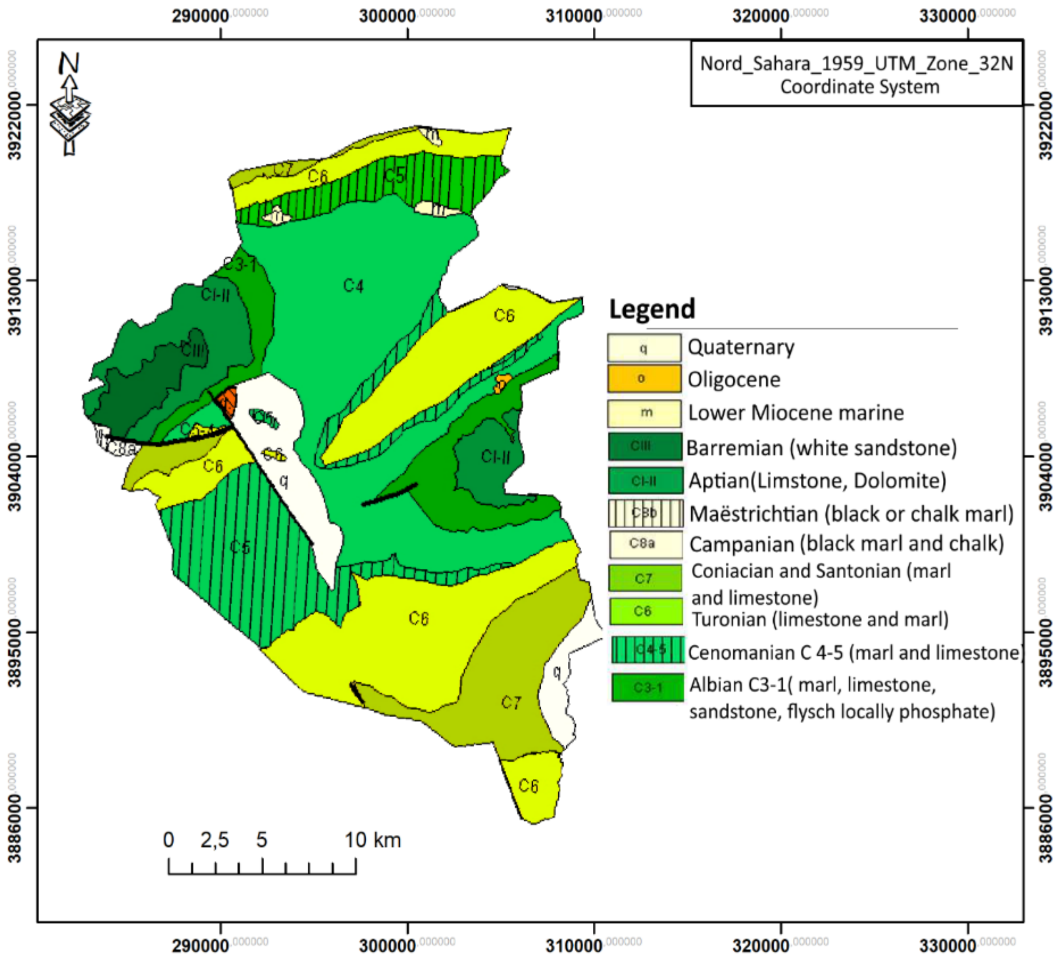

Figure 2. Geological map of the Mellagou basin (Lafitte, 1939; in Houbib., 2013).

The geology of the Bouhmama area is essentially characterized by the predominance of secondary terrains (Upper, Middle and Lower Cretaceous) with very varied facies ranging from marls to limestones via marl-limestones and sandstones, Quaternary terrains are only present in the valley of Oued Mellagou (Lafitte, 1939; Lessard, 1952). Figure 2).

Hydrogeologically, the region has two types of aquifers: the multilayer aquifers of the sedimentary basin consisting of the Plio-Quaternary aquifers and the fractured carbonate aquifers of the Cretaceous (Houha et al., 2016).

3. MATERIALS AND METHODS:

A sampling of 26 water points focused on groundwater tapping the Plio-Quaternary and Cretaceous (Figure 3), in August 2023 for physicochemical analyses. Electrical conductivity, temperature and pH were measured on site. The results of the major elements are carried out in the laboratory of the Department of Natural and Life Sciences of the University of Khenchela. The results are presented in Table 1. All groundwater samples were obtained at depths ranging from 100 to 150 m. The realization of the maps was carried out using ARC GIS software (v10.8); descriptive statistics were performed using SPSS software (v16).

4. RESULTS AND DISCUSSIONS

4.1. Hydrochemistry

The temperatures of the groundwater in the Mellagou basin (Bouhmama) range between 18 and 23 °C with an average of 21°C; we can say they are shallow waters. The pH of the waters in the study area ranges from 6.6 to 8.5. The average is around 7.3. In general, the waters are neutral (Benmoussa et al., 2018). Electrical conductivity ranges from 1226 to 3780 µS.cm-1, with an average of 2619 $\mu S.cm^{-1}$.

The climate is semi-arid characterized by low and irregular rainfall, with an annual average of 370 mm/year, the temperature is 16°C.

The study area is characterized by three main topographic units, namely the mountain zone, the piedmonts and the plain zone.

4.2. The chemical facies of the sampled waters

The Piper diagram applied to the water samples (Figure 4) shows an evolution of the chemical facies from upstream to downstream, the hydrochemical evolution of the system takes place from the calcium bicarbonate pole in the limestone outcrops in the West towards a major facies of calcium sulfate type in the center and downstream of the plain, (Houha, 2007).

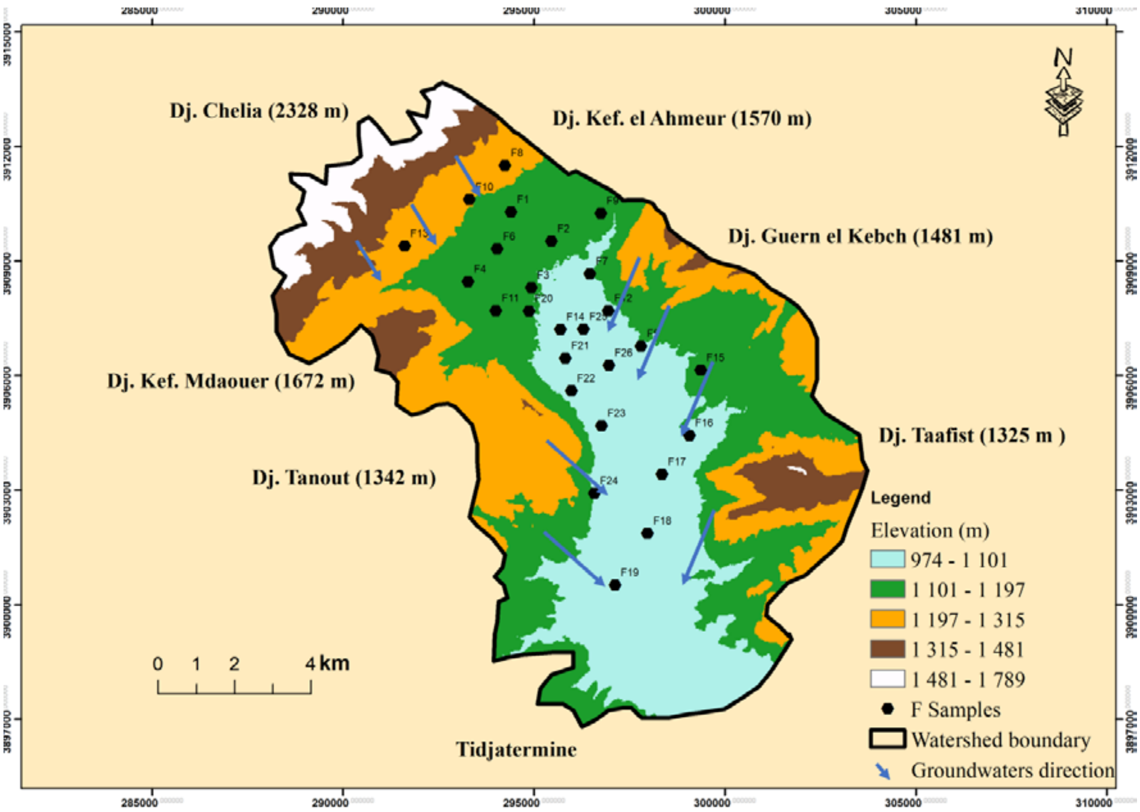

Figure 3. Different sampled points

Table 1. Results of physicochemical analyses of sampled waters

Name	T (°c)	pH	EC	Ca^{2+}	Mg^{2+}	Na^{+}	HCO_3^{-}	Cl^{-}	SO_4^{2-}
F1	19	7.88	1900	95.21	57.32	24.62	298.06	69.75	115.87
F2	20	7.8	2166	97.38	63.05	23.88	305.94	75	119.35
F3	20	7.65	2273	96.52	75.19	33.29	224.22	110.5	203.87
F4	21	7.8	2240	100.65	62.16	25.08	310.56	105	145.72
F5	22	8.07	2340	120.73	89.9	46.23	211.32	170	210.64
F6	19	7.7	2186	105.8	80.25	39.73	230.83	130.6	186.08
F7	21	7.71	2293	111.58	85.58	44.44	313.02	135	185.77
F8	19	7.6	1226	92.5	50.48	13.64	336.18	38.75	50.95
F9	18	7.52	1253	95.71	31.84	19.74	298.37	18.25	80.75
F10	19	7.25	1393	55.12	35.78	18.29	289.2	19.75	34.07
F11	21	7.4	2173	101.02	63.65	47.97	297.39	130.7	172.95
F12	22	7.5	2440	101.74	90.33	22.91	235.7	161.5	193.15
F13	19	8.55	1073	91.58	37.25	18.06	382.61	24.75	36.63
F14	21	8.25	2140	108.25	88	42.14	247.9	226	215.02
F15	17.8	6.74	2630	119.48	102.8528	100.49	223.32	300.17	214.55
F16	21	6.78	3560	189.55	141.58	125.27	237.13	390.98	429.89
F17	21.7	6.76	3640	251.36	183.2104	117.05	265.74	447.67	470.53
F18	21	6.79	3780	232.184	176.85	119.77	241.29	440	480.26
F19	21	7.04	3770	255.69	177.0012	129.36	267.39	443.25	475.79
F20	22	6.64	3420	187.81	99.062	119.38	274.2	307.67	314.27
F21	22.5	6.75	3360	199.48	108.63	129.53	302.03	320.8	351.54
F22	23	7.07	3040	201.69	109.25	147.27	307.64	418.96	266.96
F23	23	6.68	3290	198.98	140.71	123.55	294.22	404	352.96
F24	23	6.79	3460	205.63	157.232	133.26	290.3	393.33	446.88
F25	23.6	6.6	3550	188.25	179.25	153.55	307.15	445.83	362.89
F26	23	6.67	3510	182.36	159.63	174.68	301.06	419	421.81

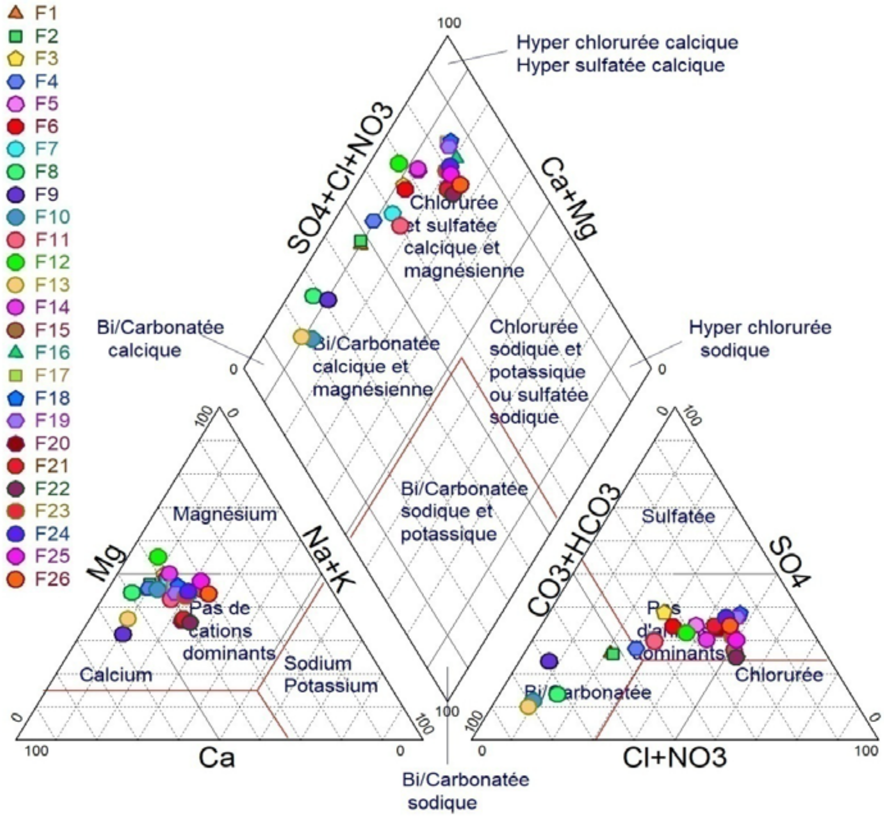

Figure 4. Piper diagram for the sampled waters

4.3. Spatial assessment of major chemical elements

4.3.1. Calcium (Ca^{++})

The calcium ion concentrations increase in the direction of flow and range from 55.12 mg/l (F10) to 255.69 mg/l (F19). Upstream of the basin, values are relatively low, as groundwater is not too mineralized and comes from the dissolution of carbonate formations on the edges (Djenba et al., 2015; Zahi et al., 2021). The high contents appear in the center and south of the study area, it is thought that they result from the dissolution of carbonate formations ($CaCO_3$) and evaporitic deposits coming from Djebel Taafist, Djebel Guern elkabch and Djebel Tanout (Figure 5).

4.3.2. Magnésium (Mg^{++})

Examination of the map (Figure 5) shows that magnesium concentrations range from 31.84mg/l (F9) to 183.21mg/l (F17). Their origins are comparable to calcium, as it comes from the dissolution of carbonate formations with high magnesium contents (magnesite and dolomite) and saline formations rich in magnesium "$MgSO_4$" (Berkani et al., 2023) from Djebel Taafist, Djebel Guern elkabch and Djebel Tanout.

4.3.3. Sodium Na+ and potassium K+

The concentrations of ($Na^{++}K$) vary between 13.64mg/l (F8) and 174 mg/l(F26). Observation of the map (Figure 5) shows that concentrations are important in the center and downstream of the study area, the Triassic evaporitic formations of Djebel Taafist and Djebel Tanout constitute the origin of sodium. The Cretaceous clays, which are found in the aquifer, can give sodium through the base exchange phenomenon by fixing a Ca^{2+} ion after releasing two Na^+ ions (Djenba et al., 2015; Zahi et al., 2021; Houha, 2007)

It should be noted that low concentrations are located upstream of the aquifer, where groundwater is at the beginning of its flow, i.e. is not yet too mineralized.

4.3.4. Bicarbonates (HCO_3^-)

Bicarbonate ion concentrations range from 211.32mg/l (F5) to 382.6mg/l (F13). The maximum values are encountered in the borders, especially in the western area of Djebel Chelia and Djebel Kef elahmeur (Figure 5), which is due to the dissolution of carbonate formations ($CaCO_3$) either the dissolution of gypsum formations CaMg (CO_3). (Berkani et al., 2023)

4.3.5. Chlorides (Cl^-)

The observation of the chloride map (Figure 5) reveals that the concentrations vary between 18.25 mg/l (9) and 447.67 mg/l (F17). The latter concentration is measured at the center and east of the study area. The clays and alluvium of the Mio-Plio-Quaternary filling deposit and the saline deposits, originating from the erosion of the gypsum formations of Djebel Taafist, Djebel Guern elkabch, and Djebel Tanout, are the sources of these chlorides. A second source is attributed to anthropogenic activity related to agriculture in the region (Berkani et al., 2023; Gouaidia et al., 2012).

4.3.6. Sulfates (SO_4^{-2})

The map representing sulfate concentrations (Figure 5) shows values ranging from 34.01 mg/l (F10) to 480.26 mg/l (F18). High concentrations are recorded in the southern part of the study area. These are attributed, firstly, to the dissolution of gypsum contained in the Emscherian marls (Sedrati et al., 2017), and secondly, to leaching from evaporitic deposits originating from Taafist and Djebel Tanout.

A second source is associated with anthropogenic activity related to agriculture, involving the use of chemical products rich in sulfates in the region. The lowest concentrations are observed upstream of the aquifer, along the limestone edges where the bicarbonate-calcium facies are located, as groundwater in these areas is weakly mineralized.

5. ACQUISITION OF GROUNDWATER MINERALIZATION

We plotted the major elements as a function of chloride to understand the groundwater mineralization process (Figure 6). Chloride is a conserved element that does not predict interactions between water and rock, characterizes the source of water salinity, and is an indicator of mixing (Fidelibus & Tulipano, 1996; Berkani et al., 2023).

The Na^+ versus Cl^- plot shows that all points are below the mixing line. Since Na+ water is mainly controlled by the cation exchange reaction between water and Pontian red clay, resulting in sodium fixation and calcium release (Houha, 2007; Gouaidia et al., 2012; Djenba et al., 2015; Berkani et al., 2023). The Ca^+-Cl^- plot clearly illustrates this by showing that the points are above the freshwater-seawater mixing line (Belkoum et al., 2017; Djoudi et al., 2017; Benmoussa et al., 2018; Berkani et al., 2023).

The Mg^+vs Cl^- relationship (Figure 6) shows that the majority of points are on the mixing line with a tendency to Mg enrichment which would be linked to dolomite dissolution, (Bouderbala., 2014).

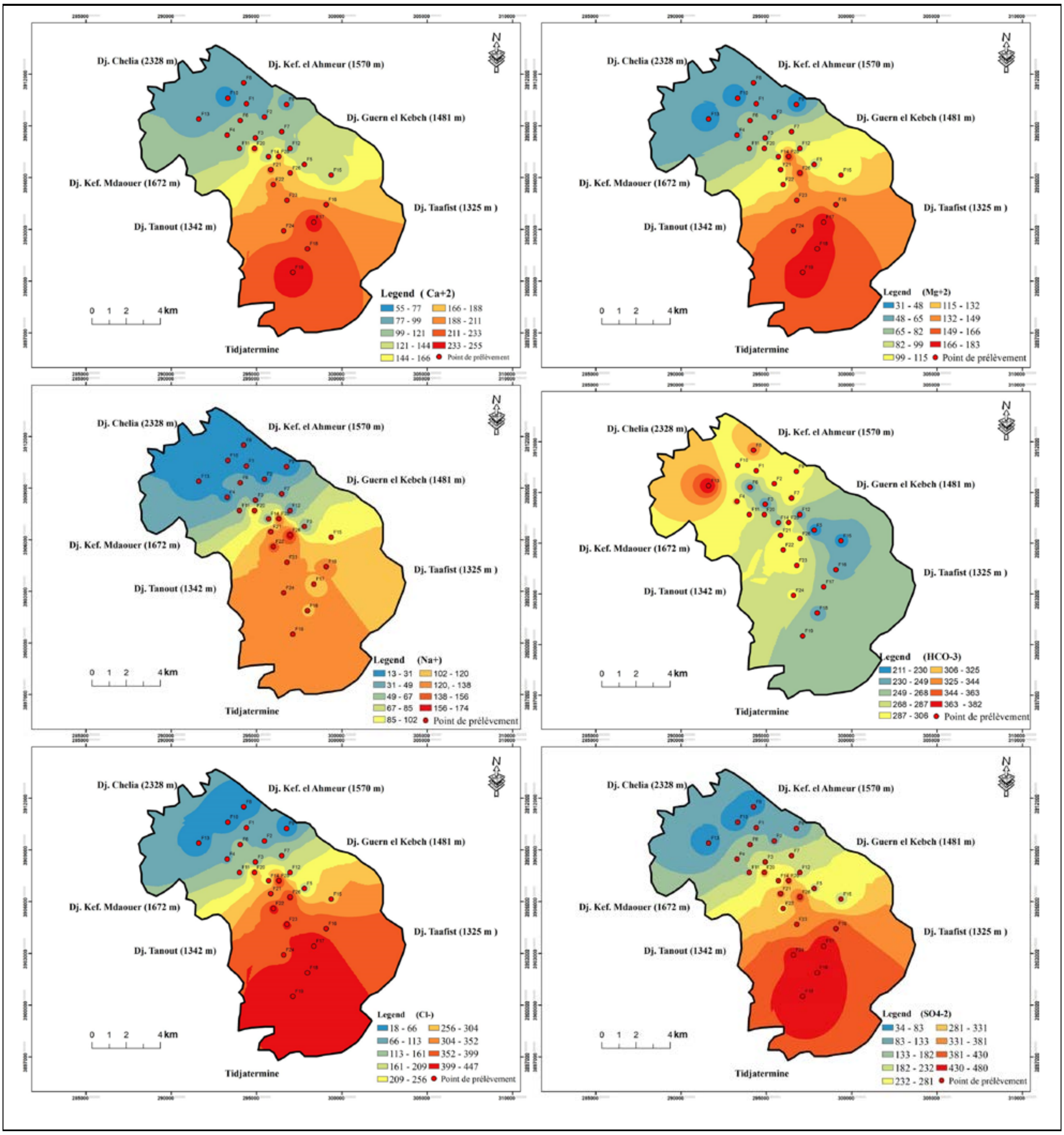

Figure 5. Map of chemical element contents in (mg/l)

Table 2 shows that except for bicarbonates all elements are correlated with each other and with electrical conductivity.

Variables	T	pH	EC	Ca^2	Mg^2	Na	HCO_3	Cl
T	1.000							
pH	-0.299	1.000						
EC	0.673	-0.723	1.000					
Ca^2	0.594	-0.632	0.914	1.000				
Mg^2	0.607	-0.648	0.934	0.91	1.000			
Na	0.632	-0.729	0.903	0.884	0.867	1.000		
HCO_3	0.021	0.1	-0.318	-0.118	-0.272	-0.087	1.000	
Cl	0.642	-0.672	0.949	0.933	0.951	0.951	-0.239	1.000
SO42	0.622	-0.674	0.966	0.937	0.961	0.878	-0.321	0.943

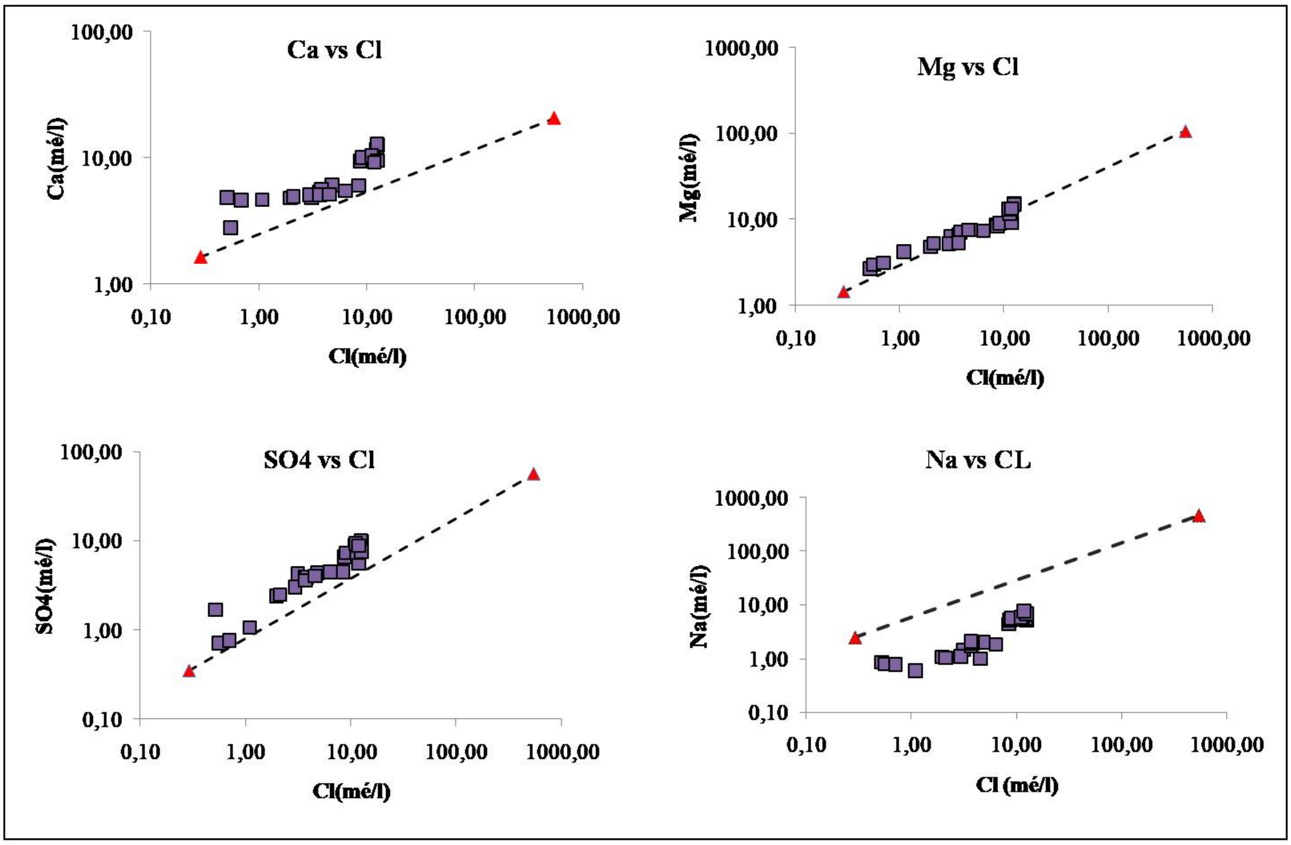

Figure 6. Relationship between major elements and chlorides

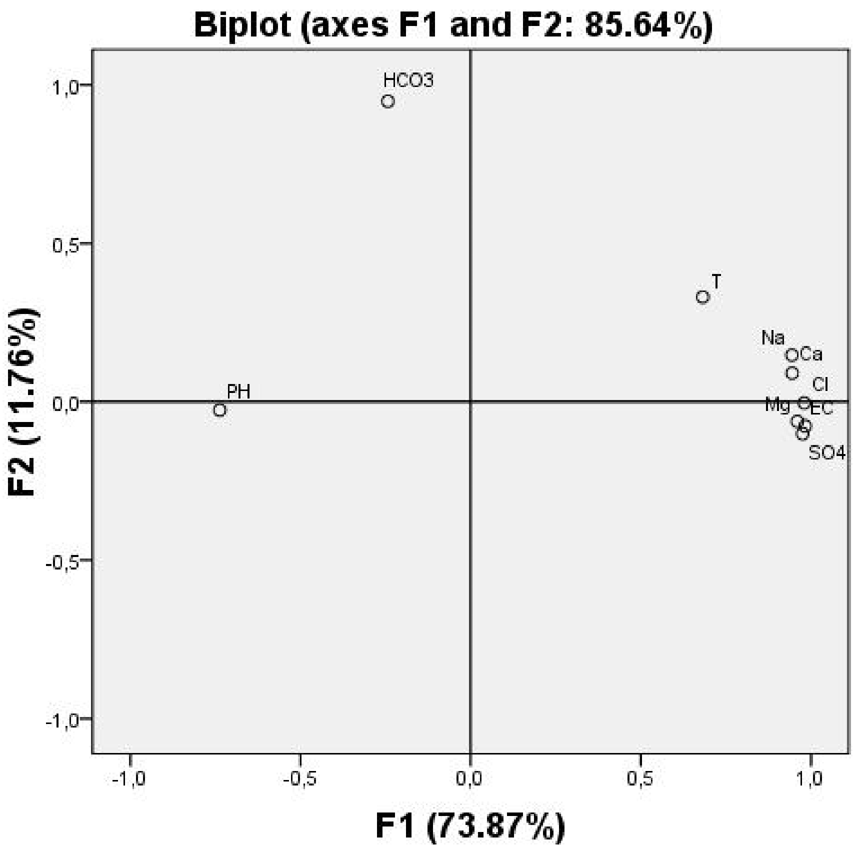

Figure 7. Espace des variables de l'ACP globale.

6. PRINCIPAL COMPONENT ANALYSIS (PCA)

A principal component analysis (PCA) was performed on a data table of nine (09) variables and 26 individuals. The analysis was carried out up to two factors and 85.64% of the variance could be expressed.

The good correlation between Na and Cl suggests that the origin of chlorides and sodium is the dissolution of halite (NaCl). Thus, the good correlation between Ca and Mg on the one hand and these latter with SO4 confirms that the origin of calcium and magnesium is the dissolution of evaporitic deposits (Drouiche et al., 2022; Hamed et al., 2010).

The projection of variables onto the factorial plane F1-F2 (Figure 7) reveals that the F1 axis is the major axis, representing 73.83% of the explained variance. It is a salinity axis, defined by electrical conductivity and all the major elements associated with it. The F2 axis represents 11.76% of the information and is defined by alkalinity, indicating recent recharge by young waters (Belkoum et al., 2017; Sedrati et al., 2017).

7. CONCLUSION

The present study, focusing on the Mellagou basin located in the Northeast of Algeria, reveals the predominance of geological formations from the secondary period (Upper, Middle, and Lower Cretaceous), exhibiting diverse facies ranging from marls to limestones, including marly-limestones and sandstones. Quaternary deposits are only present in the valley of Oued Mellagou.

The climate is semi-arid, characterized by low and irregular precipitation, with an annual average of 370 mm/year, and a temperature of 16°C.

Hydrogeochemical analysis indicates that the chemical facies evolve from a calcium-bicarbonate type in limestone outcrops to a predominant calcium-sulfate type in the central and downstream parts of the basin. Mechanisms contributing to groundwater mineralization in the Mellagou basin include water-rock interaction, dissolution and mineral precipitation, and the infiltration of irrigation water loaded with salts and fertilizers in irrigated areas.

Principal Component Analysis (PCA) was performed on a dataset consisting of nine (09) variables and 26 individuals. Explaining 85.64% of the variance, the analysis shows that, except for bicarbonates, all major elements contribute to the acquisition of groundwater salinity in Bouhmama.

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