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Hydro-chemical and microbiological characterization of Lower Cretaceous waters in a semi-arid zone Beni-Ounif syncline, South-West of Algeria

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Abstract

The article analyses the water quality of the Lower Cretaceous aquifer in the Beni-Ounif syncline. To this end, 42 samples were taken for physico-chemical analysis and 28 for microbiological analysis in March, May and October 2017 from 14 sampling points. The results of physico-chemical analysis were processed by multi-variety statistical analysis methods: principal component analysis (PCA) and hierarchical cluster analysis (HCA) coupled to hydro chemical methods: Piper diagram.

The PCA allowed us to explore the connections between physico-chemical parameters and similarities between samples and to identify the most appropriate physico-chemical elements to describe water quality.

The HCA allowed us to classify the sampling points according to the similarity between them and thus reduce them for the next follow-up analysis.

Waters of the syncline are characterized by medium to low mineralization ($320 < EC < 7600$ µS·cm^{-1} and $200 < RS < 4020$ mg·dm^{-3}) and hardness of between 22 and 123°f. Only 19% of the samples show NO_3 concentrations exceeding the Algerian standards.

Microbiologically, the study reports the presence of bacteria: coliforms (<8 CFU·0.1 dm^{-3}), *Streptococcus* D (<1100 CFU·0.1 dm^{-3}), *Clostridium* sulphito-reducer of vegetative form (<90 CFU·0.02 dm^{-3}) and sporulate (<4 CFU·0.02 dm^{-3}), total aerobic mesophilic flora at 22°C (<462 CFU·0.001 dm^{-3}) and at 37°C (<403 CFU·0.001 dm^{-3}). It must be noted that no presence of thermo-tolerant coliforms is observed.

Key words: *Beni-Ounif, groundwater, hierarchical cluster analysis (HCA), hydro-chemical characterization, Lower Cretaceous, microbiological characterization, principal component analysis (PCA), water quality*

INTRODUCTION

Water resource protection is one of the most essential concerns of any environmental policy; these resources have being identified as paramount for the future [ATTOUI *et al.* 2016].

In recent years, periodic water quality analysis has been of increasing interest in many regions because water is a precious and essential natural resource for multiple uses (domestic, industrial and agricultural). Its quality is a factor influencing the state of health and mortality in both humans and animals [KAZI *et al.* 2009]. Furthermore, it is important to underline that climate change has long-term impacts on water resources in Arab countries [EL GAYAR, HAMED 2018; HAMED *et al.* 2017].

In southern Algeria, where the climate varies from semi-arid to hyper-arid, groundwater is the only source of supply for different uses [BOUSELSAL *et al.* 2014]. Thus, a thorough understanding of groundwater's hydro-chemical characteristics is critical for adequate quantity and quality sustainable development to ensure sustainable safe use of water [BEN ALAYA *et al*. 2014; HAMED 2009; HAMED *et al*. 2014].

Although several analyses have been carried out on the national territory to determine water quality, the Beni Ounif syncline has not yet benefited from previous studies, which has led us to carry out the present work which focuses on the evaluation and determination of the physico-chemical and microbiological quality of groundwater of the Lower Cretaceous in Beni-Ounif syncline and treatment of the results of analysis by multi-varied statistical and geochemical methods.

STUDY AREA

GENERAL INFORMATION

The syncline of Beni Ounif is located in the north-eastern part of the Wilaya of Bechar at a distance of 112 from Bechar city (Fig. 1). From a climatic point of view, it is a semi-arid region due to climatic variations: very high temperatures in summer (39.7°C) and low in winter (2.6°C) with an average annual precipitation of 119 mm (1999–2009).

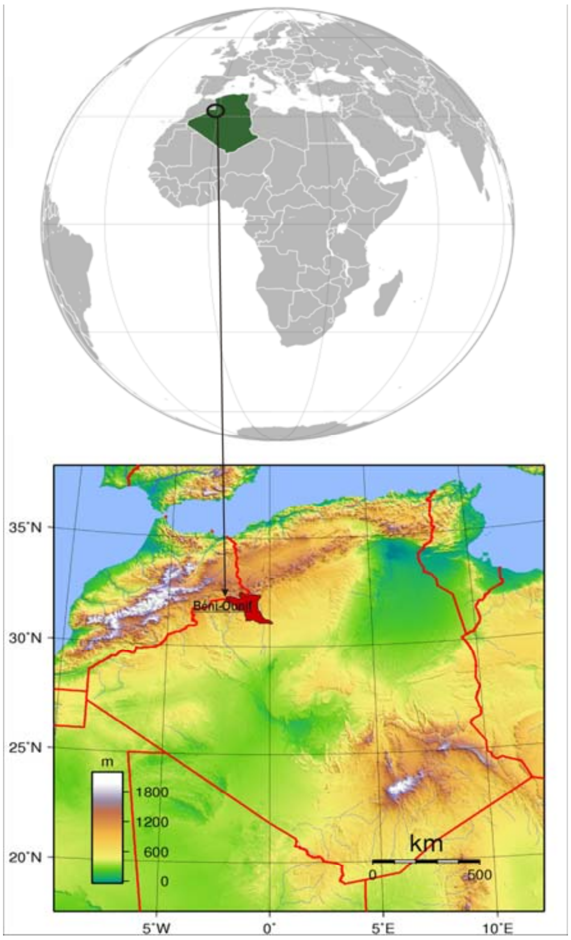

Fig. 1. Geographical situation of the study area; source: own elaboration

REGIONAL GEOLOGY AND HYDROGEOLOGY

The sector of Beni Ounif occupies a special position to the point of structural view. It marks indeed the eastern limit of the formations on which the Atlas phase has been superimposed. The outcropping Beni-Ounif geological formations belong to the Mesozoic; the litho-stratigraphic succession represented from the base to the summit by:
- Jurassic outcrop in the North of the study area;
- the Lower Cretaceous: deposits formed of sand and clay surmounting the Jurassic;
- the Quaternary usually covers the low areas [ANRH 2012].

The area's aquifers are mainly:
- sandstone unit of the lower Cretaceous;
- calcaro-dolomitic unit of the Jurassic, which, diminishing in thickness in this region, has its water encountering those of Cretaceous sandstone;
- calcaro-dolomitic unit of Turonian is resting on an impermeable substratum of clays and Cenomanian gypsum marl; this groundwater of small local importance is fed only by infiltrations of part of the atmospheric water falling on limestone and cracked dolomites;
- Quaternary alluvial units show those of the Zousfana Valley that constitute an important water table, fed each year by winter and especially spring floods.

Mainly, the waters feed the unit of Lower Cretaceous contained in the underlying captive aquifer of the Jurassic carbonate by the vertical and lateral contributions through the South Atlas flexure. The water is also fed during the heavy flooding of the large wadis, such as the Zousfana wadi (Fig. 2).

PIEZOMETER

Due to the very limited number of water level points, the drawing of a piezometric map will lack information; however, a campaign we did in March 2017 using a water level recorder gave us an idea of the water flow path (NW–SE). The measured water levels are shown on the geological map in (Fig. 2).

MATERIALS AND METHODS

SAMPLING AND ANALYSIS

The sampling of Beni-Ounif's water was carried out along three campaigns (March, May and October 2017), and 42 samples were collected from 14 sampling points as shown in (Fig. 3).

During these campaigns, samples were stored in polyethylene bottles with a capacity of 1.5 dm^3 for a physico-chemical analysis following accepted methods [ISO 5667-2: 1991]. The parameters analysed were as follows: *T*, pH, electrical conductivity *EC*, turbidity, total hardness *TH*, Ca^{2+}, Mg^{2+}, total alkalinity *TAC*, HCO_3^-, Na^+, K^+, Cl^-, NO_3^-, NH4$^+$, SO_4^{2-}, PO_4^{3-}, organic matter/oxidizable material *MO*, dry residue *RS*) – Table 1.

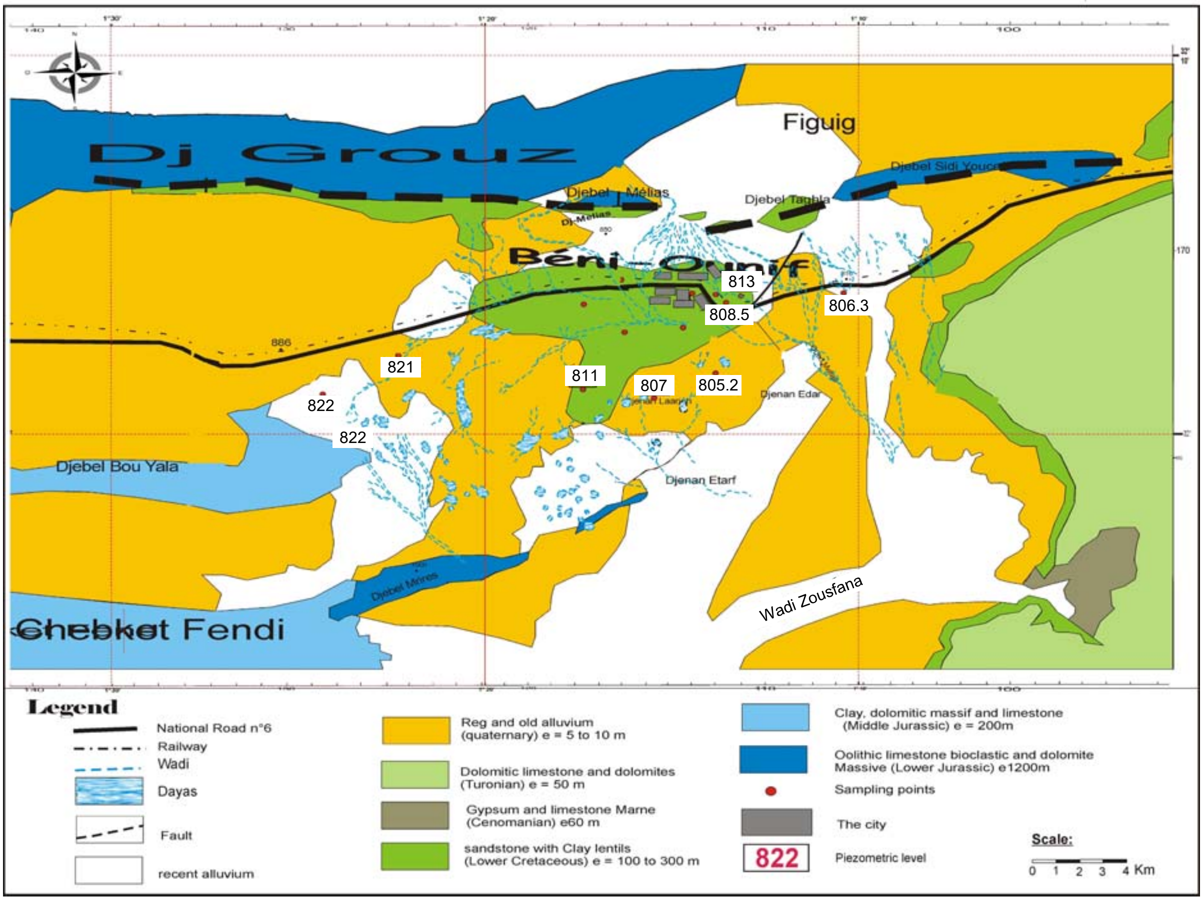

Fig. 2. Geographical map of the study area; source: own elaboration

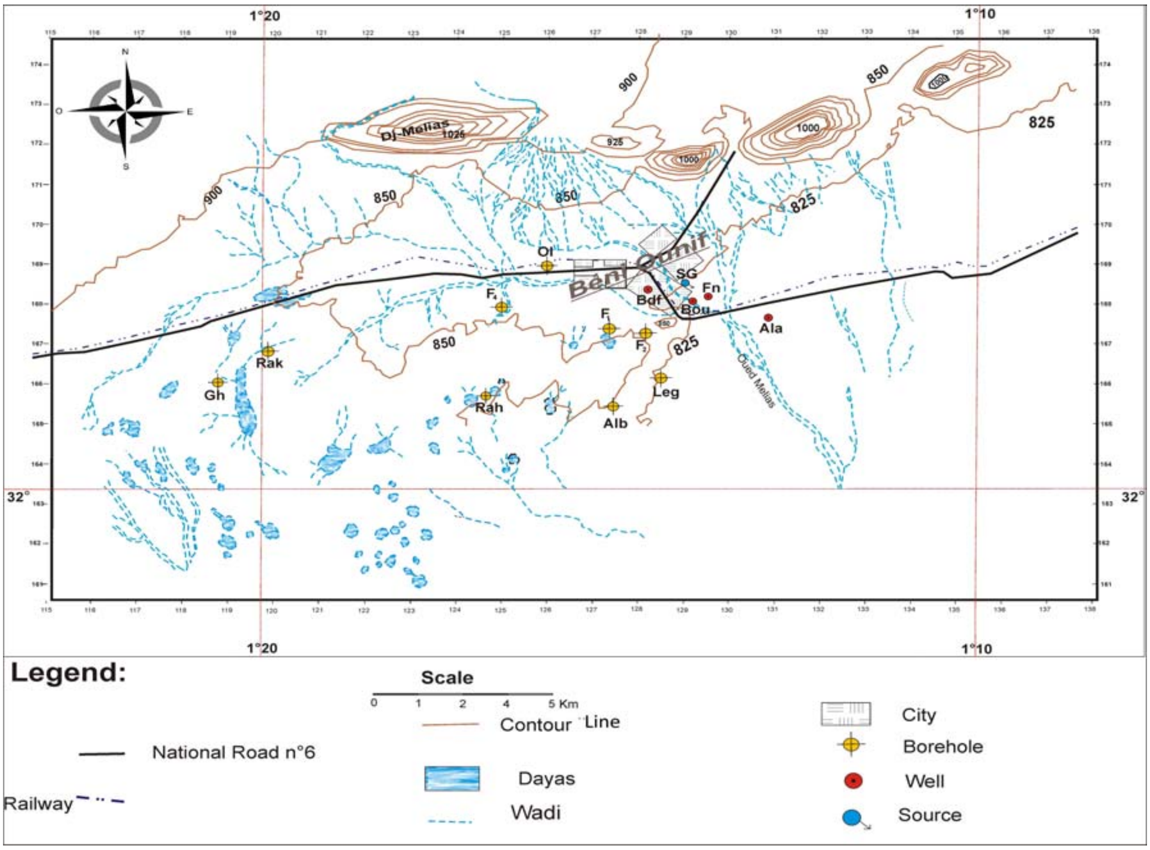

Fig. 3. Location of sampling points; source: own elaboration

The reliability of the chemical analysis was verified for the accuracy of the mass balance estimate using the equation error (1):

$$RE\ (\%) = \frac{\sum Cation - \sum Anion}{\sum Cation + \sum Anion} \cdot 100 \tag{1}$$

Table 1. Methods used for physico-chemical analysis

Element	Analysis method
TH, Ca^{2+}, Mg^{2+}	NF T90-003: 1984
Na^{+}, K^{+}	NF T 90 019: 1984.
NH_4^{+}	ISO 7150-1: 1984
NO_3^{-}	NF EN ISO 13395: 1996
PO_4^{3-}	NF EN ISO 6878: 2005
SO_4^{2-}	NFT 90-040: 1986
Cl^{-}	NF ISO 9297: 2000
HCO_3^{-}	NF EN ISO 9963-1: 1996

Explanation: *TH* = total hardness.
Source: own elaboration.

For microbiological analysis, 28 samples were stored in 250 dm^3 sterile glass vials using the following methods [NA 745: 1989; NA 762: 1990] then sent to the laboratory in a cooler at a temperature of ±4°C according to the method [NF T90-420: 1987]. The parameters analysed are total aerobic mesophilic flora (FMAT), total coliforms (CT) and thermo-tolerant coliforms (CTT), *Streptococcus* D and sulphite-reducing anaerobic spores CSR (vegetative and sporulated) (Tab. 2). The method used to isolate and determine these bacteria is the NPP liquid count technique [AFNOR NF T90-413 1985].

Table 2. Microbiological analysis methods used

Element	Analysis methods
Total aerobic mesophilic flora	NF EN ISO 6222: 1999
Coliforms	NF T 90-413: 1985
Streptococcus D	NF EN ISO 7899-1: 1999
The spores of anaerobes Sulphito-reducers	NF T 90-415: 1985

Source: own elaboration.

GEOCHEMICAL ANALYSIS METHOD

In order to study water chemistry and water facies, known hydro geochemical techniques were applied. The Piper diagram is suitable for studying the evolution of facies and for comparing groups of samples with each other and indicating the types of dominant captions and anions. It is composed of two triangles, representing the cationic and anionic facies, and a rhombus synthesizing the global facies [SEKIOU, KELLIL 2014].

STATISTICAL ANALYSIS METHODS

The statistical analyses were done by a free version of the XLSTAT 2016 software.

Bivariate statistics, in particular correlation analysis, were used to first detect inconsistencies between variables, but also links between them, processed in pairs. The linear correlation coefficient of Bravais Pearson *r*, which gives an idea of interrelations and linear dependences existing between the chemical elements, is between –1 and 1 [LEFEBVRE 1988].

PRINCIPAL COMPONENT ANALYSIS (PCA)

The PCA is a descriptive method whose objective is to present graphically the maximum amount of information contained in a database. Individuals (boreholes, sources) form this basis, in rows on which are measured "quantitative variables" (the elements analysed) arranged in columns [CLOUTIER *et al* .2008; YIDANA *et al*. 2008].

The interpretation of the graphs will make the structure of the analysed data understandable [BOUROCHE, SAPORTA 1980].

HIERARCHICAL CLUSTER ANALYSIS (HCA)

This method consists of defining a class aggregation criterion that can be defined by measuring the degree of resemblance or dissimilarity that exists between the samples [TEMPL *et al*. 2008]. The partitions represented in a classification tree or a "dendrogram" [CLOUTIER *et al*. 2008].

RESULTS AND DISCUSSION

CHEMICAL CHARACTERISTICS OF GROUNDWATER

The results show that the ionic balance for 95% of the boreholes and wells is within ±5%.

The effect of water and rock interactions during the water's retention time gives the different concentrations of chemical elements in wells water (Tab. 3) provides a summary of the different physicochemical and bacteriological elements concentration.

pH and temperature. The observed values reveal that the pH in all samples is slightly neutral to alkaline. Water temperature plays an important role in the solubility of salts [VILLERS *et al*. 2005]. It is influenced by its origin (superficial or deep) [GHAZALI, ZAID 2012]. Temperatures recorded in the study area are ranged from 20 to 26°C.

Conductivity and dry residue. For the water sampled, the *EC* is between 312 and 7200 $\mu S \cdot cm^{-1}$, with the highest values recorded in the most mineralized samples (SG, Bou, Fn and Ala). This high salt enrichment is observed in the low topographic and piezometric zones (discharge zone) and is mainly due to the residence time of groundwater. The *RS* indicates that the dry residue in water is between 200 and 4020 $mg \cdot dm^{-3}$. The values recorded were slightly too high compared to Algerian standards for the samples: Bdf, Ala, SG, Bou, Fn (*RS* > 1500 $mg \cdot dm^{-3}$).

Total hardness *TH*. Total hardness of the water is caused by dissolved calcium and to a lesser extent by magnesium [LAGNIKA *et al*. 2014]. The observed value of *TH* in the groundwater is between 22 and 123°f, samples Bou, Fn, Ala and SG have marked the highest values. The *TH* can be classified as soft, if it is less than 10°f, moderately hard if it varies between 10 to 20°f, hard if it is between 30 and 40°f; and very hard if it is more than 40°f. Table 4 shows that 43% of the samples obtained during the three campaigns are moderately hard, 21% are hard water and 36% are very hard.

Table 3. Global statistics of physicochemical and microbiological parameters of groundwater

Variable	Measurement unit	Minimum	Maximum	Average	Standard deviation	Algerian standard
T	°C	20	26	23.462	1.575	25
pH		7	8.280	7.596	0.413	6.5–<8.5
EC	$\mu S \cdot cm^{-1}$	312	7600	1 779.35	2012.46	2800
Turbidity	NTU	0.010	4.5	0.468	0.775	5
TH	°f	22	123	45.764	27.761	50
Ca	$mg \cdot dm^{-3}$	40	164	81.086	41.208	200
Mg	$mg \cdot dm^{-3}$	12.48	210	65.409	48.560	150
TAC	°F	15	55	30.602	10.418	no standard
HCO_3	$mg \cdot dm^{-3}$	183	671	372.843	127.633	no standard
Na	$mg \cdot dm^{-3}$	12	900	179.168	240.401	200[1]
K	$mg \cdot dm^{-3}$	2	10	3.917	2.325	12
Cl	$mg \cdot dm^{-3}$	2	1390	113.371	296.978	500
NO_3	$mg \cdot dm^{-3}$	14.57	186.95	50.197	33.391	50
NH4	$mg \cdot dm^{-3}$	0	0.675	0.040	0.106	0.5
SO_4	$mg \cdot dm^{-3}$	0.40	1000	101.468	207.473	400
PO_4	$mg \cdot dm^{-3}$	0	0.92	0.109	0.215	0.5
MO	$mg \cdot dm^{-3}$	0.08	8.3	1.473	1.895	5
RS	$mg \cdot dm^{-3}$	200	4020	1 092.333	1161.633	1500
CT	per 100 cm^3	0	7	0.930	2.12	10
CTT	per 100 cm^3	0	0	0	0	0/100
Streptococcus	per100 cm^3	0	1100	64.670	209.40	0
CSR vegetative	per 20 cm^3	0	90	4.280	16.90	<5
CSR sporulated	per 20 cm^3	0	3.5	0.640	1.05	0
FMAT 22°	per cm^3	1	461.670	87.738	126.260	<100
FMAT 37°	per cm^3	5.660	402.390	110.631	117.733	20

Explanation: *T* = temperature, *TH* = total hardness, *TAC* = total alkalinity, *MO* = organic matter, *RS* = dry residue, CT = total coliforms, CTT = thermotolerant coliforms.
Source: own study.

Table 4. Water classification according to their total hardness (*TH*)

TH (°f)	Class	Samples number in		
		1st campaign	2nd campaign	3rd campaign
0–10	very soft	0	0	0
10–20	pure	0	0	0
20–30	moderately hard	6	5	7
30–40	hard	3	4	2
>40	very hard	5	5	5

Source: own elaboration.

Calcium and magnesium. Calcium (Ca) and magnesium (Mg) are abundant in soil and rocks, specifically in carbonate rocks. Ca concentration varies from 40 to 164 $mg \cdot dm^{-3}$, Mg concentrations ranged from 12.48 to 210 $mg \cdot dm^{-3}$.

Sodium and potassium. Sodium (Na) varies between 12 and 900 $mg \cdot dm^{-3}$ for the three campaigns. The highest Na concentrations were recorded at the wells Ala, Bou, Fn and SG, exceeding the Algerian standards. This is due to dissolution of soil salts (water residence time) stored by the influences of evaporation and anthropogenic activities [MEYBACK 1987; STALLARD, EDMOND 1983; SUBBA RAO *et al.* 2002], in addition to the agricultural activities and poor drainage conditions. Moreover, the solubility of Na^+ is generally high [SUBBA RAO *et al.* 2012]. Potassium (K) is an element that can be found in clay rocks. In general, groundwater seldom has K levels greater than 10 $mg \cdot dm^{-3}$ [PARIZOT 2008], which we also recorded during our sampling campaigns.

Chloride and sulphate. Chloride is present in various rock types at lower concentrations than all other major constituents are of natural water [HEM 1970]. Very high concentrations were recorded in the Ala (1100 $mg \cdot dm^{-3}$), Fn (708 $mg \cdot dm^{-3}$), SG (630 $mg \cdot dm^{-3}$) and Bou (1390 $mg \cdot dm^{-3}$) during the third campaign. According to [SUBBA RAO *et al.* 2012] and [BENRABAH *et al.* 2016] the Cl^- is also derived from the non-lithological source and its solubility is generally high and is caused by the influences of poor sanitary conditions, irrigation-return flows and chemical fertilizers. Moreover, during the third campaign, very high values were recorded mainly in the Bou, Fn, Ala and SG wells varying between 400 and 1000 $mg \cdot dm^{-3}$. According to [HEM 1970] chloride and sulphate concentrations are generally much higher in irrigated areas.

Nitrates. The NO_3 is a non-lithological source. In natural conditions, the concentration in water of NO_3 does not exceed 10 $mg \cdot dm^{-3}$ [CUSHING *et al.* 1973]. Thus, a NO_3 concentration greater than 10 $mg \cdot dm^{-3}$ is an indication of anthropogenic pollution. Nitrate levels in all samples range from 14.75 to 186.95 $mg \cdot dm^{-3}$. It is important to note that during the first campaign the nitrate levels exceed the permissible value (50 $mg \cdot dm^{-3}$) in F1, Ala, SG, Rah, Bou and Alb water points (54 < NO_3 < 186.95 $mg \cdot dm^{-3}$). Meanwhile, during the second campaign, nitrates are elevated at SG (93.47 $mg \cdot dm^{-3}$ and at the Bou well with a concentration of 130.4 $mg \cdot dm^{-3}$. This is mainly due to the influence of poor sanitary conditions and the use of more fertilizers in the study area.

Orthophosphate PO_4. According to MAKHOKH [2011], the availability of orthophosphates can be explained by the release of phosphorus trapped in large quantities in sediments. Atmospheric agents (wind and rain) are also sources of phosphates. Orthophosphate levels observed during all three campaigns are low (less than 1 mg·dm^{-3}).

Oxidizable material *MO*. According to RODIER *et al.* [2009] groundwater generally has low oxidability (some milligrams per cubic decimetre) which is also confirmed by our results. The 40 samples collected have a concentration conforming to the Algerian standard (<5 mg·dm^{-3}). Only two points (Fn and Rah) of the third campaign are marked by a rate slightly above the standards (8.3 and 6.9 mg·dm^{-3}).

Turbidity. Turbidity (Turb) indicates the presence of fine particles suspended in water. The Algerian standard recommended that turbidity be less than five NTU. Our results showed values that met the required standards for water.

MICROBIOLOGICAL CHARACTERISTICS

Coliforms. In the three campaigns, the number of total coliforms in the analysed waters was in accordance with the Algerian Standard. Thus, an absence of thermo-tolerant coliforms was observed as shown in Figure 4).

Enterococci (*Streptococcus* D). Faecal streptococci are group D enterococci that live in the human gut and warm-blooded animals and are generally taken into account as controls for faecal pollution [RODIER *et al*. 2009]. Figure 5 summarizes the results of the analyses conducted during the two campaigns (first and second).

***Clostridium* sulphite-reducer (vegetative form / spore).** *Clostridium* sulphite-reducer in vegetative and sporulated forms are generally telluric germs [RODIER *et al*. 2009]. The spore form can detect an old faecal contamination. We deduce a pollution in the points SG, Fn, F1, Leg, Rak, Gh, Rah, Bou, and Ala with values varying between 0.5 to 90 CFU per 20 cm^3 (Fig. 6).

Total aerobic mesophilic flora at 22°C and 37°C. With regard to the total germs or FMAT, there are two basic hygienic categories: the saprophytic germs that develop at 22°C and the so-called pathogenic germs that develop at 37°C [AHONON 2011]. Durring the first campaign, samples (Ala, SG, Rak, and Gh at 22°C) and (F1, F2, Ala, Leg, SG, Fn, Rak, Gh, Rah, and Bou at 37°C) marked a load that exceeds the Algerian standards. Meanwhile, during the second campaign, non-standard values were recorded in the samples Alb, Rak, Gh, and SG at 22°C and Bdf, F1, F4, Ala, Leg, Al, Rak, Gh, SG, Fn, and Bou at 37°C (Fig. 7).

The presence of microbiological pollutants in groundwater is due either to poor well and borehole protection (direct entry of bacteria, corrosivity of borehole walls) or to direct mixing with wastewater.

GEOCHEMICAL FACIES

The representation of the compositions of the waters in major elements in the Piper diagram, as shown in Figure 8, illustrates common chemical facies between the first two campaigns and a change of chemical facies is noticed in the third campaign, which can be linked to the sampling period (high and low water):

- campaign 1 and 2 (high water)
  - bicarbonated calcium and magnesian facies,
  - sodium and potassium bicarbonate facies;
- campaign 3 (low water)
  - bicarbonated calcium and magnesian facies,
  - sodium chloride and potassium or sulphated sodium facies,
  - chloride sulphate calcic and magnesium facies.

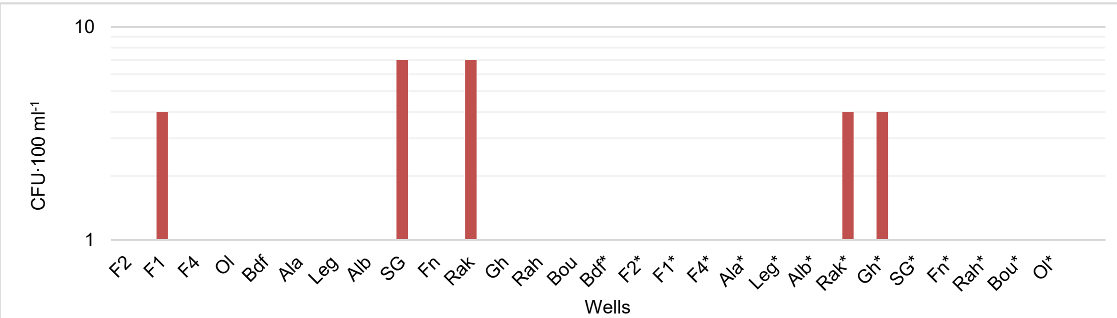

Fig. 4. Variation of total coliforms (first and second campaigns); wells as in Fig. 1, asterisks denote the second campaign; source: own study

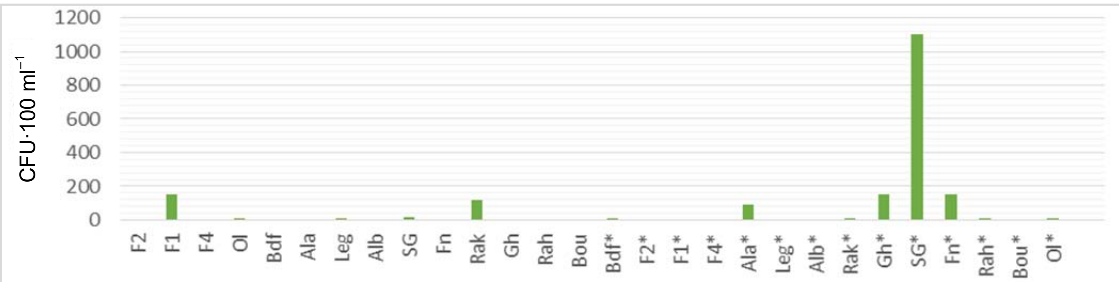

Fig. 5. Variation of streptococci D (first and second campaigns); wells as in Fig. 1, asterisks denote the second campaign; source: own study

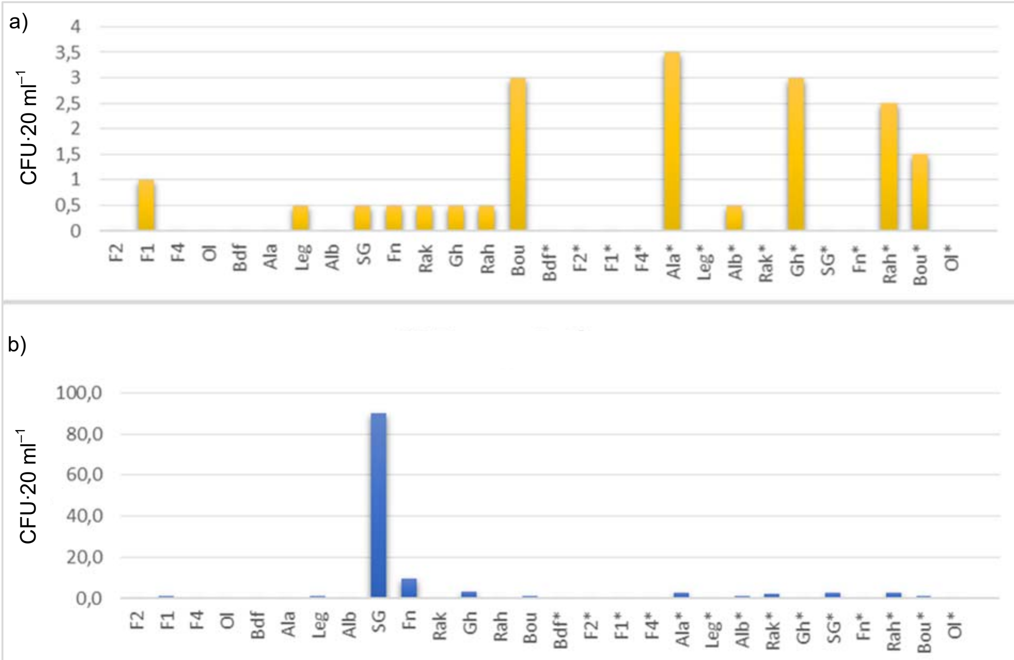

Fig. 6. Variation of *Clostridium* sulphite-reducer – CSR (first and second campaigns); a) CSR sporulated, b) CSR vegetative); wells as in Fig. 1, asterisks denote the second campaign; source: own study

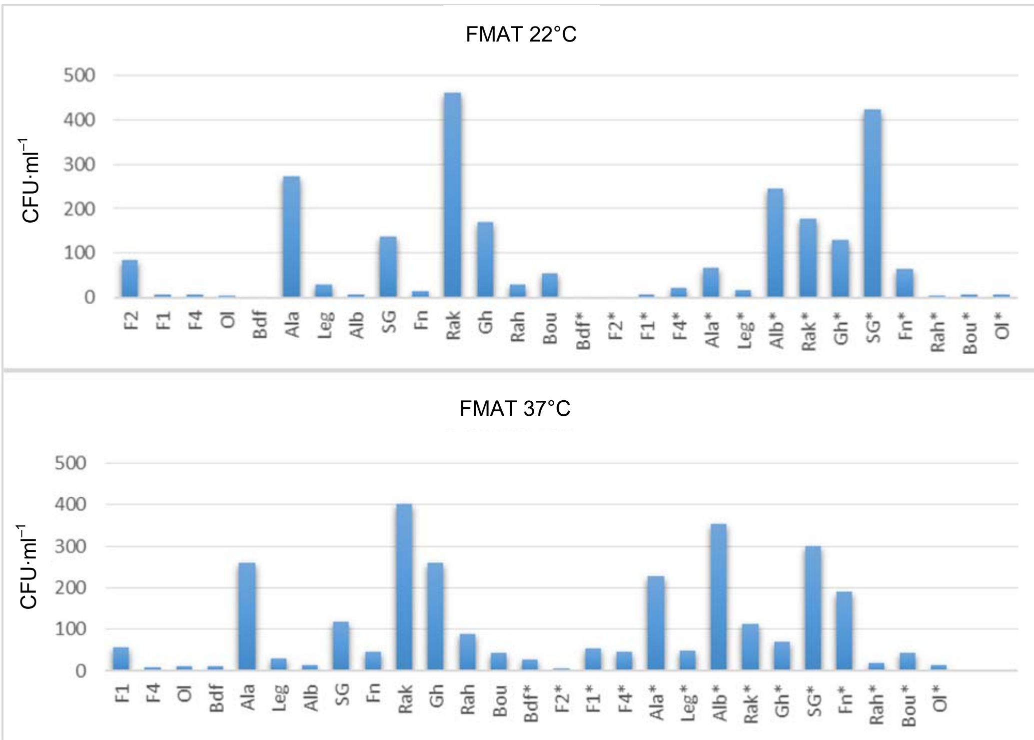

Fig. 7. Variation of total aerobic mesophilic flora (FMAT) at 22°C and 37°C (first and second campaigns); wells as in Fig. 1, asterisks denote the second campaign; source: own study

We can conclude that the dominant facies are represented by calcium bicarbonate and magnesium (69% of the samples).

According to SEKIOU and KELLIL [2014], the disadvantage of the Piper diagram is that it uses a limited number of parameters and provides little information to distinguish the differences between the separate groups.

CORRELATION ANALYSIS

The correlation matrix gives us a preliminary reading on the associations between the 18 physicochemical parameters measured during our study and it is represented in Table 5. This table illustrate the correlations that exist between the physicochemical elements of the three campaigns.

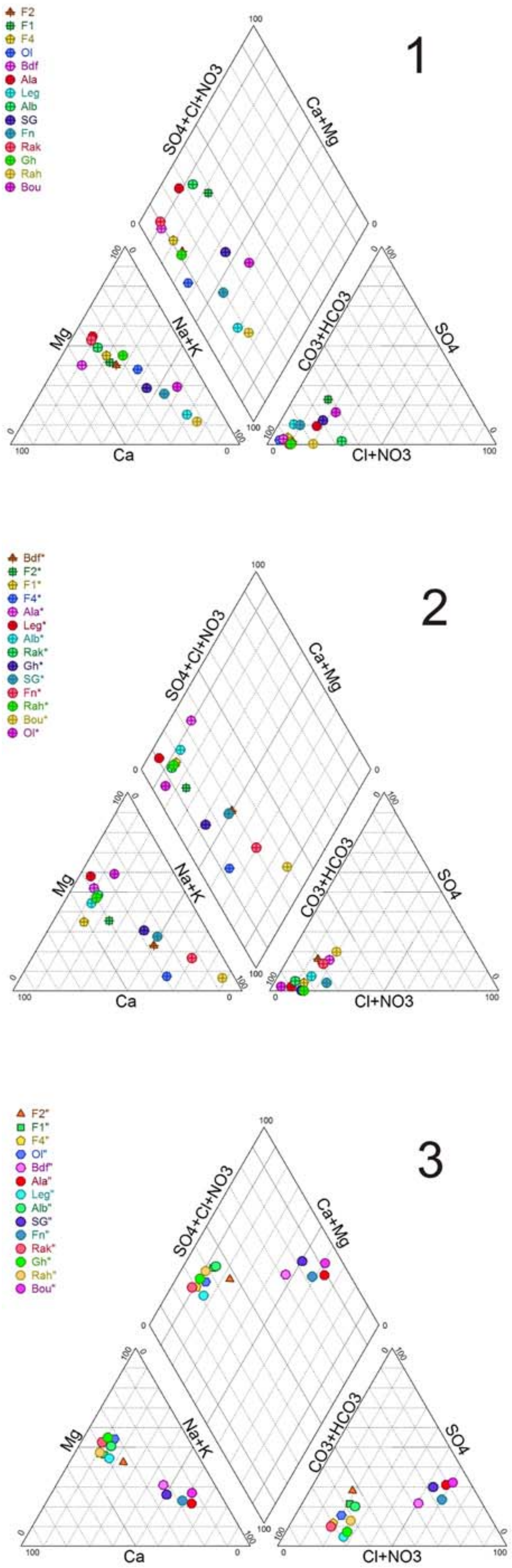

Fig. 8. Representation of the chemical facies piper diagram; wells as in Fig. 1; 1, 2, 3 = the campaigns; source: own study

Based on the correlation matrix, a very strong correlation ($0.85 < r < 0.99$) and a high correlation ($0.75 < r < 0.85$) (in bold) between *EC* and the elements (Ca, Mg, Cl, SO_4, Na, K and *RS*) reveals that groundwater mineralization is controlled primarily by elements considered dominant ions. Furthermore, we note that turbidity is not correlated with all elements except organic matter during the third campaign, which reveals an anthropogenic pollution.

PRINCIPAL COMPONENT ANALYSIS (PCA)

Campaign 1

Fig. 9a highlights the first two factors, F1 and F2, that present 61.97% of the total variance.

The F1 axis (48.52% of the total inertia) is positively correlated with the variables: *EC*, *TH*, Ca, Mg, Cl, SO_4, *TAC*, HCO_3, Na, K, and the *RS*, these elements are correlated with each other, which reveals that the F1 axis is a factor of mineralization. The F2 axis (13.44% of the total inertia) is positively correlated with the variables: turbidity, *T*, pH, NH_4. The elements PO_4, *MO*, NO_3 are not well presented by the first two components F1 and F2.

Campaign 2

Fig. 9b shows that the (F1 and F2) plan presents 57.35% of the total variance. The F1 axis gives 37.88% of the total information and is positively correlated with the variables *EC*, *TAC*, HCO_3, Cl, NO_3, SO_4, which are well correlated with each other. The F2 axis gives 19.47% of the information; it is positively correlated with the variables *TH*, Ca, Mg. The variables: *T*, pH, turbidity, NH_4, PO_4, *MO*, K are poorly presented by the first two components F1 and F2.

Campaign 3

As for **Fig. 9c,** it illustrates that the (F1 and F2) plane represents 73.28% of the total variance. F1 axis (59.14% of the inertia) is positively correlated with the variables *EC*, *TH*, Ca, Mg, Na, *TAC* , HCO_3, K, Cl, SO_4 and *RS* that correlate well with each other. Moreover, this indicates that it is a mineralizing factor. The F2 axis (14.14%) is represented by a positive correlation to the variables *MO*, turbidity and NO_3 and this means that this axis is an organic pollution factor.

Based on the results, the principal component analysis allowed us to:

- explore the links between variables (physic-chemical elements) and similarities between individuals (sampling points);
- identify the most suitable physico-chemical elements to describe the water quality of Beni Ounif syncline, which are mainly those that correlate well with the F1 and F2 axes;
- define for each factor in the three seasons its dominant characteristic (either it represents mineralization and / or organic pollution).

HIERARCHICAL CLUSTER ANALYSIS (HCA)

This method allowed us to define the similarity (physic-chemical quality viewpoint) between the wells and drillings analysed presented in a dendrogram.

Table 5. Correlation matrix – the 18 physicochemical parameters measured during study (campaign 1)

Parameter	*T*	pH	*EC*	Turbidity	*TH*	Ca	Mg	*TAC*	HCO_3	Na	K	Cl	NO_3	NH_4	SO_4	PO_4	*MO*	*RS*
									Campaign 1									
T	**1.00**																	
pH	0.36	**1.00**																
EC	0.22	0.15	**1.00**															
Turbidity	0.41	0.25	–0.29	**1.00**														
TH	0.49	0.20	**0.70**	–0.12	**1.00**													
Ca^{2+}	0.46	0.21	**0.82**	–0.03	**0.92**	**1.00**												
Mg^{2+}	0.41	0.33	**0.77**	–0.25	**0.95**	**0.87**	**1.00**											
TAC	0.32	0.18	**0.71**	–0.12	**0.53**	**0.58**	**0.55**	**1.00**										
HCO_3^-	0.32	0.18	**0.71**	–0.12	**0.53**	**0.58**	**0.55**	**1.00**	**1.00**									
Na^+	**0.82**	0.40	0.30	0.11	**0.76**	**0.61**	**0.73**	0.27	0.27	**1.00**								
K^+	0.39	0.47	**0.72**	–0.18	**0.63**	**0.62**	**0.75**	0.34	0.34	**0.55**	**1.00**							
Cl^-	0.41	0.24	**0.86**	–0.26	**0.93**	**0.89**	**0.98**	**0.61**	**0.61**	**0.67**	**0.76**	**1.00**						
NO_3^-	0.01	0.42	0.20	0.27	0.23	0.19	0.33	–0.05	–0.05	0.18	0.31	0.28	**1.00**					
NH_4^-	0.40	**0.54**	0.15	0.25	0.22	0.25	0.24	0.46	0.46	0.28	0.05	0.23	–0.14	**1.00**				
SO_4^{2-}	0.50	0.21	**0.64**	–0.25	**0.77**	**0.73**	**0.82**	0.39	0.39	**0.70**	0.53	**0.83**	0.23	0.26	**1.00**			
PO_4^{3-}	–0.11	–0.06	–0.14	–0.25	–0.15	–0.25	–0.16	0.14	0.14	–0.19	0.04	–0.21	–0.27	–0.24	–0.27	**1.00**		
MO	–0.28	–0.30	–0.17	–0.41	–0.37	–0.37	–0.23	–0.48	–0.48	–0.24	0.01	–0.20	–0.10	–0.41	0.10	0.11	**1.00**	
RS	0.39	0.24	**0.91**	–0.23	**0.91**	**0.90**	**0.96**	**0.65**	**0.65**	**0.61**	**0.77**	**0.99**	0.30	0.23	**0.80**	–0.22	–0.22	**1.00**
									Campaign 2									
T	**1.00**																	
pH	0.39	**1.00**																
EC	0.25	–0.19	**1.00**															
Turbidity	–0.18	0.23	–0.27	**1.00**														
TH	–0.30	–0.08	–0.20	–0.32	**1.00**													
Ca^{2+}	–0.37	–0.06	–0.32	–0.13	**0.90**	**1.00**												
Mg^{2+}	–0.20	–0.18	–0.16	–0.44	**0.95**	**0.82**	**1.00**											
TAC	0.26	–0.26	**0.74**	–0.45	0.18	–0.07	0.22	**1.00**										
HCO_3^-	0.26	–0.26	**0.74**	–0.45	0.18	–0.07	0.23	**1.00**	**1.00**									
Na^+	0.08	–0.19	**0.72**	–0.08	–0.09	–0.15	–0.16	**0.72**	**0.72**	**1.00**								
K^+	**–0.59**	–0.09	–0.15	0.12	0.38	0.50	0.15	–0.04	–0.04	0.29	**1.00**							
Cl^-	0.08	–0.26	**0.95**	–0.27	–0.20	–0.31	–0.17	**0.67**	**0.66**	**0.65**	–0.07	**1.00**						
NO_3^-	0.29	–0.13	**0.71**	–0.18	–0.23	–0.26	–0.29	**0.65**	**0.65**	**0.86**	0.05	**0.63**	**1.00**					
NH_4^-	0.01	–0.24	–0.10	–0.10	–0.24	–0.36	–0.21	–0.19	–0.19	–0.06	–0.04	–0.01	–0.07	**1.00**				
SO_4^{2-}	0.33	–0.11	**0.93**	–0.29	–0.31	–0.43	–0.25	**0.74**	**0.73**	**0.77**	–0.15	**0.84**	**0.68**	–0.07	**1.00**			
PO_4^{3-}	–0.48	–0.37	0.04	0.34	0.10	0.23	–0.02	–0.21	–0.21	–0.05	0.37	0.06	–0.16	0.00	–0.13	**1.00**		
MO	0.21	0.14	0.05	0.03	0.16	0.12	0.14	0.14	0.15	–0.18	0.08	0.01	–0.26	–0.25	0.10	0.11	**1.00**	
RS	0.17	–0.22	**0.98**	–0.30	–0.22	–0.34	–0.18	**0.72**	**0.72**	**0.73**	–0.08	**0.99**	**0.71**	–0.02	**0.91**	–0.04	0.02	**1.00**
									Campaign 3									
T	**1.00**																	
pH	0.01	**1.00**																
EC	0.18	0.36	**1.00**															
Turbidity	0.05	0.31	–0.08	**1.00**														
TH	0.26	0.33	**0.99**	–0.11	**1.00**													
Ca^{2+}	0.29	0.30	**0.93**	–0.10	**0.96**	**1.00**												
Mg^{2+}	0.23	0.34	**0.98**	–0.12	**0.99**	**0.90**	**1.00**											
TAC	0.21	0.13	**0.66**	–0.02	**0.70**	**0.79**	**0.63**	**1.00**										
HCO_3^-	0.24	0.12	**0.67**	–0.01	**0.71**	**0.79**	**0.63**	**1.00**	**1.00**									
Na^+	0.16	0.37	**1.00**	–0.07	**0.98**	**0.93**	**0.97**	**0.65**	**0.66**	**1.00**								
K^+	0.13	0.36	**0.98**	–0.04	**0.95**	**0.91**	**0.94**	**0.69**	**0.69**	**0.98**	**1.00**							
Cl^-	0.18	0.37	**1.00**	–0.07	**0.98**	**0.93**	**0.98**	**0.65**	**0.66**	**1.00**	**0.98**	**1.00**						
NO_3^-	0.42	0.12	–0.26	0.13	–0.23	–0.13	–0.27	0.24	0.25	–0.27	–0.24	–0.26	**1.00**					
NH_4^-	–0.25	–0.31	–0.08	–0.21	–0.06	–0.05	–0.06	0.04	0.02	–0.10	–0.13	–0.11	–0.25	**1.00**				
SO_4^{2-}	0.14	0.33	**0.99**	–0.13	**0.98**	**0.92**	**0.98**	**0.62**	**0.63**	**0.99**	**0.97**	**0.99**	–0.35	–0.04	**1.00**			
PO_4^{3-}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
MO	0.35	0.38	–0.14	**0.62**	–0.17	–0.12	–0.20	–0.13	–0.11	–0.12	–0.09	–0.12	0.39	–0.16	–0.20		**1.00**	
RS	0.18	0.36	**1.00**	–0.08	**0.99**	**0.93**	**0.98**	**0.67**	**0.67**	**1.00**	**0.98**	**1.00**	–0.26	–0.08	**0.99**		–0.14	**1.00**

Explanations: *T*, *TH*, *TAC*, *MO*, *RS* as in Tab. 3, *EC* = electrical conductivity.
Source: own study.

Campaign 1

The HCA has allowed us to distinguish four classes; each class includes the most similar drillings as shown in Figure 10a.

Class 1 collects holes F1 F2, F4, Ol, Alb, Rak, and Gh which are weakly mineralized ($413 < EC < 672$ μS·cm^{-1}).

Class 2 includes wells Bdf, Ala, Fn, Bou and SG source characterized by strong mineralization ($1100 < RS < 3900$ mg·dm^{-3}).

Class 3 Leg drilling which is similar to class 1.

Class 4 isolates the Rah drill, the least similar to other drillings.

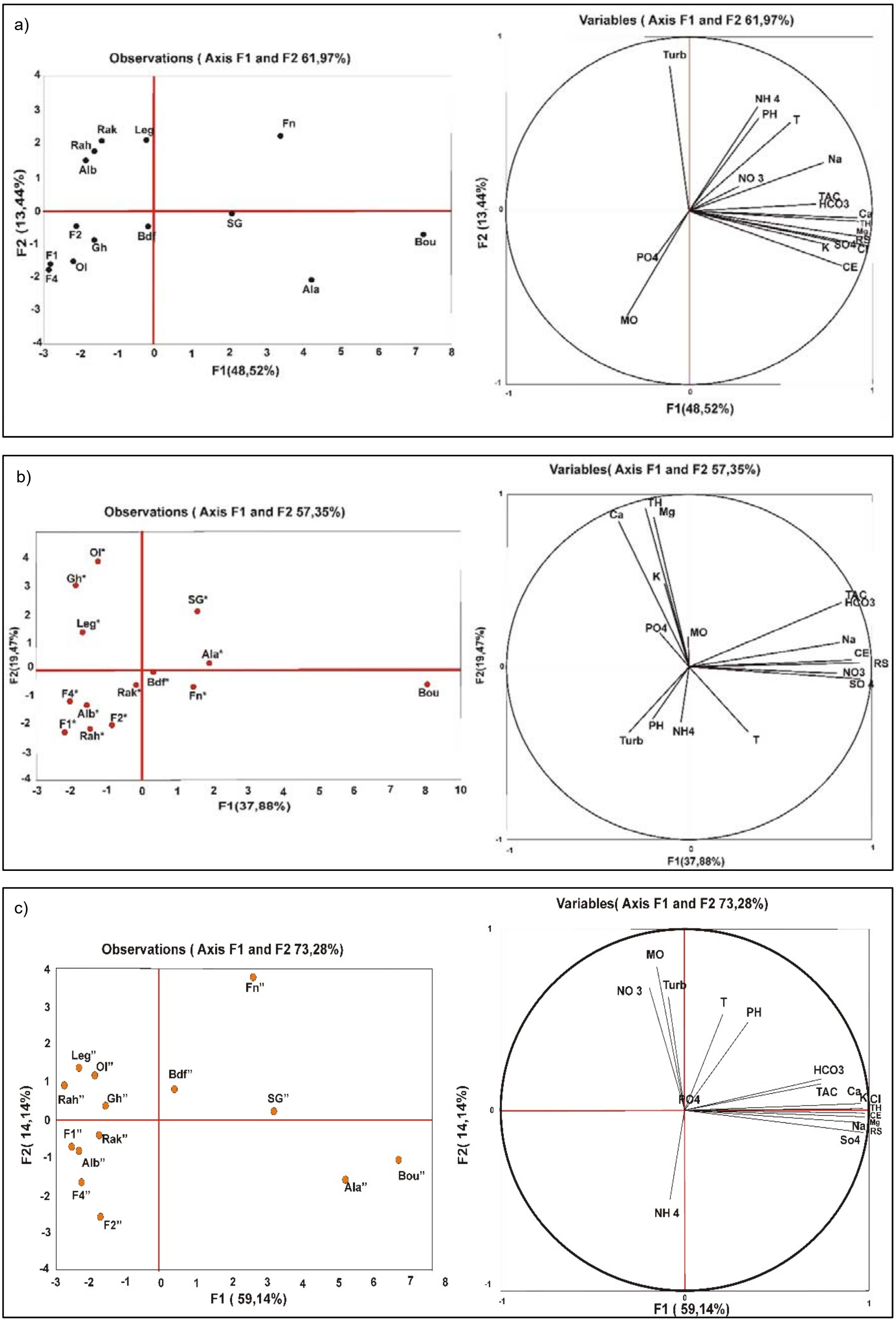

Fig. 9. Distribution of the variables on the circle of correlation and individuals according to the factorial plane F1 F2: a) first campaign, b) second campaign, c) third campaign; wells as in Fig. 1; source: own study

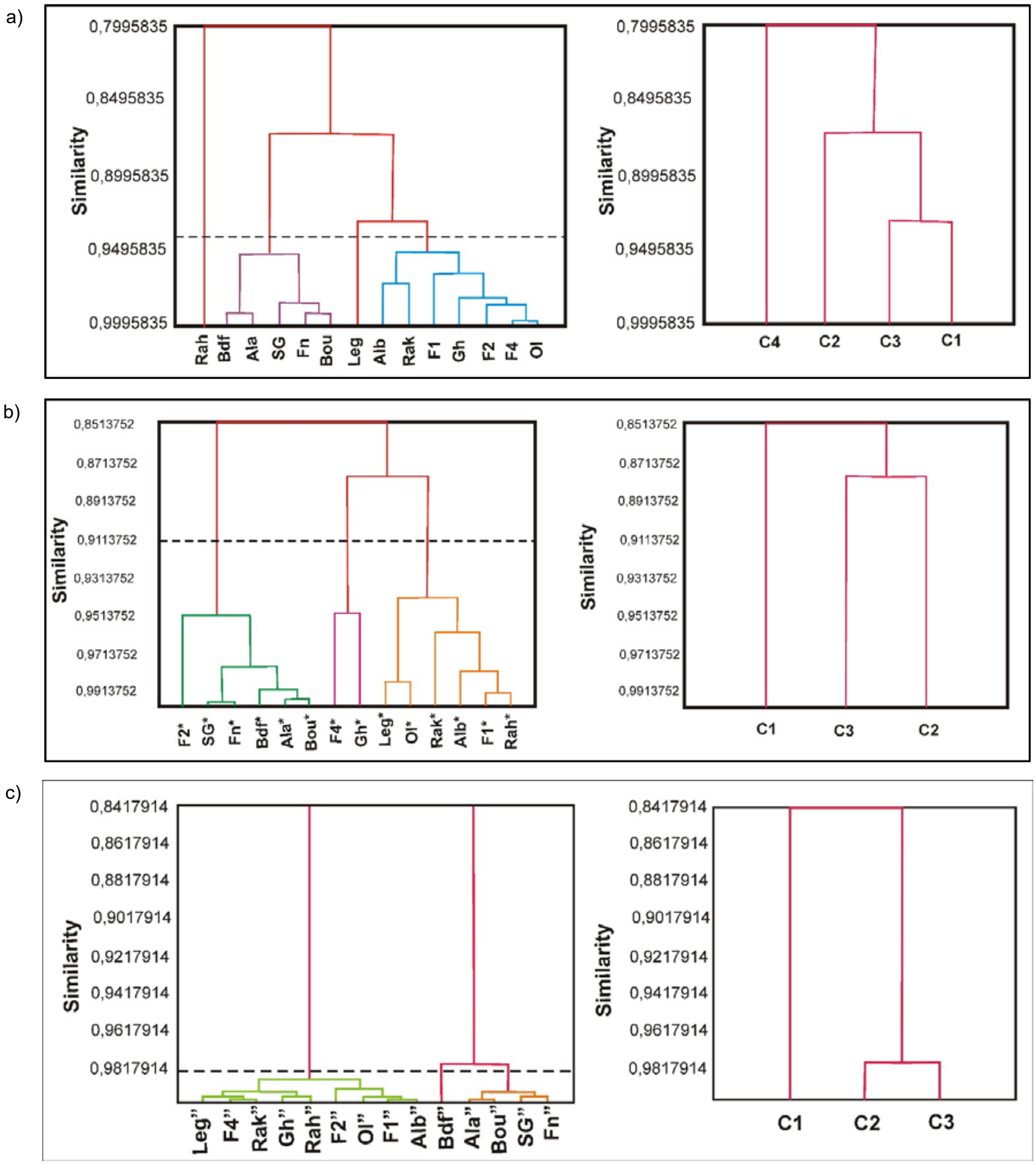

Fig. 10. Dendrogram of observations from: a) first campaign, b) second campaign, c) third campaign; wells as in Fig. 1; source: own study

Campaign 2

According to HCA, we have three classes that are presented in Figure 10b.

Class 1 includes water points: Bdf, F2, Ala, SG, Fn, and Bou highly mineralized (400 < *RS* < 4000 mg·dm^{-3}) with presence of organic pollution (nitrates >50 mg·dm^{-3} in SG an Bou), these are water average physicochemical quality.

Class 2 F1, Leg, Alb, Rak, Rah, Ol weakly mineralized (*RS* < 430 mg mg·dm^{-3}) and of good physicochemical quality.

Class 3 includes the two holes F4 and Gh which have similar physicochemical characteristics.

Campaign 3

From the HCA, we get three classes that are presented in Figure 10c.

Class 1 includes the F2, F1, F4, Ol, Leg, Alb, Rak, Gh, and Rah wells, which are all weakly mineralized but of good physicochemical quality.

Class 2 isolates the Bdf well which is the least similar to other water points.

Class 3 Ala, Bou, SG, and Fn strongly mineralized.

The application of hierarchical cluster analysis (HCA) of drilling based on physico-chemical quality has given us classes, each including the most similar drilling. This allows us to reduce sampling points for temporal and spatial water quality monitoring.

CONCLUSIONS

From the research carried out during the three campaigns and based on the results of the water sample analyses, it is possible to have an overview of the water quality in the Beni-Ounif syncline. The syncline of Beni-Ounif is located on the southern side of the Saharan Atlas. It is mainly covered with Lower Cretaceous sandstone, which forms an important water reservoir, a water table used to provide drinking water to the population of the city of Bechar.

The research was conducted by monitoring the physico-chemical and microbiological characteristics of the water samples. The results of physico-chemical analysis show that the region is characterized by a moderately hard water (42.85% of the samples). 64.3% of the water is moderately to weakly mineralize. Only 19% of the samples contains concentrations of nitrates exceeding the Algerian standards. The dominant facies is calcium bicarbonate and magnesium (69% of the samples). The facies change observed is due to the sampling period (high or low water).

Summing up the results, it can be concluded that the variation of concentration of the measured elements depend on three factors: the situation of the well (recharge/ discharge area), the residence time and the groundwater flow direction.

From a microbiological viewpoint, the result obtained indicates the presence of streptococci D, CSR of vegetative form, sporulated, FMAT at 22°C and at 37°C., respectively 46.42%, 7.14%, 46.4%, 28.57%, and 71.42% of the analysed samples exceeding the Algerian standards. There is also a presence of total coliforms but not exceeding the potability standard. However, it should be noted that no thermo tolerant coliforms were observed in our results.

Moreover, The PCA allowed discriminating the sampling points and to identify the most suitable physicochemical elements to describe the water quality of the syncline and well correlated with the F1 and F2 axes.

Meanwhile, the HCA has been able to classify wells and boreholes into classes according to the similarity between them, which allows us to reduce the number of samples for future sampling.

Therefore, the results are very important and following our methodological research approach, we believe that they could be applicable in other case studies with similar conditions.

Based on this study, the following follow-up actions are recommended:
– monitoring groundwater quantity and quality over time using available piezometers;
– assess the impact of groundwater quality on consumer health and agriculture (spatially east of the study area);
– maintain and protect wells and boreholes to avoid groundwater pollution (organic, inorganic and microbiological);
– further research on the origin, occurrence and effects of salinity on soil and plants.

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Hydrochemiczna i mikrobiologiczna charakterystyka wód dolnej kredy w półsuchej strefie synkliny Beni-Ounif w południowozachodniej Algierii

STRESZCZENIE

W artykule przedstawiono wyniki analizy jakości wody z poziomu wodonośnego dolnej kredy w synklinie Beni-Ounif. W tym celu pobrano 42 próbki wody do analiz fizycznych i chemicznych oraz 28 próbek do analiz mikrobiologicznych z 14 stanowisk w marcu, maju i październiku 2017 r. Wyniki analiz fizycznych i chemicznych przetworzono za pomocą wieloczynnikowych metod statystycznych: analizy czynników głównych (PCA) i hierarchicznej analizy skupień (HCA) połączonej z metodami hydrochemicznymi, z diagramem Pipera.

Analiza PCA umożliwiła zbadanie powiązań między parametrami fizycznymi i chemicznymi oraz podobieństwa między próbkami, a także identyfikację parametrów najbardziej odpowiednich do opisu jakości wody.

Wykorzystując HCA, sklasyfikowano stanowiska według ich wzajemnego podobieństwa oraz zredukowano ich liczbę do przyszłych analiz.

Wody synkliny charakteryzowały się małą do średniej mineralizacją ($320 < EC < 7600$ µS·cm^{-1} i $200 < RS < 4020$ mg·dm^{-3}) i twardością między 22 i 123°f. Tylko 19% próbek wykazywało stężenie azotanów przekraczające algierskie normy. W badanych wodach stwierdzono obecność bakterii z grupy *Coli* (<8 jtk·(0,1 dm^3)$^{-1}$), *Streptococcus* D (<1100 jtk·(0,1 dm^3)$^{-1}$), wegetatywnych form (<90 jtk·(0,02 dm^3)$^{-1}$) i przetrwalników (<4 jtk·(0,02 dm^3)$^{-1}$) *Clostridium* oraz całkowitej mezofilnej flory aerobowej w temperaturze 22°C (<462 jtk·(0,001 dm^3)$^{-1}$) i 37°C (<403 jtk·(0,001 dm^3)$^{-1}$). Należy dodać, że nie stwierdzono obecności termoodpornych bakterii z grupy *Coli*.

Słowa kluczowe: *analiza składowych głównych (PCA), Beni-Ounif, charakterystyka hydrochemiczna, charakterystyka mikrobiologiczna, dolna kreda, hierarchiczna analiza skupień (HCA), jakość wody, wody gruntowe*