Hydrochemical assessment and groundwater pollution parameters in arid zone: Case of the Turonian aquifer in Béchar region, southwestern Algeria

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Abstract

Groundwater samples from Turonian aquifer of Béchar region were evaluated as drinking and irrigation water sources. physicochemical parameters including pH, *EC*, *TH*, Na^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-} and NO_3^- were determined for 16 water sampling points. These characterizations show that the groundwater is fresh to brackish, slightly alkaline and the major ions are Na^+, Ca^{2+}, Mg^{2+}, Cl^- and SO_4^{2-}. According to WHO standards, 50% of the analysed water are suitable as a drinking source while the other samples are not in compliance with drinking water standards. This non-compliance is basically due to the high concentrations of Na^+, Cl^-, and SO_4^{2-} requesting further treatment to reach the stringent standards. According to the results of nitrate concentrations, anthropogenic source seems to influence the groundwater quality. The present study shows that Béchar groundwater may represent an important drinking and irrigation water source. However, a specific management strategy should be adapted in order to avoid the contamination by anthropogenic sources.

Key words: *Béchar region, groundwater, hydrochemistry, Turonian aquifer, water quality*

INTRODUCTION

Some countries bordering the Mediterranean Sea had many problems with water quantity and quality [BARAKAT *et al.* 2013; BENRABAH, ATTOUI 2016].

In developing countries with arid climate, groundwater presents the main or unique source of drinking and agricultural waters. In Algeria, the Sahara region population is greatly in need of groundwater resources to cover their basic water necessities. Hence, it is crucial to identify the current water resources, to bring information about the resources vulnerability in order to implement the suitable measures to improve, manage and protect water resources.

Water quality remains the main factor influencing its use for drinking, agricultural and industrial purposes. The chemistry of groundwater can be modified by the geological nature of the reservoir rock and anthropogenic activities. Nevertheless, the dissolution of minerals from the surrounding rock in water is the predominant factor controlling the chemical composition. Several evaporate minerals including carbonates, sulphates and chlorides dissolve rapidly and alter considerably the water chemical composition. In contrast, other minerals such as silicates dissolve slowly and therefore have a lesser effect. Previous investigations showed that groundwater chemistry results primarily as a function of the interaction between water and the aquifer mineralogical composition [HARTMAN *et al.*

2005; WUNDERLIN et al. 2001]. Currently, waterways constantly receive urban and industrial discharges often loaded with toxic elements [CAO et al. 2016; FEHDI et al. 2016]. The examination of water physicochemical properties allows not only judging the water safety towards the domestic and agricultural use but bringing complement information to the hydrogeological study.

In Béchar region (South-West of Algeria), groundwater provides excellent drinking water sources. The Turonian aquifer groundwater reserves are currently exploited to cover drinking and irrigation needs. The management of these water resources, in quantity and quality, remains at the centre of the region's concerns given the insufficient resources in Sahara, which is often aggravated by drought and excessive mineralization. In this area, water quality is mainly influenced by the geological nature. To our knowledge, no hydrogeochemistry research has been performed for the groundwater quality assessment. Hence, it seems necessary to study these water sources with respect to natural and anthropogenic effects. Such studies will help local authorities to define the suitable strategy for the protection and management of these resources. In this context, the objective of the present work is to evaluate the groundwater quality of the Turonian sheet of Béchar region and to examine its suitability for drinking and agriculture purposes.

STUDY AREA

The study area lies between North latitudes 31°15' and 32°00' and West longitudes between 2°00 and 3°00. Béchar region is located at the foot of the southern side of the Saharan Atlas at a distance of 950 km South-West of the capital Algiers (Fig. 1). It presents the major pole in the regional pattern of special planning (TARS). It is limited to the North by the massive northern (Djebel Antar 1960 m and Djebel Horriet 1461 m) and Hamada Sbaâ, the South by Chabket Mennouna, to the East by the mountain Djebel Béchar (1500 m), and the West by Barga I and II, Kénadsa

regions. Wadi Béchar comes from the slopes of Djebelntar and Horreit and silts up after 150 km journey to Dhait and Tiour without reaching the Wadi Guir [IDROTECNECO 1967]. The study area has the characteristic of an arid climate. The summers are hot (42°C in August), and the winters pretty cold (3°C in January). The annual rainfall is very low. The rainfall occurs, in general during September, June and occasionally in November.

GEOLOGY AND HYDROGEOLOGY

The study site is a portion of the Saharan old platform, which is empty, monotonous, stable and carbonized [FABRE 1975]. This region provides an excellent open-air laboratory, with a large geological diversity. It offers a wide range of land, ranging from the Precambrian era to the current era under the best conditions of out crops (Fig. 2).

The substratum of Béchar region consists essentially of more or less quartz sandstones, clays and coal-bedded shales. This formation introduces a dip average of 30° toward the North-West where it disappears under the transgressive Cuesta Cenomano-Turonian. The limestones and dolomites of the first Barga Turonian have dips of 15° to 20° North to North-West. Above its horizons comes a clay-gypsum series attributed to Senonian, Eocene and Eocene inferior. These series end with a tabular formation involving a level of brown sandstones (5–6 m) and the limestone slab of the second Barga representing the Upper Eocene. Finally the Quaternary is represented mainly by alluvial deposits, alluvial terraces of the deposits limestone or marly and sometimes conglomeratic lakes and scree.

The groundwater occupies approximately 4000 km^2 in Béchar basin which presents the eastern sector of the Great Cretaceous basin of Boudnib (8000 km^2). The transmissivity varies between 10^{-5} and $0.8 \cdot 10^{-3}$ m$^2 \cdot$s^{-1}, and the storativity varies between $1.5 \cdot 10^{-3}$ and $3 \cdot 10^{-3}$. Since the formation of the limestone Turonian has a brittle style, and suffered fracturing and even faulting, we can find the dips benches, and cliffs. The cracked limestones forming the
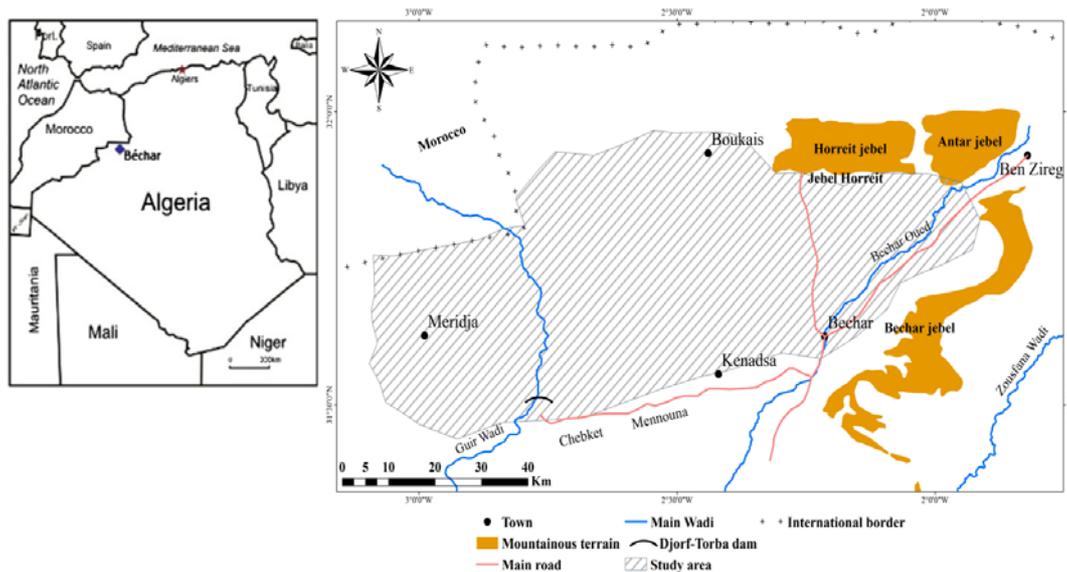

Fig. 1. Location of the study area; own elaboration

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first Baraga Béchar constitute a morpho-logical mark regional level. This carbonate training constitutes a very good aquifer to the crack movement. These cracked limestones are localized essentially in the southern edge of the basin subsidence of Béchar–Kénadsa that represents the eastern sector of the Great Cretaceous basin of Errachidia-Boudenib. The Turonian aquifer contains the main water of the region, free in border; it becomes captive toward the centre of the basin. The wall of this aquifer is formed by the marl layer from the Cenomanian, while the roof is constituted by colourful sandy marls with the banks of mineral evaporites (gypses, rock salt) of the Senonian.

The piezometer established at the level of the wells, drilling and sources (Fig. 3) reveals a movement of the water of the North-East to the South-West up to Djorf Torba natural outlet under a hydraulic gradient of 0.4%. The reserve of this pad is certainly considerable and the importance of its flow is reflected by the fact that it supplies the most important sources of the basin:

– the source of Boukais, constitutes the outfall of limestones Turonians by the intermediary of a major fault in corresponding to the flexure Saharan, its corresponding flow is 17 $dm^3 \cdot s^{-1}$.
– the water of the source of limestone of Djorf Torba flows directly into the Wadi Guir at the rate of 10 $dm^3 \cdot s^{-1}$.

MATERIALS AND METHODS

The water samples were collected from different points of Béchar region. Water sampling points (wells, boreholes, and springs) were selected to cover all the Turonian aquifers. In total, sixteen samples were carried out in March 2016. The water levels were measured using a piezometric probe. These water points were georeferenced by their Lambert coordinates determined by GPS. Sample names and their type source are reported in Table 1.

Different analytical techniques were applied to determine the physicochemical properties of water samples.

To test the reproducibility of the measurements, we repeated the analyses (3 analysis) on samples taken from the same water point.

The electrical conductivity, temperature and pH were measured in situ using a portable conductometer (Consort C5010). Then, these samples were kept cool and protected from light at a temperature of 4°C. Concentrations of cations such as Na^+, K^+ and Ca^{2+} were determined by flame
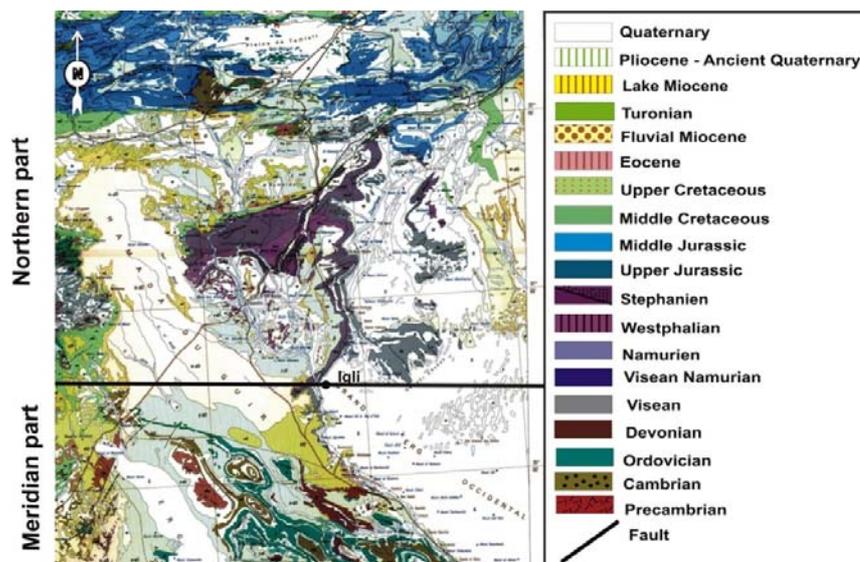

Fig. 2. Map of Béchar area representing the geology; source: own elaboration
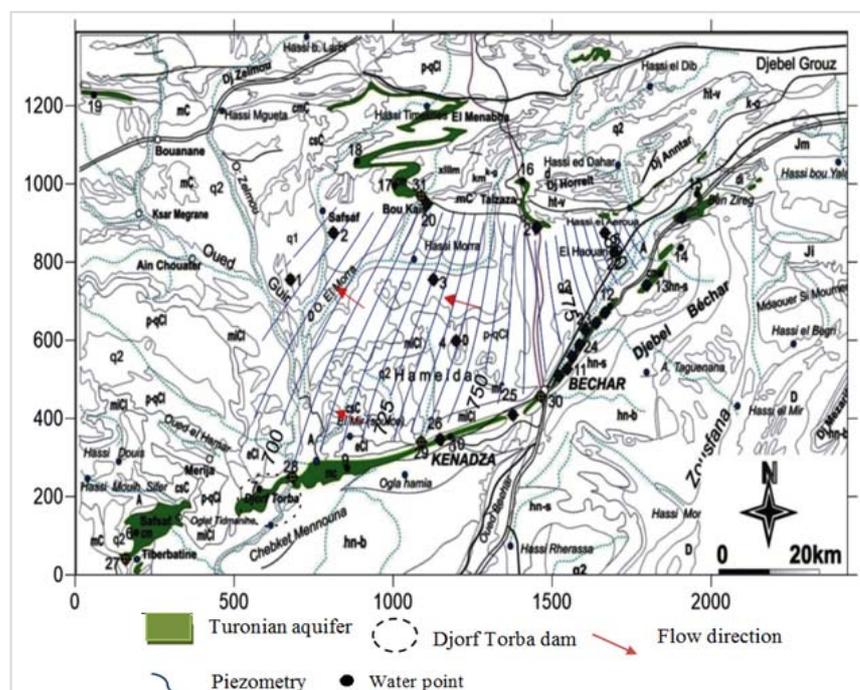
Fig. 3. Piezometric map; own elaboration

spectrophotometer (Jenway clinical PFP7). Cl^- and total hardness (*TH*) were determined by colorimetric method. Mg^{2+} was calculated as follows: $TMg^{2+} = TH - TCa^{2+}$. On the other hand, analysis of the elements NO_3^-, SO_4^- and HCO_3^- were carried out by ion chromatography (waters) in National Agency of Hydraulic Resources (Fr. Agence nationale des resources hydrauliques – ANRH) laboratory. The concentrations of chemical species are expressed in $mg \cdot dm^{-3}$) and the ionic balance is generally less than 3%.

Data collected in the field and in the laboratory were processed using descriptive and multivariate statistics coupled with hydrochemical methods. The principal component analysis (PCA) was used to highlight the origin of the water mineralization.

Table 1. Sampling site of water points

Water point	Name	Type	X	Y	Z	Depth
P1	SOURCE RIGHT DAM	source	02°46'21"W	31°30'38"N	686	–
P2	SOURCE LEFT DAM	source	02°46'16"W	31°30'36"N	684	–
P3	HASSI 20	drilling	01°56'50"W	31°12'53"N	724	87
P4	HYCOBAR 01	drilling	02°12'50"W	31°36'18"N	809	75
P5	OUAKDA 02	drilling	02°09'44"W	31°00'40"N	815	132
P6	HYCOBAR 02	drilling	02°15'21"W	31°37'39"N	808.5	80
P7	OUAKDA 03	drilling	02°19'22"W	31°37'41"N	817	83
P8	HASSI *ABD EL* AALI	drilling	02°31'16"W	31°55'33"N	846	150
P9	STRONG DRILL	drilling	02°33'20"W	31°51'28"N	851	120
P10	UAE AIN BOUKAÏS	source	02°28'02"W	31°55'36"N	883	–
P11	SOURCE200 M	drilling	02°28'04"W	31°55'39"N	885	119
P12	HASSI 02	drilling	02°27'29"W	31°55'47"N	994	126
P13	MERIJA P1	well	02°56'55"W	31°33'14"N	796	132
P14	MERIJA P2	well	02°56'57"W	31°33'17"N	794	160
P15	MERIJA P3	well	02°57'05"W	31°33'12"N	791	170
P16	MERIJA P AIN LACHE	well	03°05'27"W	31°27'15"N	797	175

Source: own elaboration.

This method has been widely used in many fields dealing with the study of the natural environment [JEGUIRIM *et al.* 2017; MATINI, RASMUSSEN 2009; ZENG *et al.* 2005]. This approach involved twelve hydrochemical parameters: pH, dry residue, HCO_3^-, Cl^-, SO_4^-, NO_3^-, Ca^{2+}, Mg^{2+}, Na^+, K^+; NO_3^-, SiO_2. Statistica software version 7 was used for this statistical analysis.

RESULTS

PHYSICOCHEMICAL PARAMETERS

In the study area, the temperature ranges from 21 to 23°C. The values of pH show no significant variations, with a minimum of 6.75 and a maximum of 8.38 which reflects a slight alkalinity (*TA*). The pH is always in direct relationship with alkalinity. It concerns strong base when the pH exceeds 8.3. The alkalinity (*TA*) of water is related to the presence of OH^-, CO_2 and HCO_3^- bases. Alkalinity or acidity of water is linked to the crossed ground nature For the studied water, the *TA* equals 0 since the pH does not exceed 8.3. Measurements of electrical conductivity (*EC*) of all samples vary between 1 and 10.88 mS·cm^{-1}. The results show that 43.75% of the samples exceed the permissible limit 1.5 mS·cm^{-1} [WHO 1995].

In the study area, total dissolved solids (TDS) range from 683 to 5824 mg·dm^{-3}. About 66% of water samples are fresh since the TDS is less than 1000 mg·dm^{-3}. However, 44% of samples are brackish according to ground water quality since their TDS varies from 1001 to 5824 mg·dm^{-3}.

The Ca^{2+} concentrations of Turonian ply range between 53 mg·dm^{-3} and 636 mg·dm^{-3}. More than half of samples exceed the permissible limit. The high calcium contents may be attributed to the dissolution of the calcite

and other calcium minerals such as gypsum [JALALI 2005; KUMAR *et al.* 2015]. The levels of Mg^{2+} in water of the same region are between 14 and 164 mg·dm^{-3}. This element is predominant in water draining containers aquifers such as dolomite [REIMER 1995] .

In the waters of the Turonian aquifer, sodium dominates the cations present in water. Thus, the total saline load of these waters is controlled mainly by the contents of this element. Their contents vary from 76 to 1100 mg·dm^{-3}.

Potassium is much less abundant than sodium in the water taken. The potassium content of the waters of the Turonian aquifer is almost homogeneous at the same sampling site. They vary between 1 and 5 mg·dm^{-3}.

The sulphate concentrations in water vary widely. They range from 60 to 2100 mg·dm^{-3}. Elevated levels are detected in seven water points (P1, P2, P8, P9, P11, P15 and P16) exceeding the permissible limit 250 mg·dm^{-3} [WHO 1995]. Upon contact with the gypsum, the water becomes charged with calcium sulphates and becomes hard and unhealthy for human consumption.

The chloride contents show a great variability, they vary from 118 to 1700 mg·dm^{-3}, their evolution is due to the leaching of the crossed lands.

Bicarbonate contents of survey points are ranged between 95 and 253 mg·dm^{-3}. The high concentrations of bicarbonate may be due to the leaching of carbonate rocks. However, silica (SiO_2) concentrations are low and the maximum value is 11.5 mg·dm^{-3} in the waters of the Turonian sheet. SiO_2 is abundant in magmatic rocks, sandstones and clays.

In the studied waters the nitrate levels vary from 0.07 to 37.38 mg·dm^{-3}. From these results, it appears that nitrate levels are not exceeding the permissible limit (50 mg·dm^{-3}) and the high nitrate levels of the study area may reflect agricultural and domestic pollution.

Table 2. Base exchange indices (IEB) of groundwaters of Turonian table

The water point	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16
IEB	0.34	0.23	0.33	0.29	0.30	0.34	0.31	0.36	0.35	0.78	0.30	0.33	0.50	0.48	0.27	0.13

Explanations: sampling points number as in Fig. 3.
Source: own study.

HYDROCHEMICAL FACIES FOR GROUNDWATER

Groundwater types in the study area were analysed by Piper diagrams. Figure 4 shows that 70% of waters are typified by chloride, sulphate, calcium and magnesium. It is linked to the salts dissolution of the aquifer reservoirs. Chloride sodium and potassium or sodium sulphate represents 10%. The various facies reveal that hydrogeochemical processes govern the mineralization of the groundwater. The results highlight the impact of lithology on the quality of groundwater.
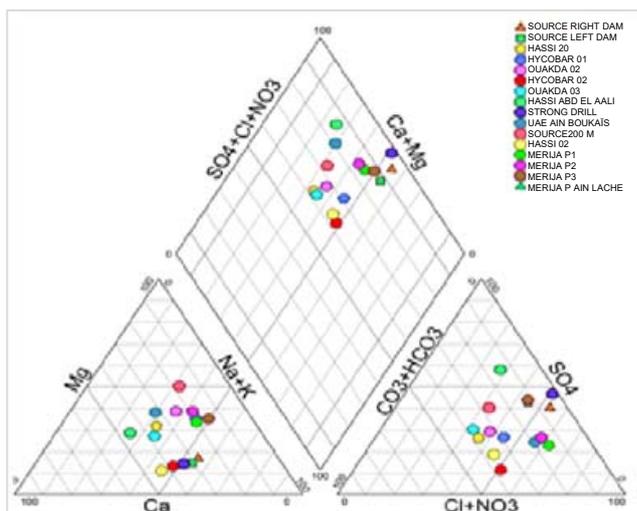

Fig. 4. Triangular diagram Piper companion of Turonian table;
source: own study

FACTORS CONTROLLING THE HYDROCHEMICAL PARAMETERS AND THEIR SOURCES

The base exchange index (BEX) is the ratio of the exchanged ions and ions of the same originally existing in nature. It is obtained by the following relationship:

$$BEX = rCl^- - r(Na^+ + K^+) / rCl^-$$

An examination of the results (Tab. 2) shows that 100% of samples have a positive base exchange index, ranging from 0.133 to 0.782. This can be attributed to several phenomena: either the exchange of alkaline water against alkaline earth permutolites; or anthropogenic inputs causing an excess of chloride ions in the water.

These exchanges contribute, on the one hand, to considerably increasing the ionic and weight contents of these alkaline-earth metals in water and, on the other hand, to lowering the alkaline contents.

Saturation indices of minerals (*SI*) were calculated to better identify the water mineralization and chemical changes in the aquifers. *SI* > 0 indicates oversaturation and minerals may be subject to precipitation, *SI* < 0 means undersaturation and minerals will dissolve, and *SI* = 0 suggests saturation and minerals are in equilibrium status with respect to the solution. The results obtained in Figure 5 show that the water studied are under saturation by report to the gypsum and anhydrite and aragonite. We note that the saturation indices of gypsum and anhydrite are mani-

fested in the same way, and this is due to the time of stay (short) of the water in contact with the rock. It is also noted that the majority of groundwater sampling points are oversaturated regarding to the calcite and dolomite. These waters are under-saturated concerning to the halite which indicates a significant dissolution of sodium.
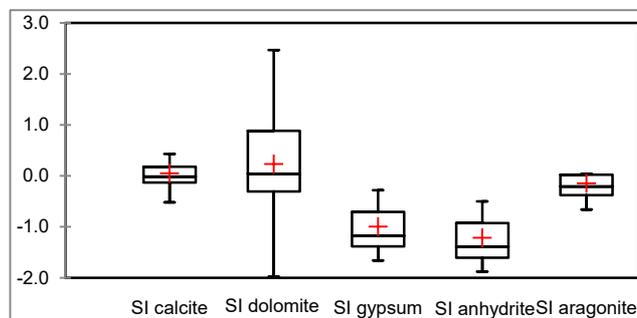

Fig. 5. Box plots illustrating the variation of the saturation indices (*SI*) of certain minerals of the aquifer formation;
source: own study

EVOLUTION OF WATER

Correlation

The mean and median values of the concentrations of the different elements of the water are presented in Table 3.

The correlation between the chemical elements is presented as matrix in Table 4. From the number of samples, we deduce the acceptable correlation coefficient, in this case *r* = 0.53.

Table 3. Statistical parameters of the series of the slick Turonian

Variable	Unit	Min	Max	Average	Standard deviation
NO_3^-	mg·dm^{-3}	0.00	37.38	14.20	12.64
pH	–	6.75	8.38	7.24	0.43
DR	mg·dm^{-3}	630.00	6500.0	1370.0	1435.5
Ca^{2+}	mg·dm^{-3}	53.00	636.00	148.18	168.50
Mg^{2+}	mg·dm^{-3}	14.00	164.00	66.25	39.27
Na^+	mg·dm^{-3}	76.00	1100.0	212.37	254.51
K^+	mg·dm^{-3}	1.10	6.00	2.55	1.36
Cl^-	mg·dm^{-3}	118.00	1700.0	347.31	392.50
SO_4^{2-}	mg·dm^{-3}	60.00	2100.0	393.93	490.89
HCO_3^-	mg·dm^{-3}	95.00	253.00	202.06	51.89
CO_3^{2-}	mg·dm^{-3}	0.00	0.00	0.00	0.00
SiO_2	mg·dm^{-3}	2.50	19.00	8.57	3.58

Explanation: DR = dry residue.
Source: own study.

The observation of the table of correlations, allows us to reveal that the majority of elements are positively correlated. Whereas, the ions of HCO_3^- and NO_3^- are negatively correlated with the other elements. It proves that the origin of the nitrate is from anthropogenic source. The low correlation between the HCO_3^- and the cations shows that the dissolution of silicate minerals is not the single process leading to the solution of these cations. The best positive correlations are found between the Ca^{2+} and SO_4^{2-} (0.81), Mg^{2+} and SO_4^{2-} (0.8), Na^+ and Cl^- (0.98), Na^+ and SO_4^{2-}. (0.96).

Table 4. Correlation matrix of chemical elements of water from the study area

Variables	NO_3^-	pH	Dry residue	Ca^{2+}	Mg^{2+}	Na^+	K^+	Cl^-	SO_4^{2-}	HCO_3^-	SiO_2
NO_3^- (mg·dm^{-3})	1										
pH	0.513	1									
Dry residue	−0.335	−0.262	1								
Ca^{2+}	−0.496	−0.235	0.774	1							
Mg^{2+}	−0.037	0.147	0.785	0.642	1						
Na^+	−0.323	−0.327	0.988	0.732	0.742	1					
K^+	−0.632	−0.486	0.578	0.706	0.317	0.596	1				
Cl^-	−0.295	−0.194	0.980	0.700	0.742	0.981	0.552	1			
SO_4^{2-}	−0.405	−0.285	0.985	0.809	0.800	0.962	0.631	0.941	1		
HCO_3^-	0.489	0.493	−0.530	−0.287	−0.268	−0.583	−0.517	−0.564	−0.537	1	
SiO_2	−0.203	−0.031	0.789	0.681	0.779	0.724	0.182	0.730	0.781	−0.120	1

Source: own study.

Correlations established between the concentrations of the main major elements (Cl^-, SO_4^{2-}, NO_3^-, HCO_3^-, Ca^{2+}, Mg^{2+}, Na^+ and K^+) and the conductivity of the water (Tab. 4) allows to go back to the origin of the water mineralization. The presence of a positive correlation between the major ions and the conductivity reflects the participation of these elements to the acquisition of the mineralization of groundwater.

Table 4 shows that there is a good correlation between the two elements Ca^{2+} and SO_4^{2-}. This correlation reflects the alignment points on almost the same line, indicating probably a common origin from anhydrite and gypsum [TRAVI 1993].

The couple Na–Cl illustrates that there is a great correlation between the two elements (Na^+ – Cl^-). This relationship indicates a common origin which is halite (NaCl). This type of minerals accumulates by evaporation and is present in groundwater by dissolution [NAGESWARA et al. 2015].

All analysed water provides concentrations of Na^+ superior to those of K^+. This result could be explained by the greater stability of feldspars and micas potassium as well as the absorption and the mobilization of the K^+ in the minerals formed during the alteration [MARECHAL 1976].

Principal component analysis (PCA)

The purpose of principal component analysis (PCA) highlights the different water points that have concentrations of chemical elements throughout the plain. This gives a preliminary idea of the elements and the pollution sites. The principal component analysis (PCA) was performed considering 12 variables (pH, temperature, salinity and major elements) for 16 samples according to Pearson correlation.

The study of the eigenvalue spectrum shows that there are two axes to be retained for the exploitation of the results. These axes represent 80.142% which is very significant (see Tab. 5). The F1 axis represents 61.90% and it is considered as axis of mineralization, since it presents strong correlations with the majority of the major elements, while axis 2 represents 18.25

The factor F1 determines the Ca^{2+}, Mg^{2+}, Cl^-, Na^+, HCO_3^-, SO_4^{2-} ions and SiO_2. However, factor F2 determines the pH and NO_3^- (Tab. 6).

The factorial design (F1–F2) alone represents 80.14% of the variances expressed; hence they offer the following information:

Table 5. Eigenvalues and percentages expressed by the main axes

Specification	F1	F2	F3	F4
Own value	6.809	2.007	0.798	0.543
Variability (%)	61.896	18.247	7.252	4.932
% accrued	**61.896**	**80.143**	87.395	92.328

Source: own study.

Table 6. Variables and main roads

Variable	F1	F2
NO_3^-	−0.48	**0.65**
pH	−0.34	**0.74**
Ca^{2+}	**0.84**	0.01
Mg^{2+}	**0.76**	0.52
Na^+	**0.96**	0.07
K^+	0.69	−0.49
Cl^-	**0.94**	0.15
SO_4^{2-}	**0.98**	0.09
HCO_3^-	−0.59	0.48
SiO_2	0.00	0.00
NO_3^-	**0.75**	0.46

Source: own study.

The dry residue that reflects the mineralization is well correlated with the factor 1 (Tab. 6), also the other major elements have a good correlation with the factor 1.

It reflects the natural mineralization of the water as well as the degree of weathering of the rocks. The horizontal F1 axis expresses 61.90% of the variance.

It opposes the highly mineralized waters rich in Cl^-, SO_4^{2-}, Na^+ and K^+ with high conductivity. This allows us to consider this factor as a factor of mineralization.

The F2 axis opposes nitrates and pH. Indeed, in this grouping, the association of these ions corresponds to the anthropic pole of the mineralization of the water.

It reflects here the importance of domestic and agricultural pollution. This shows certain originality, in this case of study. We can say that F2 is the factor of pollution. According to the interpretation of the graphical representation of the chemical elements, one can interpret the representation by individual.

Figure 7 shows two categories. The first category (A) groups the majority of the water points. These are the most mineralized waters. They represent the water points located in the cracked environment where water circulation is slow.

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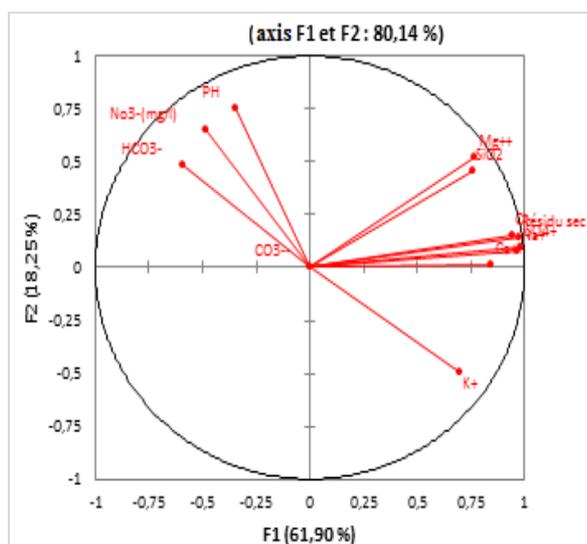
Fig. 6. Graphical representation in principal component analysis (PCA) waters; source: own study
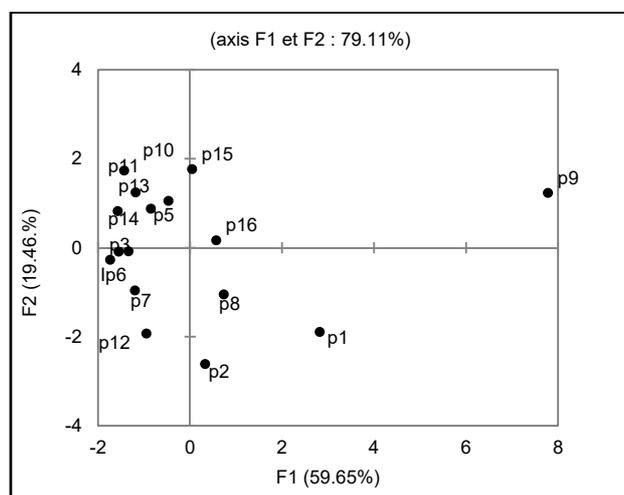
Fig. 7. Graphical representation of individuals; source: own study

The second category (B) tends towards the negative part of the axis F2. It is the intermediate waters between the most mineralized and the least mineralized, it also represents sodium chloride facies.

Suitability of water for drinking and irrigation use

The concentrations of the chemical elements in the water are directly involved in the quality and the potability of water. The WHO standards of water potability are related to the content of these elements. Table 6 reports the potability of water from the Turonian sheet. From the comparison of the concentrations of studied water with WHO standards, we note that drinking water sources are located in the points P2, P3, P4, P5, P6, P7, P11 and P12. In the other points, waters reported as unsafe because the concentrations of Na^+, Cl^-, and SO_4^- exceed standards which implies the necessity of further treatment before its consumption for drinking.

The most important factors to determine the required quality of the water in agriculture are: risk of salinity – risk of sodium – degree of adsorption of sodium or SAR. The salinity causes direct effects on plants and the risk of soil salinization. In fact, it disrupts the development of the plant by limiting the assimilation of nutrients. The salinity of the water is expressed in terms of electrical conductivity. Table 8 shows the classification of irrigation water in Turonian aquifer according to AYERS and WESTCOT [1976].

Most analysed samples are located in the class C4, indicating that the groundwater of the slick Turonian are satisfactory for most of the major crops, but salinity conditions will develop if the leaching and drainage are not adequate. The obtained values from the analysed samples are deferred on the diagram of riverside (Fig. 8) where we note that the total points of water are located in 3 classes:
– (C4, S2): the quality is extremely poor, the water is highly mineralized; it presents 12% of samples;
– (C3, S2) and (C3, S1): the quality is allowable; in this case the salinity must be controlled; this class contains 78% of samples.

Table 7. Potability of water from the Turonian sheet

Water point	Ca^{2+}	Mg^{2+}	Na^+	K^+	Cl^-	SO_4^{2-}	NO_3^-	Note
	mg·dm⁻³							
P1	187	69	420	6.0	650	660	998.10	no drinking
P2	76	22	150	3.0	200	260	0.07	drinking
P3	71	39	76	2.0	118	130	20.64	drinking
P4	53	58	140	2.0	200	180	37.38	drinking
P5	53	50	88	2.0	130	150	24.91	drinking
P6	80	17	115	2.0	178	60	26.93	drinking
P7	76	33	80	2.0	120	155	2.11	drinking
P8	204	78	130	3.0	210	600	0	no drinking
P9	636	164	1100	5.0	1700	2100	0	no drinking
P10	80	58	84	2.0	396	238	18.24	no drinking
P11	53	92	110	2.0	160	290	23.00	drinking
P12	89	14	105	2.0	160	90	0	drinking
P13	87	88	230	1.3	470	240	20.00	no drinking
P14	62	77	160	1.1	315	205	25.00	no drinking
P15	82	116	310	1.4	430	595	23.00	no drinking
P16	482	85	100	4.0	120	350	6.00	no drinking
WHO standards	**200**	**150**	**200**	**12**	**250**	**500**	**500**	**–**

Explanations: values exceeding WHO standards are underlined.
Source: own study.

Table 8. Classification of irrigation water in Turonian aquifer according to Ayers and Westcot

| Class	EC (μS·cm^{-1})	%
C1	<250	0
C2	250–750	0
C3	750–2250	81.20
C4	2250–5000	18.75

Source: own study.
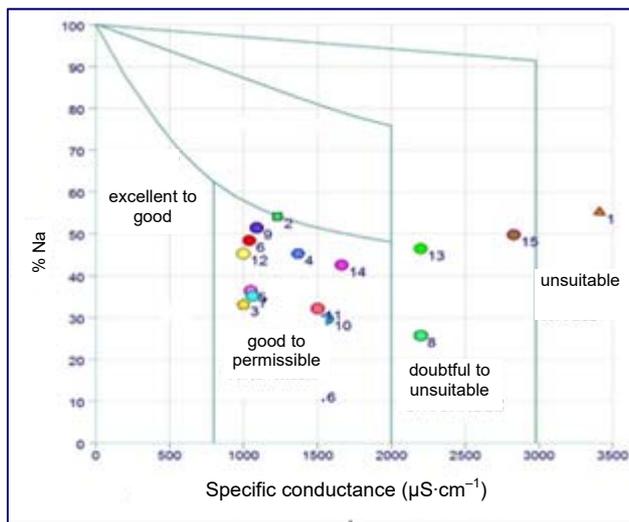
Fig. 8. Classification of irrigation water according to the diagram of riverside; source: own study

DISCUSSION

The results of the multivariate analysis in the level of Turonian water show that organic pollution constitutes an important phenomenon in the mineralization of water. The region being an agriculture area, the intakes in the mineralization are marked by the enrichment of water in nutrient salts. The vulnerability of the water to the pollution is the result of the intensification of agriculture, which exposes more groundwater. The examination of the results (Tab. 3) shows that 100% of samples exhibit an index of positive base exchange. This behaviour can be attributed to several phenomena such as to the trade of alkali of water against the alkaline-earth metals of permutolites and the anthropogenic input causing an excess of nitrate ions in the water.

The sub saturation in aragonite, gypsum and anhydrite of groundwater in the Turonian aquifer is in perfect agreement with the quasi absence of carbonate formations and evaporites in this region.

The principal components analysis has allowed characterize two phenomena whose a contribution of origin in space and a rapid mineralization and easy of the water.

The influence of geology and tectonics on the quality of the bad waters proved by the results of analysis (the case of the right source of the dam salinity exceeds the norms).

The origin of this salinity is due to the dissolution of the gypsiferous formation of the aquifer.

The spatial distribution of the water quality shows that the lowest values characterize the eastern and western part of the water table or the Max recharge is carried out.

The highest salinities characterize the waters in the centre of the basin where the discharge takes place.

From the spatial distribution of the different parameters studied, it emerges that at the level of the study area, the hydrochemical nature of the waters is determined essentially by the lithological nature of the formations of the recharge zones, by the distances travelled as well as by the lessening of the depth of the piezometric level.

The good quality offered by these waters on the East and West side is due by the recharge zone and by the hydrodynamic aspect of this aquifer. According to the physicochemical characteristics, these waters can be used for drinking and irrigation.

CONCLUSIONS

This study has examined the physicochemical parameters of the groundwater in order to analyse the water quality in Béchar region. The obtained results revealed that the groundwater is fresh to brackish and slightly hard to very hard. It is observed that 50% of water points are not acceptable as drinking sources. The most ions influencing the quality of water are Na^+, Ca^{2+}, Mg^{2+}, Cl^- and SO_4^{2-}. The source of the present ions with high concentrations is natural or originating from the sediments composition. However, anthropogenic source seems to be responsible for the nitrate concentration in the groundwater. According to these results, the groundwater of the study area offers an interesting potential for the drinking and irrigation water production. However, a specific management strategy should be adapted in order to avoid the contamination by anthropogenic sources.

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Ocena hydrochemiczna i zanieczyszczenie wód gruntowych w strefie klimatu suchego – przykład poziomu wodonośnego z turonu (późna kreda) w regionie Béchar w południowo-zachodniej Algierii

STRESZCZENIE

Oceniano przydatność wód gruntowych z wieku/piętra turonu w regionie Béchar do nawadniania i zaopatrzenia ludności w wodę pitną. W próbkach wody z 16 stanowisk oznaczano pH, przewodność elektrolityczną (*EC*), całkowitą twardość (*TH*), Na^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-} i NO_3^- Analiza wykazała, że wody gruntowe są słodkie do słonawych, alkaliczne, a głównymi jonami są: Na^+, Ca^{2+}, Mg^{2+}, Cl^- i SO_4^{2-}. Według norm WHO 50% analizowanych próbek spełnia wymogi stawiane wodzie przeznaczonej do picia. W pozostałych próbkach zbyt duże stężenie Na^+, Cl^- i SO_4^{2-} wskazuje na konieczność uzdatniania wody, aby osiągnęła ona wymagane standardy. Stężenie azotanów wskazuje na antropogeniczne źródło zanieczyszczenia tymi jonami. Badania dowodzą, że wody gruntowe Béchar mogą być źródłem wody do nawadniania i do celów spożywczych. Należy jednak przyjąć szczególną strategię gospodarowania wodą, aby uniknąć zanieczyszczenia ze źródeł antropogenicznych.

Słowa kluczowe: *hydrochemia, jakość wody, poziom wodonośny z turonu, region Béchar, wody gruntowe*