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Multivariate Statistical Analysis of Groundwater Quality of Hassi R’mel, Algeria

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ABSTRACT

The quality of Groundwater is characterized by physico-chemical parameters. They determine the way in which this water is used (water supply, irrigation, industry, etc.). This present study gives the highlighting of the hydrogeological and physico-chemical characteristics of aquifer waters in question resulting from the various wells, which aims to; gather, exploit and analyze the data, in order to determine their conformity with potability standards and their suitability for irrigation. Using multivariate statistical techniques including Principal Component Analysis (PCA), Hierarchical Cluster Analysis (ACH) and Diagram Analysis. They are applied to a dataset composed of 17 boreholes with 12 chemical variables over the entire study area, they were sampled in 2020. These boreholes are the principal water resources suppling Hassi R’mel w. Laghouat region in terms of drinking water and irrigation. Obtained results showed that the majority of groundwater in the Hassi R’mel region is hard; where approximately 20% of boreholes are characterized by fairly soft water, and approximately 5% are characterized by very hard water.

Keywords: groundwater, water quality, principal component analysis (PCA), ascending hierarchical classification (HAC), diagram analysis, Hassi R’mel region.

INTRODUCTION

The groundwater, is a resource that circulates in the depths of the earth representing about 97% of the total liquid continental fresh waters supposed to be far from pollution caused by human beings (industrial, agricultural and urban).

Desert regions such as Hassi R’mel have experienced rapid population growth in recent years, followed by significant human activities that covers almost all areas, and consequently; water requirements are increased.

This situation prompted the authorities concerned to look for other hydraulic potentials. Unfortunately, a shortage of drinking water has become a reality, especially in the summer period, caused by a continuous drop in the static level of the surface water table.

From hydrogeological vision, the groundwater reserve of Sahara aquifer system is non-renewable (fossil), so, the exploitation must be rational, the nature of the quality of this water comes from the formations crossed. It influences the variation in the levels of certain elements likely to be present in the water (Adimalla et al., 2018 and Reddy et al., 2010).

In order to qualify groundwater as good or harmful for human health, or its suitability or not for irrigation. There are usage standards which set the limit levels not to be exceeded for a certain number of substances such as (chloride, magnesium, calcium, sodium, bicarbonate, sulphates, nitrate) and certain parameters such as pH, electrical conductivity, salinity and turbidity (Steli et al., 2019 and Sinduja et al., 2023).

This study constitutes a contribution to the highlighting of the hydrogeological and physico-chemical characteristics of aquifer waters in question resulting from the various wells, and which aims to; gather, exploit and analyze the data, in order to determine their conformity with drinking water standards.

MATERIALS AND METHODS

Study area presentation

The Hassi R'mel region is situated in sahara north, 550 km south of Algers and 120 km south of w. Laghouat (Figure 1), between the meridians 2°55` and 3° 50` East, and the parallels 33°15` and 33°45` North, an average altitude of 750 m above sea level, with an area of 3500 km², and a perimeter of 380 km (Baouche et al., 2012).

Region geology and hydrogeology

Hassi R'mel region, with an anticlinal structure-oriented North-South, It is situated at the western end of the Triassic province (Aït Ouali et al., 1995, 1996). This anticline is grafted on a Paleozoic relief eroded until the Ordovician and the Cambrian. It is located at the intersection of two main axes. One is the prolongation northern of the Hoggar-Idjerane M'Zab ridge with a slight curvature to the west (Figure 2). The other, in an east-west direction, including the high zones of Tilrhemt and Djemaa, is probably the buried extension of the Anti-Atlas reliefs (Hamel et al., 1988).

Hassi R'mel dips structure gently towards the North towards the saharan flexure and extends towards the South-West by the small anticlinal structure of Djebel Bissa and towards the South by that of Hassi R'mel Sud. It is limited

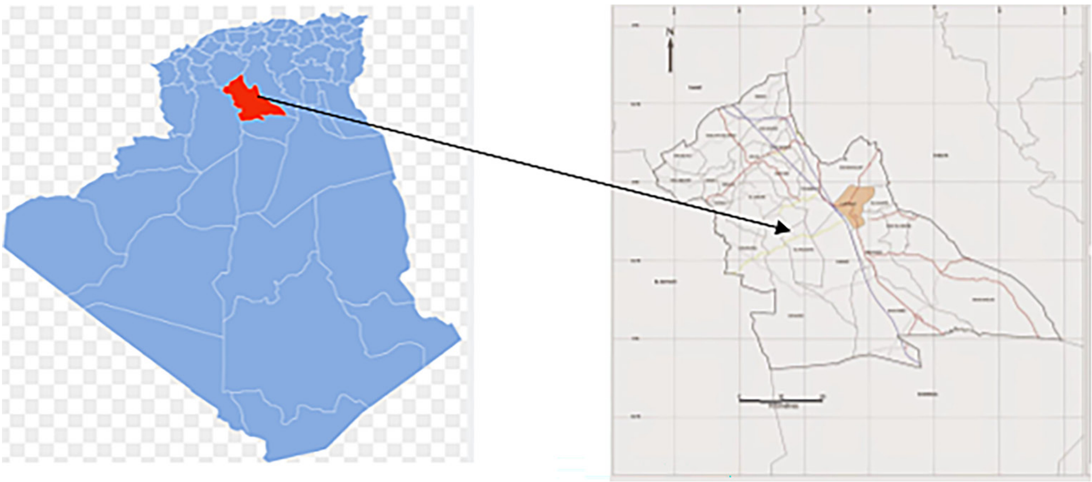

Figure 1. Geographic location of the study area

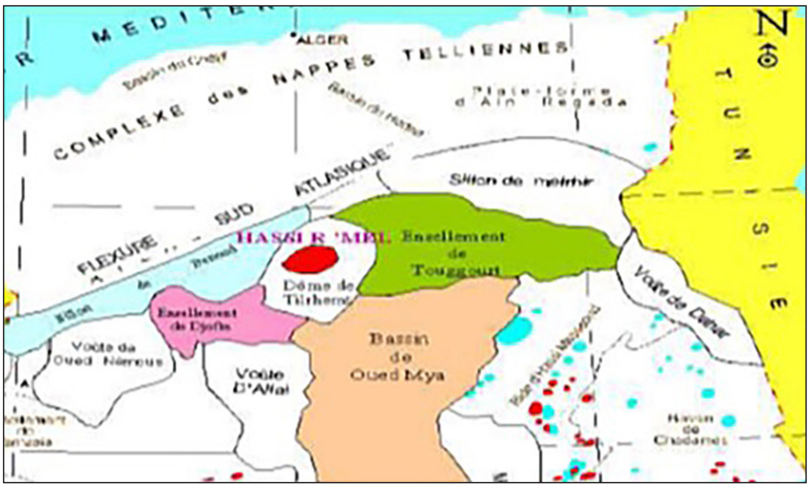

Figure 2. Soil map of the Hassi R'mel (Sonatrach 1972)

Table 1. Physico-chemical data of borehole water in the Hassi R'mel region (2020)

Name	pH	Hardness	CE	T	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-
HRH126	7.8	0.30	1103.43	19.4	104	49	4.00	67	284.00	85.00	280	4.5
HRH127	7.2	0.30	1103.43	20.6	126	47	4.00	46	342.00	62.00	210	43
HRH138	8	0.30	851.16	19.6	86.73	32.97	3.31	48.23	292.80	53.61	128	43
HRH139	7.2	0.30	1103.43	19.3	126	47	4.00	46	342.00	62.00	210	43
HRH145	7.2	0.30	1244.49	19.4	100	11	4.00	170	342.00	74.00	244	40
HRH151	7.1	0.30	981.12	20.6	107.04	35	5.72	54.9	323.30	63.47	155	1.6
HRH105	7.9	0.30	769.78	19.6	78.076	23.25	5.19	55.91	207.40	76.59	137.5	1.5
HRH106	7.7	0.30	1029.69	19.9	114.428	38.912	5.82	56.56	248.27	132.08	185	1.4
HRH107	8.3	0.30	697.79	19.8	67.495	26.655	4.89	35	262.91	56.73	75	1.6
HRH114	7.3	0.40	1308.76	21	108.817	40.493	6.81	141.2	186.66	143.78	365	6.8
HRH132	7.3	0.40	1694.23	20.8	174.548	59.827	8.70	113.6	382.17	211.32	335	1.4
HRH137	7.4	0.30	761.35	20.7	70.34	25.171	5.67	43.04	217.16	56.73	120	3.9
HRH147	7.1	0.40	1448.99	19	135.486	42.464	8.14	119.7	283.04	294.29	200	3.4
HRH122	7.3	0.40	1264.29	19.2	121.442	43.776	6.22	103.7	271.45	132.43	280	3.3
HRH123	8	0.40	1298.54	21	125	44	7.00	109	281.00	137.00	282	3.5
HRH142	7.3	0.40	1175.72	20.8	113.627	39.034	6.57	91.77	276.03	99.81	265	0.9
HRH148	7.3	0.30	1054.49	20.7	101.002	35.507	6.13	78.71	272.37	86.16	220	1.8

Note: data in (mg/L) except (TH, EC, pH and T).

to the south by the Oued Mya depression and to the east by the Djemaa Touggourt area (Hamel et al., 1988).

Measurements and samples

Samples of 17 boreholes were done by the laboratory of Sonatrach of Boumerdes in 2020. In order obtain groundwater physico-chemical characteristics, which are given in Table 1.

The study is interested by three parameters: temperature, pH, and conductivity. The measurements are realized in situ. Water analyzes determine the contents of the major elements (SO_4^{2-}, HCO_3^-, NO_3^-, Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-).

Before starting the study of the chemical parameters and validating our analyses, it was deemed necessary to determine the quality of the analyzes by calculating the ionic balance (IB %) which makes it possible to determine the percentage of error.

The ionic balance is the ratio of the difference between the major cations and the major anions contents to the sum of the same contents (Semar et al., 2013). It is calculated as follows:

$$IB = \frac{\sum Cations - \sum Anions}{\sum Cations + \sum Anions} \times 100 \quad (1)$$

The unit of contents of cations and anions is meq/L:

- -2% < IB < 2%: Excellent reliability of analysis results,
- -5% < IB < 5%: Reliability of analysis results acceptable,
- -10% < IB <10%: Poor but usable reliability of analysis results,
- IB < -10% or IB > 10%: Poor reliability of analysis results.

Table 2. Ionic balance (IB%) results

Boreholes	BI (%)
HRH126	-2.76
HRH127	1.95
HRH138	1.01
HRH139	1.95
HRH145	1.94
HRH151	1.73
HRH105	-0.64
HRH106	-0.84
HRH107	-2.2
HRH114	1.1
HRH132	-1.35
HRH137	0.73
HRH147	-4.76
HRH122	0.85
HRH123	1.22
HRH142	0.44
HRH148	0

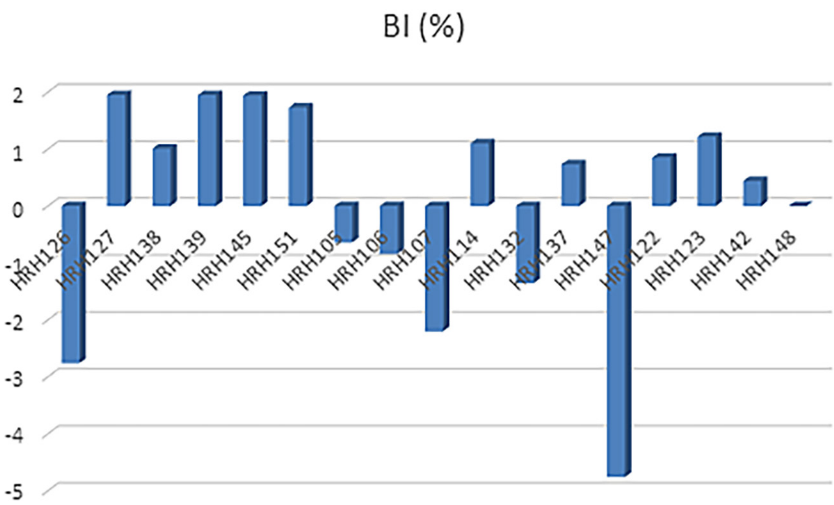

Figure 3. Presentation of the ionic balances of drillings in the Sahel watershed

Table 2 and Figure 3 gives the presentation of the BI results. Ionic balance index of all boreholes does not exceed 10%, so the results of the water samples analyzes to be studied are acceptable.

Different techniques: principal component analysis (PCA), hierarchical cluster analysis (ACH) and diagram (Piper and Schoeller-Berkaloff) are carried out using XLSTAT and software diagram. They are widely employed to present the geographical distribution of groundwater quality parameters and hydro-chemical characterization (Seikhy Narany et al., 2014).

The physico-chemical analyzes of our study were compared to Algerian standards and the World Health Organization standards (WHO). which are given in the Table 3 (Bengherbia et al., 2014).

Table 3. Water classification standards according to Algerian and World Health Organization (WHO) (World Health Organization, 2006; Official Journal of the Algerian Republic, 2011).

Parameters	Algerian standards	WHO standards
pH	6.5-9	6.5-9.5
Conductivity (µS⁄cm)	2800	no guide value
Temperature (°C)	25	no guide value
SO_4^{2-} (mg/L)	400	500
HCO_3^-	no guide value	no guide value
NO_3^- (mg/L)	50	50
Ca^{2+} (mg/l en $CaC0_3$)	200	30
Mg^{2+} (mg/L)	no guide value	100
Na^+ (mg/L)	200	no guide value
K^+ (mg/L)	12	12
Cl^- (mg/L)	500	250
Dissolved oxygen (mg /L)	no guide value	no guide value
Salinity (psu)	no guide value	no guide value
Turbidity (NTU)	5	5
Copper (mg /L)	2	2
Lead (mg /L)	0.01	0.01
Cadmium (mg /L)	0.003	0.003
Total coliforms	10 00	no guide value
Faecal coliforms	00 00	no guide value
Faecal streptococci	00 00	no guide value
Clostridium sulphite-reducer	00 00	no guide value
Salmonella	Absence / Presence	Absence / Presence

RESULT AND DISCUSSION

Multivariate statistical analysis

Principal component analysis

Principal Component Analysis (PCA) goal is to exploit and to describe the data, it's applied to identify the pricipal parameters of groundwater (Anazawa et al., 2005; Dagnélie., 2006; Ruiz-Pico et al., 2019; Christofi et al., 2020 and Chen et al., 2022) and in Algeria (Belkhiri et al., 2010; Rouabhia et al., 2011; Khechana et al., 2014; Tiri et al., 2014; Bencer et al., 2016; Rahal et al., 2021; Djafer Khodja et al., 2022 and Ferhati et al., 2022, 2023). This kind of analysis is considered very helpful and used largely in hydrogeochemical studies (Duffy et al., 2001; Khedidja et al., 2014 and Wu et al., 2018). This study discusses the strength of multivariate analysis used to determine the characteristics of water quality in the region.

In our study, Principal Component Analysis, is realized on a data set of 17 boreholes, basing on 12 elements (hardness, pH, conductivity, T, Cl^-, SO_4^{2-}, HCO_3^-, NO_3^-, Ca^{2+}, Mg^{2+}, Na^+, K^+) (Table 1).

Correlation matrixes calculating by PCA are given in Tables 4 and 5, which represents the variability of water quality. Conductivity shows strong positive correlations with Ca^{2+}, Mg^{2+}, K^+, Na^+, Cl^- and SO_4^{2-}: 0.90, 0.60, 0.64, 0.74, 0.76 and 0.83 respectively, which shows the salinity of the groundwater of the region. Mg^{2+} also shows strong positive correlations with Cl^- and NO_3^-: 0.81 and 0.63, respectively. Turbidity further shows strong positive correlations with conductivity, Ca^{2+}, K^+, Na^+, Cl^- and SO_4^{2-}: 0.74, 0.59, 0.79, 0.61, 0.73 and 0.68, respectively. Ca^{2+} indicates a medium positive correlation with pH, hardness: 0.497, 0.596 respectively, and strong correlation with EC: 0.907. K^+ shows strong positive correlations with hardness, EC and $Ca^{2+:}$ 0.79, 0.645, and 0.565 respectively. Na^+ shows strong positive correlations with hardness, EC: 0.619, 0.74 respectively. HCO_3^- shows strong positive correlations with Ca^{2+}: 0.604. Cl^- indicates a medium positive correlation with pH, hardness, EC, K^+ and Na^+: 0.737, 0.764, 0.669, 0.815, and 0.544, respectively. SO_4^{2-} indicates a medium positive correlation with pH, hardness, EC, K^+ and Na^+: 0.680, 0.834, 0.682, 0.556, and 0.712, respectively.

The factors obtained from the use of the PCA technique show that there are six factors explaining more than 70% of parameters total variance (Khelif et al., 2018).

The factor F1 and F2 represents about 66.35% of the total parameters variance; They gives best correlation with conductivity, turbidity, Ca^{2+}, K^+, Cl^- and SO_4^{2-}, which is owing to the reactions of mineral waters. Table 4 and the Figure 4 give more explanations.

Figure 4 projection analysis for boreholes in the F1 factorial plane accounts for about 47.88% of the variance, it correlates well with relatively high loads such as EC, Ca^{2+}, Mg^{2+}, Na^+, K^+, SO_4^{2-}. It is probably, due to reactions of mineral water in the region, therefore, factor F1 can be named as salinization factor.

The F2 factor represents more than 18.47% of the variance, indeed, this factor better indicate the bicarbonates parameter, on the contrary, an inverse correlation is observed with the parameters ($NO_3^{-,}$ HCO_3^-) and (temperature T, pH).

Table 4. Correlation matrix of the physico-chemical parameters of the waters in the Hassi R'Mel region (Pearson)

Variables	pH	Hardness	CE	T	Ca^{2+}	Mg^{2+}	K^+	Na^+	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-
pH	1											
Hardness	-0.226	1										
CE	-0.512	0.745	1									
T	-0.097	0.233	0.114	1								
Ca^{2+}	-0.497	0.596	0.907	0.124	1							
Mg^{2+}	-0.194	0.476	0.603	0.185	0.785	1						
K^+	-0.277	0.79	0.645	0.376	0.565	0.409	1					
Na^+	-0.384	0.619	0.74	0.034	0.416	-0.032	0.451	1				
HCO_3^-	-0.343	-0.046	0.444	-0.09	0.604	0.347	-0.08	0.091	1			
Cl^-	-0.283	0.737	0.764	-0.083	0.669	0.462	0.815	0.544	0.054	1		
SO_4^{2-}	-0.388	0.68	0.834	0.283	0.682	0.556	0.452	0.712	0.153	0.456	1	
NO_3^-	-0.145	-0.387	-0.069	-0.279	0.006	-0.127	-0.685	-0.049	0.474	-0.384	-0.108	1

Table 5. Correlations between variables and factors.

Parameter	F1	F2	F3	F4	F5
pH	-0.497	-0.383	-0.173	-0.307	0.601
hardness	0.848	-0.306	0.091	-0.03	0.17
CE	0.964	0.218	0.098	-0.014	0.066
T	0.237	-0.319	-0.453	0.759	-0.027
Ca^{2+}	0.88	0.362	-0.238	-0.113	-0.025
Mg^{2+}	0.651	0.172	-0.635	-0.2	0.185
K^{+}	0.799	-0.498	-0.079	-0.062	-0.26
Na^{+}	0.677	0.008	0.668	0.21	0.14
HCO_3^-	0.28	0.814	-0.212	-0.059	-0.123
Cl^-	0.819	-0.201	0.145	-0.429	-0.139
SO_4^{2-}	0.82	0.08	0.085	0.297	0.377
NO_3^-	-0.277	0.841	0.168	0.117	0.176

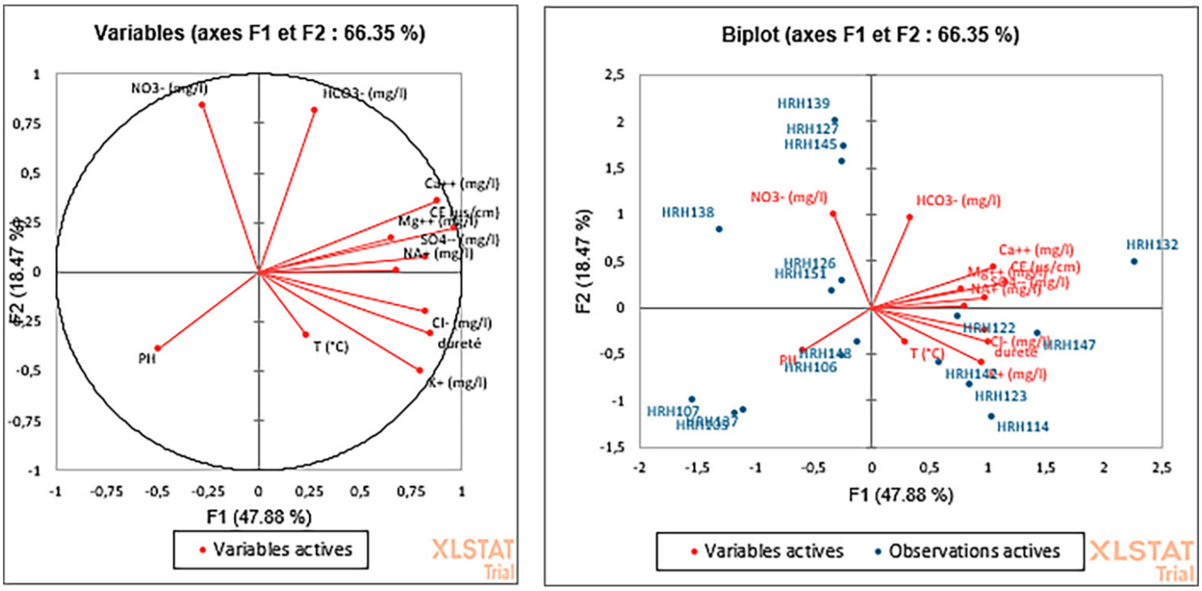

Figure 4. Diagram of individuals (Correlations between variables and factors)

The principal component analysis of 17 boreholes in the F1-F2 gives two groups shown in Figure 4 (actives observations).

1. Characterized by strong mineralization from boreholes which are: HRH114, HRH122, HRH123, HRH142, HRH132, HRH147.
2. The least mineralized water boreholes are: HRH126, HRH127, HRH138, HRH145, HRH151, HRH147, HRH106, HRH107, HRH148, HRH139.

Hierarchical cluster analysis

Hierarchical Ascending Classification (HAC) analysis objective is to obtain a collection of clusters of observations (Ferhati et al., 2022).

The classification of 12 hydro-chemical parameters conductivity, pH, T, NO_3^-, Cl^-, SO_4^{2-}, Mg^{2+}, Na^+, Ca^{2+}, K^+, turbidity and HCO_3^- in function of boreholes is done for statistical purposes. It gives two families.

The basic criterion of choosing the classes of the dendrogram is the visual investigation (Figure 5a et 5b). The grouping is recognized by their hydrochemical factors. Figures 5a and 5b give the classification of 12 factors into two groups:

- C1: T, pH, HCO_3^-. NO_3^-.
- C2: hardness, conductivity, K^+, Cl^-, Na^+, SO_4^{2-}, Mg^{2+}, Ca^{2+}.

This is what we have seen in the principal component analysis. Group 1 corresponds to factor F2 and group 2 corresponds to factor F1.

After summarizing the hydrochemical parameters in two clusters, we come to applying

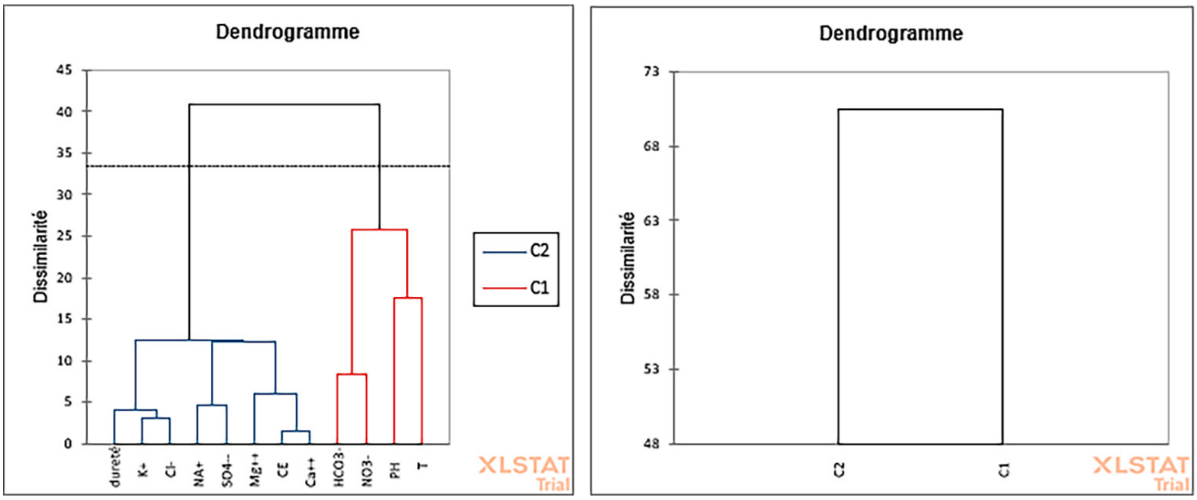

Figure 5. Cluster dendrogram for variables (a, b)

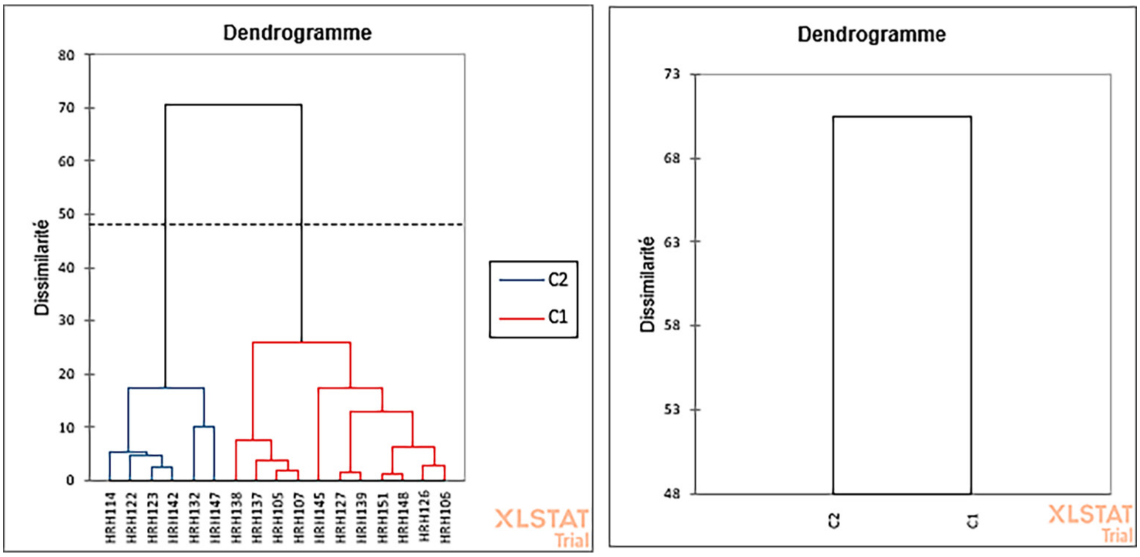

Figure 6. Cluster dendrogram (a, b)

the same technique with the boreholes. Results of analysis are shown in Figures 6a and 6b.

The investigations of the result summarize the existing of two kinds of boreholes, where in the same group of boreholes, the chemical characteristics are close (Figure 6a and Figure 6b). The two groups are the following:

- C1: HRH114, HRH122, HRH123, HRH132, HRH142, HRH147.
- C2: HRH105, HRH106, HRH107, HRH126, HRH127, HRH137, HRH138, HRH139, HRH148, HRH151.

This is what we saw in the principal component analysis in Figure 4 (active observation).

Diagram

Piper diagram

Piper diagram represent the chemical elements of water of several boreholes. It gives the combination between major cations and the major anions in a triangular diagram of the groundwater. The position of the combination of different elements indicates the relative composition of groundwater (Thilagavathi et al., 2012; Blake et al., 2016 and Barkat et al., 2021).

Results representation of water chemical analysis sampled from 17 boreholes on the Piper diagram is shown in Figure 7, they indicate two chemical facies:

1. Chloride, sulphate, calcium and magnesium.
2. Calcium and magnesium bicarbonate.

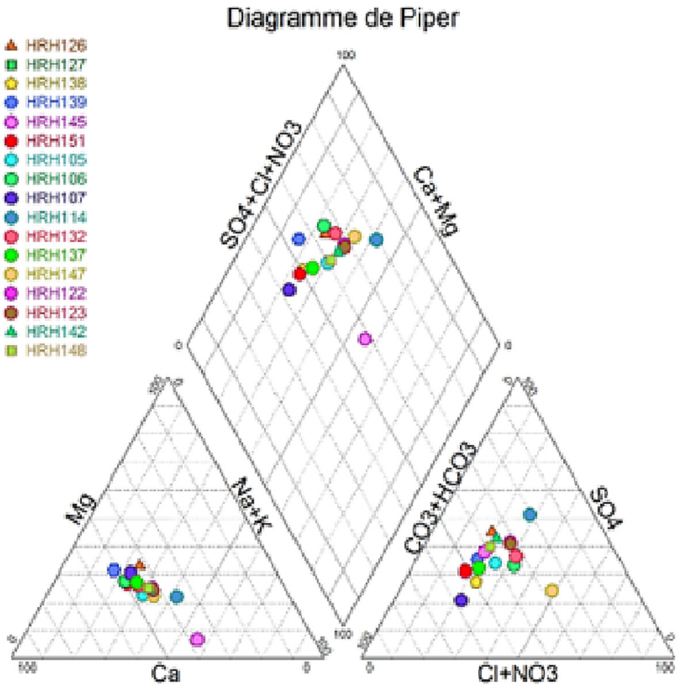

Figure 7. Classification of drillings in the Sahel watershed on the piper diagram (F1-F17)

It’s clear that that calcium and magnesium are the major cations, and bicarbonates and chlorides are the major anions for all boreholes.

Chloride, sulphate, calcium and magnesium represent 82.35% of the analyzed water (HRH105, HRH106, HRH126, HRH127, HRH138, HRH139, HRH145, HRH147, HRH148, HRH151). It generally represents the most mineralized waters.

The bicarbonate, calcium and magnesium facies represent 17.65% of the analyzed waters (HRH114, HRH122, HRH123, HRH132, HRH142, HRH147), it is the least dominant facies. It is the least dominant facies. It generally represents weakly mineralized waters because of the infiltrations from rocks.

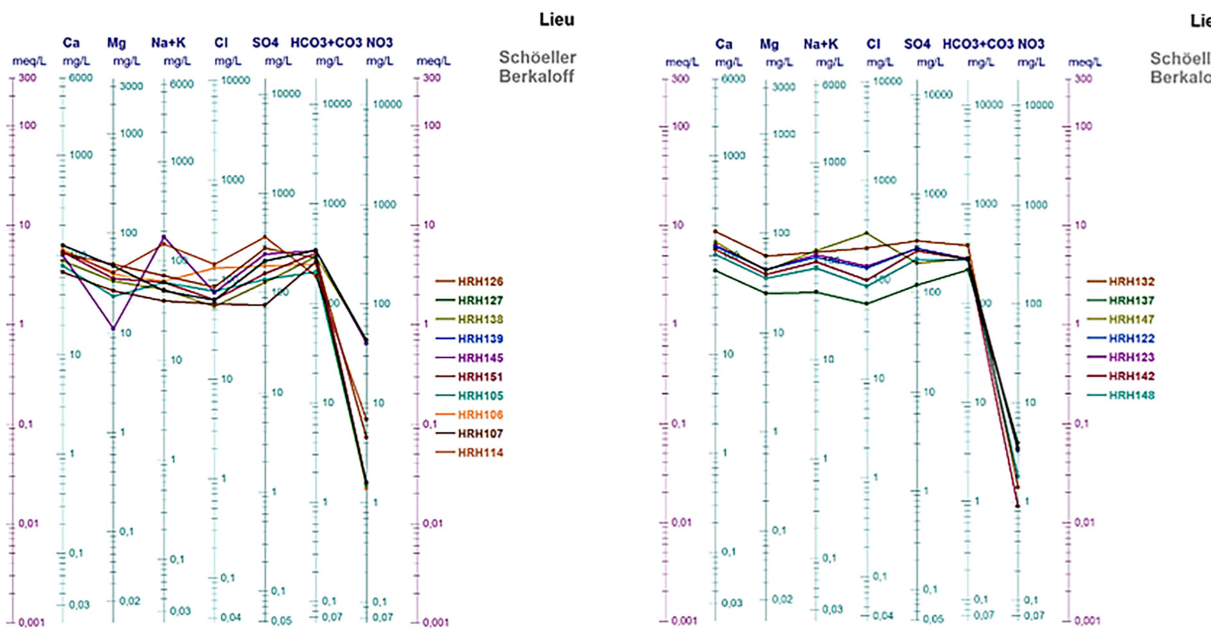

Figure 8. Classification of drillings in the Sahel watershed on on the Schoeller-Berkaloff diagram (F1-F10) and (F11-F17)

Schoeller-Berkaloff diagram

The Schoeller-Berkaloff diagram allows the representation of several analyzes on the same graph of the different ions in mg/L. If concentrations are identical, we find a superposition of the straight lines obtained and in the opposite case, we notice a relative offset of the latter (Djafer Khodja et al., 2022).

The characterization of 17 boreholes waters using the Schoeller-Berkaloff diagram (Figure 8) gives two facies:

1. Chloride, sulphate, calcium and magnesium.
2. Bicarbonate, calcium and magnesium.

CONCLUSION

This article aims to investigate the hydrochemical water quality mechanism of the region of Hassi R'mel using multivariate statistical analysis techniques and diagram analysis.

The study of water quality using different analysis techniques of the region has shown the existence of two chemical families.

Multivariate statistical analysis has given very satisfactory result; 66.35% of the data used, so, it can be said that these techniques are very promoteurs for the understood of water quality, and to determine the chemical characteristics of water, which are used effectively in the durable gestion of waters.

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