Hydrochemical analysis of groundwater quality in central Hodna Basin, Algeria: a case study

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Hydrochemical analysis of groundwater quality in central Hodna Basin, Algeria: a case study

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Abstract: This paper aims to identify the mineralisation origin and distinguish between the different classes of groundwater quality in several regions of the semiarid basin of Hodna in central Algeria. Many multivariate statistical techniques are applied to a dataset composed of 64 georeferenced individuals with 19 chemical variables. The obtained results from this principal component analysis show that the first five factors explain more than 78% of the groundwater quality variance. Other methods such as CA cluster analysis, CAH hierarchical cluster analysis and geochemical analysis using the Piper diagram are more appropriate to contemplate nodule-facies development and to distinguish clusters. The endorheic characteristic of the study basin consequents the basin centre named Chott El Hodna to be a sanility source. Bit by bit, salinity raises from North to South, from unsalted water to strongly salted water close to the Chott. The outcomes demonstrate that this groundwater is portrayed, the facies definite assessment outlines that the Chloride, Calcium and Magnesium Sulfate facies indicate 84% of cases, trailed by Sodium sulfate facies with 14% and the rest (2%) is identified by the Bicarbonate facies.

Keywords: GIS; groundwater quality; Hodna; hydrogeochemistry; multivariate statistical analysis; piper hydrochemical facies; principal component analysis; PCA; Algeria.

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1 Introduction

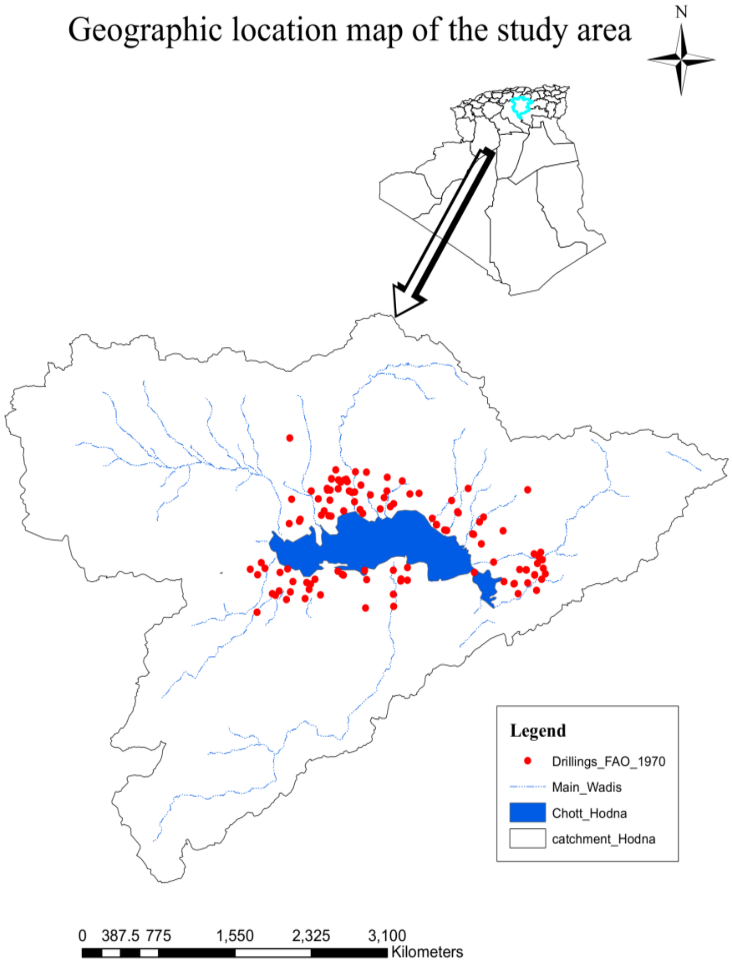
Groundwater is the main source of human consumption of water, especially in arid and semiarid regions suffering from surface water scarcity. The assessment of water quality has become also a vital part of water resource studies; it is unavoidable for such preservation and integrated management of groundwater resource. It is in continuous degradation because of extraordinary urbanisation, industrialisation and agrarian exercises with the excessive use of fertilisers (Khelif and Boudoukha, 2018). In this context, several studies have been conducted on groundwater to assess the water chemistry and its spatial distribution over an extended area, based on field observations using multivariate statistical techniques. These multivariate statistical methods have been widely used to examine hydrological factors such as aquifer boundaries, groundwater flow paths and hydrochemical parameters around the world. The hierarchical clustering analysis (HCA) method and principal component analysis (PCA) as multivariate statistical tools have been extensively used to formulate geochemical models based on the available data. In this context, many studies are conducted in Algeria (Belkhiri et al., 2010, 2011; Bencer et al., 2016; Dougha and Hasbaia, 2019; Gaagai et al., 2017; Ghodbane et al., 2016; Khedidja and Boudoukha, 2019); that summarised the most important and fundamental objective of this study which is highlighting the mechanisms that command the groundwater quality. The purpose of the work presented here in this paper is to identify the mineralisation origin and distinguish between the different classes of groundwater quality in the Hodna semiarid basin, the fifth biggest basin in Algeria. Comparing with previous studies, this paper is exceptional to analyse big dataset by many techniques methods in this Algerian basin.

Sixty four drilligs were chosen to achieve the analysis of 3 samples from each one of them. The analysis of 19 physicochemical parameters was implemented for each sample, to obtain the 64 average values of these 19 parameters.

1.1 Study area

The Hodna watershed is the fifth largest basin in Algeria (Figure 1), it is located 150 km by bird flight south of the Mediterranean coast Bejaïa Golf, the situation of the Hodna basin between two series of mountains in the north and south organises the basin around a closed Chott (Hasbaia et al., 2012). This plain with a normal elevation of 450 m is situated between latitudes 35°30' N, and 35°50' N and longitudes 04°20' E and 04°50' E. The area is portrayed by a dry to semi-dry climate, with yearly normal precipitation of 215 mm and a yearly normal temperature of 19°C.

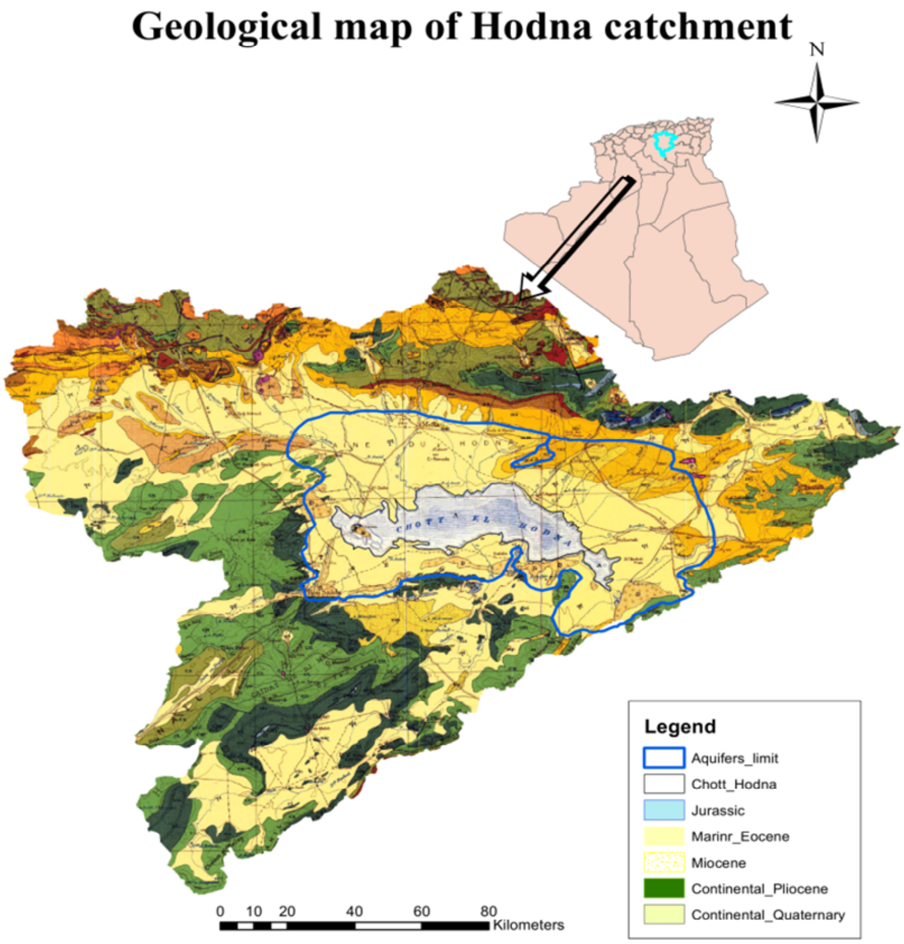
Figure 1 Geographic location of the study area (see online version for colours)



Note: Red points refer to drillings; blue straights refer to main wadis in the Hodna basin

The Hodna basin has various geological components and structures Tallien and Saharian, is shown in Figure 1, characterised by a flat relief. The geological formations found in the region are primarily Mesozoic, Triassic and the Jurassic occupy only of reduced surfaces; generally, Trias appears in Diapirs, whereas the cretaceous forms the majority of the outcrops in relief. The quaternary recovers all the Hodna plain (Dougha and Hasbaia, 2019). The presence of carbonated and cracked sandstone reliefs on the northern and southern limits may establish a forced imposed flow. This breaking is the consequence of the stun between Atlasics and the Tellian chains (Belhadj et al., 2017a, 2017b). The lithological arrangement are finished and spread out from Triassic to Quaternary. The MioPlio-Quaternary formations are based on a syncline structure showing lateral variation of forces (Kieken, 1970). The region is characterised by structural complexity resulting from the installation of the Triassic slides; this exotic Triassic is shaped by clays and maren with limestone-dolomitic ice which exist in the North East and North West. The study region lithology is reconstructed from many geological cuts and geophysics surveys conducted by Food and Agriculture Organization of the United Nations FAO during the period 1968-1970. The Quaternary arrangements surmount other layers of Miocene marine and Pliocene. The Pliocene layers are reached for drilling exceeding 200 m (Kieken, 1970) more geological details in Dougha and Hasbaia (2019) and Kieken (1970).

Figure 2 Geological map of the study area, where blue straight represents the aquifer limit with the Hodna Chott in the centre (ANRH) (see online version for colours)



2 Materials and methods

2.1 Sample collection and analysis

To estimate the physicochemical parameters, the American Public Health Association (APHA) standard strategies were utilised. The majority of the parameters analyses are conducted out in the Algerian drinking water services laboratory, the others are realised in the technology faculty laboratory of M'sila University (Algeria). Nineteen parameters were measured as follows: Temperature T, pH, Electrical Conductivity EC (in situ using a portable multiparameter), nitrate NO_3- and sulfate $SO_4{}^2$- (spectrophotometric method), iron Fe^{2+}, magnesium Mg^{2+}, calcium Ca^{2+}, chloride Cl^- ,alkalinity HCO_3- and total hardness *TH* (titrimetric method), turbidity (turbidmeter), sodium Na^+ and potassium K^+ (flame photo method), salinity which is the salt amount in grams dissolved per water litre and total dissolved solids *TDS* (*gravimetric method*), ammonium $NH_4{}^+$, nitrite NO_2- and full alkalimetric title *FAT* (*atomic absorption method*) (Ebadati and Hosseini, 2018). Sixty four drillings were considered during the period from January to July 2018 as shown in Figure 1,the whole samples have been collected from the Mio-Plio-Quaternary aquifers as appeared in Figure 2, they were gathered subsequent to pumping for 15 min to ensure a stable temperature of the groundwater.

Electrical conductivity and *pH* were measured in the field immediately after sampling however the remaining parameters were determined in laboratory within 24 h.

2.2 Multivariate statistical analysis

2.2.1 The PCA

The PCA is a descriptive method whose goal is to exhibit graphically the most extreme measure of data contained in a database, where, in lines on which are estimated quantitative factors masterminded in segments, the elucidation of the charts will make the structure of the examined information reasonable (Merzougui et al., 2019). PCA supplies the details of most indicative parameters, which depicts the entire informational collection by reducing the data that has no influence on the whole data presentation (Gulgundi and Shetty, 2018). Although, PCA is an exploratory and illustrative method, the point of the treatment is to recognise the principle factors that control the science of the groundwater quality (Ogunbode and Akinola, 2019).

2.2.2 The cluster analysis

Cluster analysis (CA) is one of the multivariate techniques, which gathers the entity dependent on their qualities. It masterminds the objects, such that each entity is same as the others in the bunch as indicated by a predefined choice measure. The bunches of items gained should then show high inner within the cluster, similarity and high outside between groups and decent variety. Hierarchical agglomerative clustering is usually the most utilised methodology (Gulgundi and Shetty, 2018), these multivariate factual examined tests were utilised effectively to study the hydrogeochemical forms. Thus this work manages the power of multivariate techniques to portray hydrochemical varieties in the zone (Bencer et al., 2016). Two strategies can be utilised to recognise clusters, including R- or Q-modes. R-mode is generally utilised to water quality factors to uncover the correlation between them, while Q-mode uncovers the correlation between the test samples (Ghodbane et al., 2016).

2.2.3 Hierarchical cluster analysis

Hierarchical cluster analysis (HCA) is the most generally utilised and refined multivariate statistical techniques for interpretation hydrochemical and geochemical datasets, complex structures inside the compound datasets could be disclosed by lessening them to couple of noteworthy factors without losing any data (Jampani et al., 2018; Zhang et al., 2019), the hierarchical cluster analysis permits the utilisation of a mathematical depiction of the closeness to aggregate various measures into a similar sample or between the various samples (Tiri et al., 2017). An arrangement plan utilising Euclidean separation (straight line separation between two points in c-dimensional space characterised by c factors) for likeness estimation, together with Ward's technique for linkage, creates the most unmistakable gatherings where every part inside the gathering is more like its kindred individuals than to any part outside the gathering (Wu et al., 2016), groupings of samples as per their parameters are known as Q-mode orders. In the present work, Q-mode HCA was utilised to characterise the samples into particular hydrochemical gatherings. The Ward's linkage technique was used in this analysis (Belkhiri et al., 2011).

2.2.4 Geochemical analysis method

So as to study water chemistry and water facies, known hydro geochemical systems were applied (Merzougui et al., 2019), the Piper chart is appropriate for highlighting the development of facies (Sekiou and Kellil, 2014). It is made out of two triangles, allowing the representation of the cationic and anionic facies, and on a quadrilateral. The point cloud chart of the study area drillings speak for the different examples of the mixture of cationic and anionic components (Boualla et al., 2017).

3 Results and discussion

3.1 Physical and chemical characteristics of groundwater

The examination of the physical and chemical parameters of all the drillings show that the mean temperature of water ranges from 10°C to 20°C. The water has a low alkalinity with a *pH* varied from 6.53 to 7.50; which means the water is on average for standards of potability. The electrical conductivity EC values extend from 774 to 8,970 µS/cm, which follows the average standards of World Health Organization (WHO) between 180 and 1,000 µS/cm for just some drillings, although speaking of other drillings, the water is not suitable.

Table 1 Matrix correlation (Pearson) of major parameters

Variables	*TDS*	*EC*	*Na^+*	*SO_4^{2-}*	*Mg^{2+}*	*Cl^-*	*HCO_3^-*	*TH*	*Ca^{2+}*	*T*	*pH*	*Turb*	*K^+*	*NO_3^-*	*Sali*	*FAT*
TDS (mg/l)	1															
EC (µs/cm)	1.00	1														
Na^+ (mg/l)	–0.01	–0.01	1													
SO_4^{2-} (mg/l)	0.42	0.42	–0.16	1												
Mg^{2+} (mg/l)	0.71	0.71	–0.01	0.42	1											
Cl^- (mg/l)	0.14	0.13	–0.12	0.10	–0.31	1										
HCO_3^- (mg/l)	0.29	0.29	0.10	0.13	0.39	–0.26	1									
TH (°F)	0.80	0.80	–0.03	0.47	0.94	–0.17	0.30	1								
Ca^{2+} (mg/l)	0.77	0.77	–0.05	0.45	0.70	0.01	0.15	0.91	1							
T (°C)	0.20	0.20	–0.10	0.02	–0.14	0.03	–0.06	–0.17	–0.18	1						
pH	–0.14	–0.13	0.01	–0.16	–0.31	0.01	–0.06	–0.37	–0.38	0.43	1					
Turbidity (NTU)	0.72	0.72	–0.12	0.20	0.30	0.18	0.15	0.36	0.37	0.43	0.12	1				
K^+ (mg/l)	0.19	0.19	0.05	–0.10	0.18	–0.02	0.02	0.15	0.10	0.09	0.11	0.18	1			
NO_3^- (mg/l)	0.07	0.07	0.05	0.09	–0.01	0.17	0.06	–0.01	–0.01	0.02	–0.01	–0.19	0.05	1		
Salinity (mg/l)	0.99	0.99	0.01	0.43	0.76	0.12	0.31	0.86	0.83	0.05	–0.22	0.65	0.19	0.08	1	
FAT (°F)	0.29	0.29	0.10	0.13	0.39	–0.26	1.00	0.30	0.15	–0.06	–0.06	0.15	0.02	0.06	0.31	1

3.1.1 Principal component analysis

In our study the analysis, by centred reduced component, is performed on a dataset of 64 individuals and 19 variables (*T*, *pH*, *EC*, NO_3-, Cl^-, SO_4^{2}-, Mg^{2+}, Na^+, Ca^{2+}, $^{K+}$,Fe^{2+}, HCO_3-, *TH*, salinity, turbidity, *TDS*, NH_4^+, NO_2-, *FAT*), the first step of the PCA is to calculate the correlation matrix of the parameters (Table 1), it represents the level of commonly shared variability between individual pairs of water quality variables. The total dissolved solids TDS shows a strong positive correlation (1, 0.71, 0.80, 0.77, 0.72, and 0.99) with *EC*, Mg^{2+}, *TH*, Ca^{2+}, salinity and turbidity. This reflects the main role of these components in the obtaining of salted groundwater in our study region.

Electric conductivity EC indicates likewise a strong positive correlation (0.71, 0.80, 0.77, 0.72, and 0.99) with, Mg^{2+}, *TH*, Ca^{2+}, salinity and turbidity. This reflects the participation of these elements in the acquisition of saline load of groundwater in the region.

The Mg^{2+} shows also a strong positive correlation (0.94, 0.70, and 0.76) with *TH*, Ca^{2+}, and salinity, by definition of total hardness *TH*, the correlation of it with Mg^{2+} is obvious, both Mg^{2+} and Ca^{2+} have found to be linearly correlated with *TH* values indicating primary salinity contributors for groundwater. There is a perfect relationship between alkalinity HCO_3-and full alkalimetric title *FAT*, so the quality of water is on average (HCO_3- is one of FAT components).

Table 2 Correlations between variables and factors

Variables / *Factors*	*PC1*	*PC2*	*PC3*	*PC4*	*PC5*
TDS (mg/l)	*0.948*	0.251	0.072	0.034	0.059
EC (μs/cm)	*0.948*	–0.251	0.072	0.034	0.059
Na^+ (mg/l)	–0.03	0.25	0.143	–0.108	*0.627*
SO_4^{2-} (mg/l)	*0.515*	–0.046	–0.214	0.338	–0.318
Mg^{2+} (mg/l)	*0.854*	0.273	–0.091	–0.196	0.006
Cl^- (mg/l)	–0.017	*–0.563*	–0.219	*0.541*	0.105
HCO_3^- (mg/l)	0.426	*0.601*	*0.591*	0.236	–0.108
TH (°F)	*0.925*	0.162	–0.231	–0.152	0.014
Ca^{2+} (mg/l)	*0.853*	0.003	–0.356	–0.075	0.022
T (°C)	0.023	*–0.598*	*0.566*	–0.015	–0.13
pH	–0.277	–0.388	*0.602*	–0.048	0.024
Turbidity(NTU)	*0.607*	–0.528	0.335	–0.122	–0.144
K^+ (mg/l)	0.187	–0.167	0.196	–0.337	*0.583*
NO_3^- (mg/l)	0.035	0.022	–0.018	*0.703*	0.49
Salinity (mg/l)	*0.968*	–0.148	–0.019	0.038	0.101
FAT (°F)	0.426	*0.601*	*0.591*	0.236	–0.108
Eigenvalue	6.16	2.166	1.844	1.227	1.165
Variability %	38.502	13.539	11.527	7.666	7.281
Cumulative %	*38.502*	*52.042*	*63.568*	*71.234*	*78.515*

The *TH* indicates additionally a strong positive correlation (0.91 and 0.86) Ca^{2+} and salinity, the dolomite rocks present in the region are the main source of Mg^{2+} and Ca^{2+}, which directly affect groundwater salinity. The obtained factors from the use of the PCA technique show that the five first factors explain more than 78% of the total variance of the parameters. As seen in Table 2, the Kaiser standard was applied to decide the absolute number of significant factors (Khelif and Boudoukha, 2018).

PC1 represents about 38.50% of the variance, it is well correlated with relatively high loads such as *EC*, Ca^{2+}, Mg^{2+}, *TDS*, SO_4^{2-}, turbidity, TH and a salinity. It is probably, due to the mineral water reactions in the area, consequently, the factor PC1 can be named as salinisation factor.

The factor PC2 represents more than 13.54% of the variance, in fact, this factor explains better the bicarbonates parameter, contrary, an inverse correlation is observed with the both parameters temperature *T* and Cl^-, indeed, PC2 present the sodium bicarbonates factor .

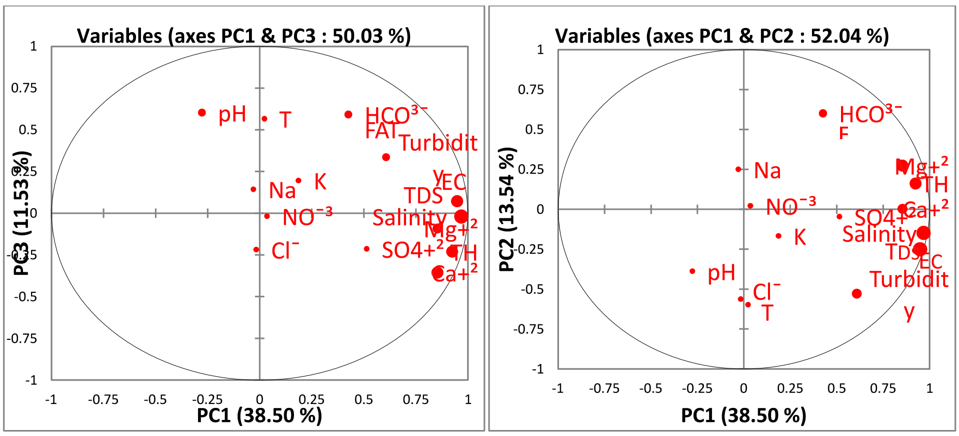
The factor PC3 expresses more than 11.53% of the variance of parameters which includes four parameters *pH*, HCO_3^- *T* and *FAT*. The full alkalimetric title measures the sum of free alkalis, carbonates and bicarbonates that explains the good correlation with *pH*.

Factor PC4 explains 7.67% of the total parameters variance, and has strong NO_3^- to moderate Cl^- positive load. The disintegration of Evaporite formations generates the saltiness of Cl^-, while the saltiness origin due to NO_3^- presence is the organic materials.

Factor PC5 explains the lowest parameters variance with 7.28 %, where the Na^+ gives the most contribution with a positive load in addition to K^+. The presence of Na^+ is due to the water-rock interaction.

More explanation of the five previous factors is showing in Table 2 and Figure 3.

Figure 3 Correlation between the principal factors (see online version for colours)

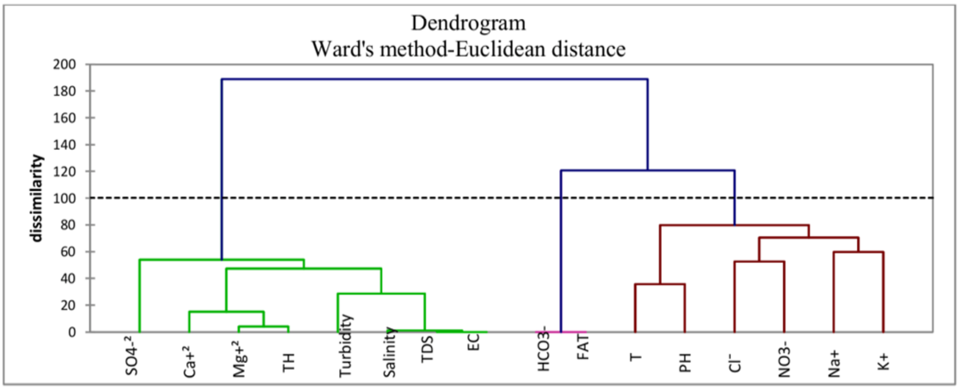


Note: The more the red points are bigger the more the parameters are strongly correlated and vice versa.

3.1.2 Cluster analysis

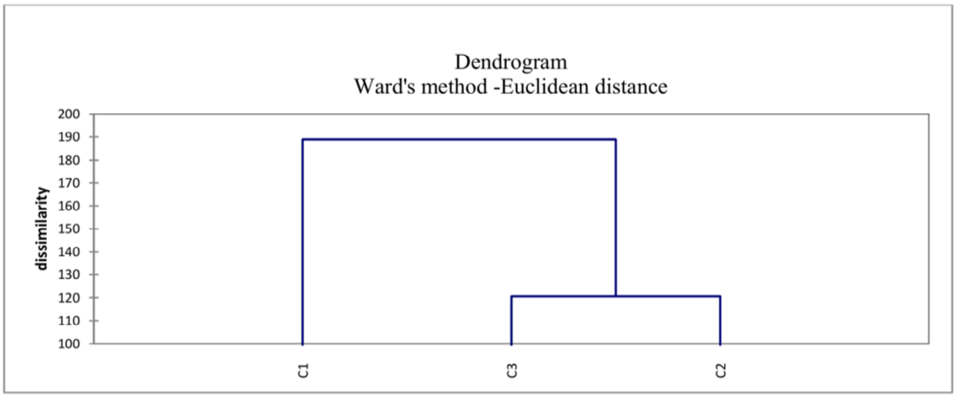
The cluster analysis CA was elaborated using the Ward's method in which the distance between two clusters is how much the sum of squares will increase when we merge them, also by using the Euclidian distance which is the ordinary straight-line distance between two points, for grouping the hydrogeochemical parameters issued from Hodna zone.

Figure 4a Cluster dendrogram for variables (see online version for colours)



Note: We distinguish three different families: green, pink and red, starting from the left to the right.

Figure 4b Cluster dendrogram for variables (see online version for colours)



Note: We distinguish three different clusters: C1, C2 and C3.

In this study, for statistical purpose, they were classified in their standard arrange. In this approach, 19 hydrochemical parameters *T, pH, EC*, NO_3^-, Cl^-, SO_4^{2-}, Mg^{2+}, Na^+, Ca^{2+}, K^+, *TDS*, HCO_3^-, *TH*, *FAT*, *salinity*, *turbidity*, Fe^{2+}, NH_4^+, NO_2^- are used, however the last three parameters are relatively negligible.

The visual investigation is the main criteria to choose the classes in the dendrogram [Figure 4(a)]. The characterised Phenon line was picked at a dissimilarity of 100. At this separation, the gatherings could be recognised regarding their hydrochemical factors.

As appeared in Figure 4(a), 16 factors were ordered into three clusters as appeared in Figure 4(b). These groups are:

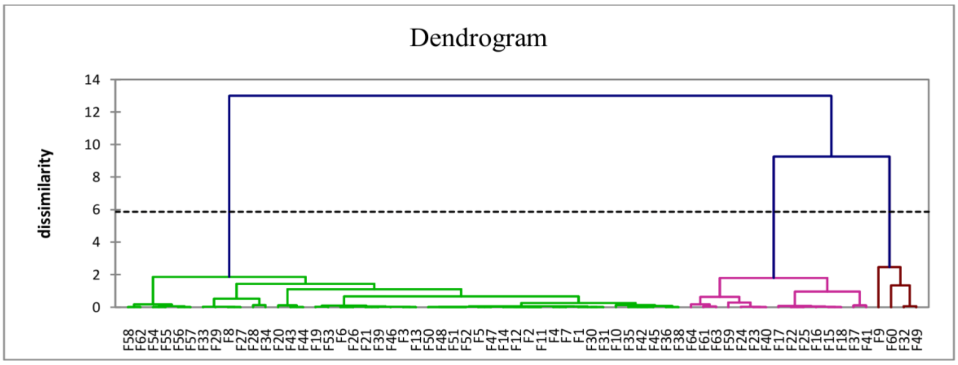
Group 1 (C1): *TDS*, *EC*, SO_4^{2-}, Mg^{2+}, Ca^{2+}, *TH*, *turbidity*, *salinity*

Group 2 (C2): Na^+, Cl^-, *T*, *pH*, K^+, NO_3^-

Group 3 (C3): *FAT*, HCO_3^-.

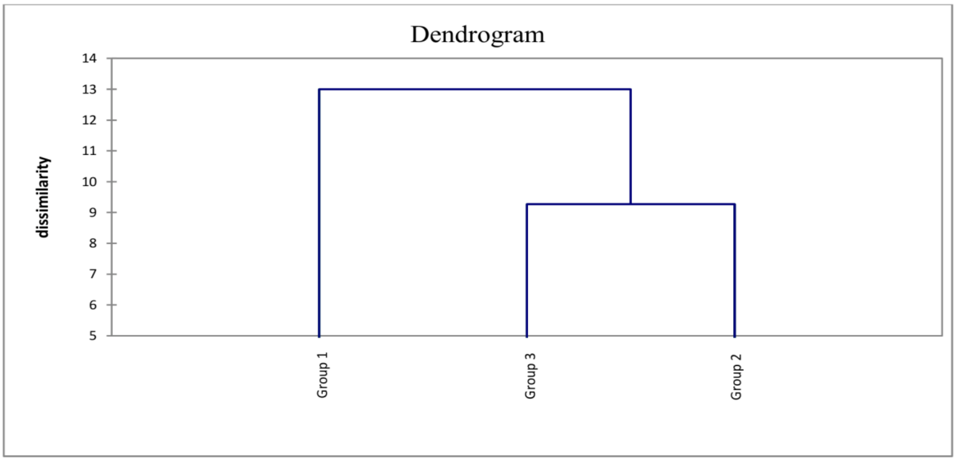
After we summarise the hydrochemical parameters in three clusters, we come to work with the water samples of all drillings studied, by applying the same previous technique which is cluster analysis. More details about the cluster analysis of drillings are showed in Figures 5(a) and 5(b).

Figure 5a Cluster dendrogram for water samples of drillings (see online version for colours)



Note: We distinguish three different drillings families: green, pink and red; starting from the left to the right.

Figure 5b Cluster dendrogram for water samples of drillings (see online version for colours)



Note: We distinguish three different drillings groups.

The dendrogram of individuals [Figure 5(a)] summarised by group in Figure 5(b), allows to recognise three groups as indicated by the degree of mineralisation. Table 4 shows the mean parameters values for each principal water group.

The projection of individuals on the factorial plane PC1-PC2 (Figure 3) shows that PC1 expresses the upward rate of mineralisation, the more positive the drilling on the PC1 axis, the more mineralised the water is. Cluster 1, highly mineralised, is represented by low values on the PC1 axis. The more the drillings are positive on the PC1-PC3 axis, the more water is mineralised, the cluster 1, highly mineralised, is represented by a high values on the PC1 axis (Figure 3).

Table 3 shows the grouping of drillings using hierarchical grouping analysis. Group 1 is represented by drillings that expresses 68.75% of the variance of water samples, group 2 and group 3 explain 6.25% and 25% of the this variance; respectively.

Table 3 Groupings of drillings using hierarchical grouping analysis

Gr1	*Gr 2*	*Gr3*
F1, F2, F3, F4, F5, F6, F7, F8, F10, F11, F12, F13, F14, F19, F16, F20, F21, F26, F27, F28, F29, F30, F31, F32, F33, F34, F35, F36, F38, F39, F42, F43, F44, F45, F46, F47, F48, F50, F51, F52, F53, F54, F55, F56, F57, F58, F62	F9, F32, F49, F60	F15, F16, F16, F18, F22, F22, F23, F24, F25, F37, F40, F41, F59, F61, F63, F64

The Q-mode was used for classifications of drillings, according to their parameters; it yielded the dendrogram in Figures 5(a) and 5(b).

The group 1 includes 44 samples corresponding to a high salinity (*EC* >3 033 μS·cm–1), the drilling number 11 presented the highest average values of the most studied parameters, especially *TDS*, *EC*, SO_4^{2-}, Mg^{2+}, *TH*, Ca^{2+},turbidity and salinity. Concerning the group 3, it presents the drillings with low salinity (*EC* <1600 μS·cm^{-1}), group 2 is represented by 4 samples, corresponds to an intermediate and average salinity (1600 < *EC* > 3100 μS·cm–1), It occupies 6.25 % of the total water samples variance (see Table 3 and Table 4).

Table 4 Mean parameters values of the three principal water groups (determined from HCA)

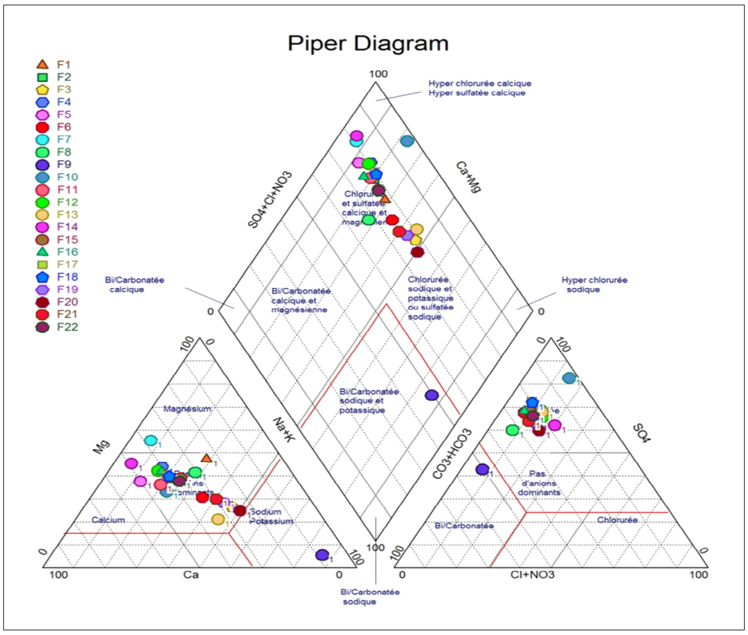
Class	*TDS*	*EC*	Na^+	SO_4^{2-}	Mg^{2+}	Cl^-	HCO_3^-	*TH*
1	2,298.63	3,033.29	187.74	874.71	132.19	189.49	381.24	112.18
2	1,355.51	1,788.75	1,121.00	714.25	85.54	129.65	366.00	71.50
3	1,105.83	1,459.27	242.20	854.73	76.40	153.22	361.93	63.65
Class	Ca^{2+}	*T*	*pH*	*Turbidity*	K^+	NO_3^-	*Salinity*	*FAT*
1	231.11	19.92	7.02	16.01	6.33	14.35	1.76	31.25
2	145.20	19.60	7.07	1.04	4.25	5.73	1.05	30.00
3	128.85	20.80	7.23	2.50	4.53	19.27	0.76	29.67

Note: *pH* (standard units), *EC* (μ.Siemens/cm), *TH*, *FAT* (°F), Turbidity (NTU), *T* (°C) and mean concentrations (mg/l)

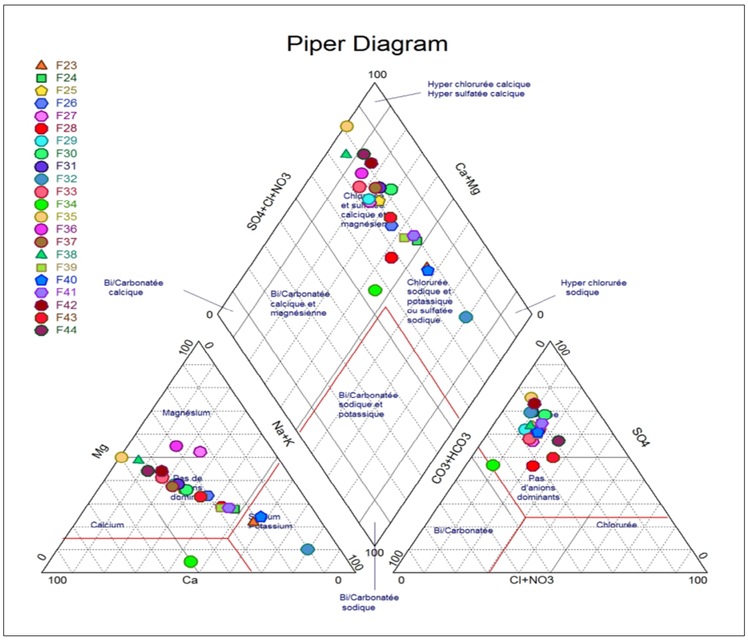
3.2 Chemical classification of water

In our study area, the distinctive water samples were characterised from their chemical composition using the Piper diagram (Bencer et al., 2016). This outline is a plot with multiple facies wherein the concentrations rate of significant cations (Ca^{2+}, Mg^{2+}, Na^+ and K^+) and anions (HCO_3^-, SO_4^{2-}, and Cl^-) are in milliequivalent.

Figure 6a Piper diagram applied to Hodna groundwater for F1to F22 (b) Piper diagram applied to Hodna groundwater for F22 to F44 (c) Piper diagram applied to Hodna groundwater for F45 to F64 (see online version for colours)



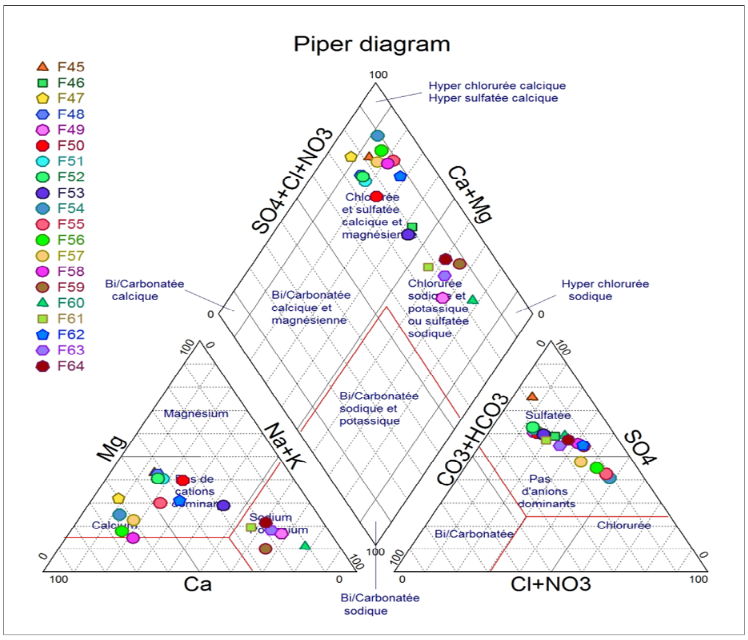
(a)



(b)

Note: The two ternary plots at the left- and right-hand refer to cations and anions respectively, which are then projected into one diamond-shaped plot.

Figure 6a Piper diagram applied to Hodna groundwater for F1to F22 (b) Piper diagram applied to Hodna groundwater for F22 to F44 (c) Piper diagram applied to Hodna groundwater for F45 to F64 (continued) (see online version for colours)



(c)

Note: The two ternary plots at the left- and right-hand refer to cations and anions respectively, which are then projected into one diamond-shaped plot.

In the present study, hydrochemical diagrams software was used to plot this diagram (Khelif and Boudoukha, 2018). The first two facies are related to the existence of a salty lake (Chott Hodna) where we can find some marl and mud, while the third one concerns carbonate facies developments located at the limits of the water recharge zone. This facies typology focuses on the multiple facies nature of the hydrochemical forms that oversee the saltiness of this groundwater; the development of limestone in kastified regions nearby on the North and North West limits is a consequence to the penetration of precipitation enabling their bicarbonate mineralisation.

The diagram of Piper constitutes of two trilinear diagrams, the left one has the cations concentrations and the right one has the anions concentrations, the last one is a diamond-shaped diagram designed for both of them.

Drillings from F1 to F22 [Figure 6(a)] have no dominance neither in anions nor in cations, except of the drilling number 7 and 9; the first one has a Magnesium dominance and the other one is in the Sodium Potassium cations triangle and in the Bicarbonates anions triangle.

All drillings from F23 to F44 [Figure 6(b)] have a sulfates dominance in the anions triangle except of F28, F34 and 43. Speaking of the cations triangle, F27 and F36 are in Magnesium zone, F23, F32 and F40 are in Sodium Potassium zone, lastly the drilling F34 which appears in the calcium zone.

According to Figure 6(c) which represents drillings from F45 to F64, the left diagram presents two dominances; Calcium dominance of drillings F47, F54, F56, F57 and F58, and a Sodium Potassium dominance of drillings F49, F59, F60, F61, F63 and F6. By going to the right diagram, all drillings are gathering in the Sulfates zone except of F54, F55, F56 and F57 which have no dominance at all. The main source of calcium in groundwater is limestone in sedimentary rocks; the chloride particles are generally distributed in common water. The dominant components give a nodule-facies of chloride and calcium, sulfate and magnesium. The chemical analysis graph in the Piper diagram shows in the anions triangle, a clear hyper-sulphate calcium trend, on the other side, the cations triangle indicates a slight magnesium impact [see Figures 6(a), 6(b), 6(c)].

4 Conclusions

This paper aims to identify the mineralisation origin and distinguish the different classes of groundwater quality in Hodna region using diverse multivariate statistical techniques.

According to the obtained results from the hydrogeochemical approach, on Piper diagram, the central and downstream parts of the study area are dominated by the facies Ca^{2+} , Cl^{-} ,Mg^{2+} and SO_4^{2-} , Ca^{2+} , Mg^{2+}, with the dominance of the sulfate facies.

The obtained factors from PCA explain more than 78% of the total variance of used data, the analysis of outcomes shows that the PC1 characterises the salinity , however, the factor PC2 indicates that the content of the groundwater on Bicarbonates. The factor PC3 expresses the dependence between the *pH* and *FAT*, the Factors PC4 and PC5 explain the content of groundwater on organic material and Na^{+}; respectively.

The cluster analysis has shown that the groundwater of Hodna can be grouped into 3 families, the obtained groups are similar to the obtained factors from the PCA approach, that is , the group 1 is similar to PC1 which characterise the salinity, also the group 2 is the same as both factors PC4 and PC5 which characterise the groundwater content of organic material and Na^{+}, finally, group 3 is equivalent to factor PC2 and PC3 which characterise the groundwater content on sodium bicarbonate. These results make the identification of the groundwater quality of Hodna easier; by reducing the multiple quality variables to identical five factors obtained from PCA approach and three groups obtained from CA approach.

Consequently, this examination outlines that multivariate statistical techniques are an admirable exploratory device for interpreting complex water quality informational indexes and for understanding spatial varieties, which are helpful and compelling for water quality sustainable and effective management.

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References

Belhadj, M., Boudoukha, A., Amroune, A., Gaagai, A. and Ziani, D. (2017a) 'Statistical characterization of groundwater quality of the northern area of the basin of Hodna, M'sila', *LARHYSS Journal P-ISSN 1112-3680/E-ISSN 2602-7828*, No. 31, pp.177–194.

Belhadj, M., Boudoukha, A., Amroune, A., Gaagai, A. and Ziani, D. (2017b) 'Statistical characterization of groundwater quality of the northern area of the basin of Hodna, M'sila. Southeastern Algeria', *LARHYSS Journal P-ISSN 1112-3680/E-ISSN 2602-7828*, No. 31, pp.177–194.

Belkhiri, L., Boudoukha, A., Mouni, L. and Baouz, T. (2010) 'Application of multivariate statistical methods and inverse geochemical modeling for characterization of groundwater a case study: Ain Azel plain (Algeria)', *Geoderma*, Vol. 159, Nos. 3–4, pp.390–398.

Belkhiri, L., Boudoukha, A., Mouni, L. and Baouz, T. (2011) 'Statistical categorization geochemical modeling of groundwater in Ain Azel plain (Algeria)', *Journal of African Earth Sciences*, Vol. 59, No. 1, pp.140–148.

Bencer, S., Boudoukha, A. and Mouni, L. (2016) 'Multivariate statistical analysis of the groundwater of Ain Djacer area (Eastern of Algeria)', *Arabian Journal of Geosciences*, Vol. 9, No. 4, p.248.

Boualla, N., Benziane, A. and Ait-Mokhtar, K. (2017) 'Geochemistry exploration environment analysis of waters: the case of the basin of the Great Sebkha of Oran', *Water Science and Technology: Water Supply*, Vol. 17, No. 6, pp.1801–1812.

Dougha, M. and Hasbaia, M. (2019) 'Contribution of the multivariate analysis and origin for groundwater quality of mixed aquifer in the M'sila plain (Algeria)', *International Journal of Hydrology Science and Technology*, Vol. 9, No. 2, pp.154–172.

Ebadati, N. and Hosseini, A.H. (2018) 'Quality assessment of qanat water for drinking and agriculture uses in Tahran', *International Journal of Hydrology: Int. J. Hydro*., Vol. 2, No. 2, pp.198–203, DOI: 10. 15406/ijh.2018.02.00069.

Gaagai, A., Boudoukha, A., Boumezbeur, A. and Benaabidate, L. (2017) 'Hydrochemical characterization of surface water in the Babar watershed (Algeria) using environmetric techniques and time series analysis', *International Journal of River Basin Management*, Vol. 15, No. 3, pp.361–372.

Ghodbane, M., Boudoukha, A. and Benaabidate, L. (2016) 'Hydrochemical and statistical characterization of groundwater in the Chemora area, Northeastern Algeria', *Desalination and Water Treatment*, Vol. 57, No. 32, pp.14858–14868.

Gulgundi, M.S. and Shetty, A. (2018) 'Groundwater quality assessment of urban Bengaluru using multivariate statistical techniques', *Applied Water Science*, Vol. 8, No. 1, p.43.

Hasbaia, M., Hedjazi, A. and Benayada, L. (2012) 'Variability of water erosion in the hodna basin: case of the Elham wadi sub-watershed', *Moroccan Journal of Agronomic and Veterinary Sciences*, Vol. 1, No. 1, pp.28–32.

Jampani, M., Huelsmann, S., Liedl, R., Sonkamble, S., Ahmed, S. and Amerasinghe, P. (2018) 'Spatio-temporal distribution and chemical characterization of groundwater quality of a wastewater irrigated system: a case study', *Science of the Total Environment*, 15 September, Vol. 636, pp.1089–1098.

Khedidja, A. and Boudoukha, A. (2019) 'Quality assessment of shallow groundwater for irrigation purposes in Tadjenanet–Chelghoum Laid area (Eastern Algeria)', *International Journal of River Basin Management*, Vol. 19, No. 2, pp.1–18.

Khelif, S. and Boudoukha, A. (2018) 'Multivariate statistical characterization of groundwater quality in Fesdis, East of Algeria', *Journal of Water and Land Development*, Vol. 37, No. 1, pp.65–74.

Kieken, M. (1970) 'Résumé des connaissances acquises au cours des vingt dernières années dans le Hodna, le Titteri et la partie occidentale des Biban', *Bulletin BRGM*, Section IV(1).

Merzougui, F.Z., Makhloufi, A. and Merzougui, T. (2019) 'Hydro-chemical and microbiological characterization of lower cretaceous waters in a semi-arid zone Beni-Ounif syncline, South-West of Algeria', *Journal of Water and Land Development*, Vol. 40, No. 1, pp.67–80.

Ogunbode, T.O. and Akinola, O.T. (2019) 'Hydrochemistry and water quality index application in the assessment of groundwater quality in Oyo state, Nigeria', *International Journal of Hydrology*, DOI: 10.1504/IJHST.2019.103446.

Sekiou, F. and Kellil, A. (2014) 'Empirical, graphical and multivariate statistical characterization and classification of bottled spring water from Algeria', *LARHYSS Journal P-ISSN 1112-3680/E-ISSN 2602-7828*, No. 20.

Tiri, A., Lahbari, N. and Boudoukha, A. (2017) 'Assessment of the quality of water by hierarchical cluster and variance analyses of the Koudiat Medouar Watershed, East Algeria', *Applied Water Science*, Vol. 7, No. 8, pp.4197–4206.

Wu, L., Gao, J., Zhao, W., Xu, X., Yin, Y. and Wu, L. (2016) 'Quality assessment of rainwater and harvested rainwater stored in different types of cisterns', *Water Science and Technology: Water Supply*, Vol. 17, No. 3, pp.652–664.

Zhang, Y., Li, Y., Li, Y., Da, W., Yu, M. and Quan, Q. (2019) 'Application of multivariate statistical methods in the assessment of water quality in selected locations in Jialing River basin in Guangyuan, China', *Water Science and Technology: Water Supply*, Vol. 19, No. 1, pp.147–155.

Abbreviations

ADE	Algerian Drinking Water
ANRH	National Agency of Hydraulics Resources
APHA	American Public Health Association
CA	Cluster analysis
DSA	Agricultural Services Directorate
FAO	Food and Agriculture Organization of the United Nations
HCA	Hierarchical clustering analysis
PCA	Principal component analysis.