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Multivariate statistical characterization of groundwater quality in Fesdis, East of Algeria

Safia KHELIF¹⁾ ABCDE ✉, Abderrahmane BOUDOUKHA²⁾ CDEF

¹⁾ University of Batna 1, Department of Agronomic Sciences, Laboratory of the Improvement of Agricultural Productions and Protection of Ecosystems in Arid Zones, Road of Chahid Boukhrouf Mohamed El Hadi, 05000 Batna, Algeria; e-mail: safiakhelif@gmail.com

²⁾ University of Batna 2, Department of Hydraulics, Laboratory of Applied Research in Hydraulics, Algeria; e-mail: boudoukha_abderrahmane@yahoo.fr

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Abstract

This study is a contribution to the knowledge of hydrochemical properties of the groundwater in Fesdis Plain, Algeria, using multivariate statistical techniques including principal component analysis (PCA) and cluster analysis. 28 samples were taken during February and July 2015 (14 samples for each month). The principal component analysis (PCA) applied to the data sets has resulted in four significant factors which explain 75.19% of the total variance. PCA method has enabled to highlight two big phenomena in acquisition of the mineralization of waters. The main phenomenon of production of ions in water is the contact water-rock. The second phenomenon reflects the signatures of the anthropogenic activities. The hierarchical cluster analysis (CA) in *R* mode grouped the 10 variables into four clusters and in *Q* mode, 14 sampling points are grouped into three clusters of similar water quality characteristics.

Key words: *cluster analysis, Fesdis Plain, groundwater, hydrochemistry, multivariate statistical techniques, principal component analysis*

INTRODUCTION

Water is called matrix of life because it is an essential part of all living systems and is the medium from which life evolved and in which life exists [FRANKS 2000]. The quality as well as the quantity of clean water supply is of vital significance for the welfare of humanity [DARA 2008]. Polluted water is a source of many diseases for human beings [NAG 2006]. Groundwater is the major source of drinking water in both urban and rural areas in many countries [HAMMOURI *et al.* 2015; HOSSAIN, BAHAUDDIN 2013]. The multi-usage of groundwater for drinking, agricultural and industrial purposes, fisheries and energy productions depend considerably on their quality [ISCEN *et al.* 2008]. This quality, defined in terms of physical, chemical and biological compositions, is governed by

both natural (precipitation, watershed geology, topography, climate) and anthropogenic (point and non-point sources like urban and industrial activities, other domestic activities, agricultural runoff) factors [MUSTAPHA, ABDU 2012; NOURBAKSH, YOUSEFI 2017].

The assessment of water quality has become an important part of water resource studies, planning and management. It is gaining significant importance due to intense urbanization, industrialization and agricultural activities that are increasing the risk of contamination of soil and water [TIWARI 2011]. The Fesdis Plain, as a part of the Gourzi River basin, is located in the Eastern part of Algeria, and it is one of the biggest and most important vegetable production bases in Batna area. In this area, urbanization and the development of agricultural activity have created a growing demand for groundwater. The use of fertilizers in in-

tensive agriculture, irrigation of land by sewage effluents, has increased the risk of contamination of waters of the area. Hence, the characterization of the hydrochemistry of different water sources, especially groundwater has paramount importance.

In recent years, with increasing number of chemical and physical variables of groundwater, a wide range of statistical methods are now applied for proper analysis and interpretation of data [BAK *et al.* 2014; BELKHIRI *et al.* 2010; MEÏTRAK *et al.* 2014; SHRESTHA, KAZAMA 2007]. Multivariate statistical analysis comprises a number of statistical methods or a set of algorithms that may be applied to several fields of empirical investigation. These methods of cluster analysis and principle component were used with remarkable success as a tool in the groundwater quality studies. These methods are also giving a better understanding of the physical and chemical properties of the groundwater system in space as well as in time [BOUSSAHA, LAIFA 2017; HACHOËL *et al.* 2017; SAYAD *et al.* 2017; SUBYANI, AL AHMADI 2010]. The objective of the present work was to characterize the chemistry of groundwater and determine the origin of the chemical elements present in the waters of the plain of Fesdis in Algeria, by using the multivariate statistical techniques: principal component analysis (PCA) and cluster analysis (CA).

DESCRIPTION OF STUDY AREA

GENERAL INFORMATION

Fesdis city is located on latitude 35°37'04" N and on longitude 6°14'51" E with more than 8,000 inhabitants. Fesdis Plain has an average altitude of 960 m and surrounded by reliefs culminating between 1,080 m and 1,744 m. The main river, Wadi Gourzi runs through the area in the middle of the plain and drains the waste water of Batna city and industrial zone located North and drains a flow rate that ranges between 1,650 and 27,210 m³·day⁻¹ [HANNACHI *et al.* 2015]. The climate of the region is semi-arid, with an annual average rainfall of about 350 mm and an annual average temperature of 15.7°C [BELOUANAS 2012]. This semi-arid behavior essentially is due to irregular rainfall, exposing the region to increased temperature and high evapotranspiration provoking a loss of water balances that exceed 560 mm·y⁻¹ [MEBARKI 2009] about 85% of which occurring from September to May.

GEOLOGY AND HYDROGEOLOGY

The geological setting of the area was established from a detailed surface geological map of the area [WILDI 1983]. Four main units are identified: 1) Triassic saliferous, 2) Jurassic carbonate, 3) Cretaceous carbonate, 4) Mio-Plio-Quaternary. Triassic saliferous diapir is found in the northern part of the study area. This unit is composed by crushed ice and hand complex limestone dolomitic. Jurassic and Cretaceous

carbonate formation are formed by dolomitic limestone and sandstone, sometimes with thick marl layers of about 1,400 m thick. The Mio-Plio-Quaternary formation is a heterogeneous continental detrital sedimentation. It is corresponding to red clay, sometimes gypsum overcome by lacustrine limestones, conglomerates and alluvium. The thickness of this formation varies between 200 and 300 m [MENANI 1991]. Mineralogically, most of the soils are dominated by kaolinite, illite, smectite, and chlorite [BELOUANAS 2012] typical for most arid and semi-arid soils.

Tectonics of the region led to the formation of a syncline filled with detrital elements, of Mio-Plio-Quaternary age. The superposition of several tectonic phases allowed the Triassic carbonate formations staked Triassic and development of severe fracture network direction South-West, North-East and North-West, South-East.

Hydrogeologically, the studied area is situated in the alluvial plain of the Mio-Plio-Quaternary. The shallow groundwater is unconfined and mainly occurs 2.5–17.0 m below the surface, 17.0 m in these limits and 2.5 m in the center of the plain. The rocks forming the aquifer are alluvial, containing sand, gravel, silt and in some places, clay. The substratum of the shallow groundwater is formed by clays and marls sometimes are gypsum of Mio-Pliocene. The pumping tests on different wells showed high transmissivity (10⁻⁴ m·s⁻¹) indicating high yields. Groundwater is recharged by vertically infiltrating meteoric water, by the Gourzi River in the basin and by stream water coming from different reliefs surrounding the depression intermountainous of the plain (Fig. 1).

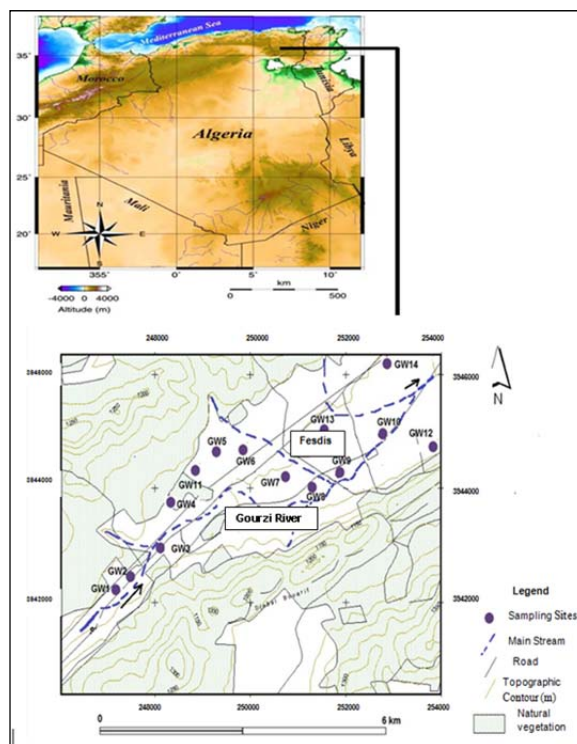


Fig. 1. Study area and sampling sites in the Fesdis Plain; source: own study

MATERIALS AND METHODS

GENERAL INFORMATION

To examine the evolution of the physicochemical parameters, 28 samples were taken during the months of February and July 2015 from fourteen sampling stations (14 samples for each month). In the study area, February represents the wet season and July represents the dry season. The samples were collected after pumping for 15 min after stabilizing the temperature of the water to remove groundwater stored in the hydraulic structure. These samples were collected using 1 liter clean polyethylene bottles. First the bottles were cleaned by acid washing and then labeled with an identification number. Then, the number of the bottle was recorded on the sampling datasheet in line with the sampling location. The location of the sampling area was registered using GPS. All the samples were stored in an ice chest at a temperature of $<4^{\circ}\text{C}$ and later transferred to the Algerian Laboratory of Batna Waters (Fr. Laboratoire d'Algérienne des eaux de Batna) for the analysis of chemical parameters, following standard test methods [RODIER 2005; 2009]. Immediately after sampling, pH, temperature water (T), dissolved oxygen (DO) and electric conductivity (EC) are measured in the field using a multi-parameter WTW (P3 MultiLine pH/LF-SET). For the laboratory analysis, EDTA titration method was used for the determination of calcium and magnesium whereas the contents of potassium and sodium were measured by flame photometry. Measurements of the levels of phosphate, sulphate and nitrate were performed by UV-visible spectrophotometry. Titrimetry was used for the determination of bicarbonate and chloride. BOD_5 was measured using a BOD meter and COD using a COD meter.

MULTIVARIATE STATISTICAL ANALYSIS

The application of different multivariate statistical techniques can facilitate the interpretation of complex data matrices, and can help to simplify and organize large datasets to provide meaningful insight [LAAKSOHARJU *et al.* 1999]. In the present study, two multivariate statistical techniques were used to evaluate physicochemical parameters of groundwater samples. The Statistica 6 (Stat Soft, Inc. ®) was used for the multivariate statistical analysis.

The principal component analysis (PCA). The PCA method was also applied to the treatment of hydro chemical data. PCA is a widely-used technique that attempts to transform an original data set into a smaller set comprising uncorrelated factors known as principal components (PCs). It uses eigenvalues and eigenvectors associated with the covariance matrix to generate PCs by multiplying the original correlated variables by the eigenvector [VAROL *et al.* 2012]. The PCs allow for data reduction by extracting the most important variables to interpret the original

data sets with a minimal loss of information [HELENA *et al.* 2000]. Although PCA is an exploratory and descriptive method, the aim of the treatment is to identify the main factors that control the chemistry of the groundwater [DAGNÉLIE 2006]. Thirteen hydro chemical measured variables (EC , Ca^{2+} , Mg^{2+} , Na^+ , K^+ , Cl^- , SO_4^{2-} , HCO_3^- , NO_3^- , PO_4^{3-} , DO, COD and BOD_5) were utilized in this analysis.

The cluster analysis (CA). Cluster analysis is a technique for grouping individuals or objects into unknown groups. This technique can be used to group the commonly collected water quality data, where each cluster indicates the water of a particular quality. So there are two types of cluster analysis: R and Q-modes. R-mode was performed on different water quality variables. Q-mode cluster analysis was performed on the water chemistry data to group the samples in terms of water quality [DAVIS 2002]. In clustering, the objects are grouped such that similar objects fall into the same class [DANIELSSON *et al.* 1999]. A classification scheme using Euclidean distance (straight line distance between two points in c -dimensional space defined by c variables) for similarity measurement, together with Ward's method for linkage, produces the most distinctive groups where each member within the group is more similar to its fellow members than to any member outside the group [GÜLER *et al.* 2002]. Ten hydro chemical measured variables (pH, EC , Ca^{2+} , Mg^{2+} , Na^+ , K^+ , Cl^- , SO_4^{2-} , HCO_3^- , and NO_3^-) were utilized in this analysis. For statistical purpose, all the variables were log-transformed and more closely correspond to normally distributed data. Subsequently, they were standardized to their standard scores (z -scores) as described by GÜLER *et al.* [2002].

RESULTS AND DISCUSSION

GENERAL HYDROCHEMISTRY

The analytical measurements obtained are summarized in Table 1 and the results were compared with the standard permissible limits recommended by the World Health Organization [WHO 2008] and Algerian norms [JORADP 2011].

Temperature values of the groundwater samples of the studied area ranged from 9.8°C and 22.7°C . The examination of the chemical analyses (Tab. 1) shows that the pH values ranging from 6.91 to 7.35 in the wet season and from 6.86 to 7.52 in the dry season which indicate that the groundwater is slightly basic. It is known that the process of buffering calcite and dolomite is dominant for the pH range 6.5 to 7.5 [BLOWES, PTACEK 1994]. The values of pH measured for all groundwater samples are in accordance with the WHO (6.5–8.5) permissible limit for drinking water.

The electrical conductivity was in range of 1680 to $3520 \mu\text{S}\cdot\text{cm}^{-1}$ in the wet season and 1467 to $3370 \mu\text{S}\cdot\text{cm}^{-1}$ in the dry season, which indicates that the entire aquifer is highly mineralized. All groundwater

Table 1. Parameters and chemical compositions for groundwater (GW) in the Fesdis Plain

GW	pH	<i>T</i>	<i>EC</i>	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	Cl ⁻	SO ₄ ²⁻	HCO ₃ ⁻	NO ₃ ⁻	PO ₄ ³⁻	COD	BOD ₅	DO
February 2015															
GW1	7.31	10.0	1 680	160	68	225	12	176	197	308	60	0.0	21	2	6
GW2	7.07	9.8	2 220	172	69	205	14	250	167	470	64	0.0	20	3	4
GW3	7.17	10.6	2 060	175	74	175	11	254	320	307	58	0.0	7	1	7
GW4	7.16	10.9	2 580	219	101	165	10	292	394	379	126	0.0	22	4	6
GW5	7.35	10.1	2 970	285	134	235	9	303	369	399	106	0.0	15	2	7
GW6	6.92	10.4	2 530	204	94	220	7	309	235	402	18	0.0	24	3	6
GW7	6.91	9.4	2 580	271	135	236	10	300	241	420	93	0.0	30	3	7
GW8	6.96	10.0	2 550	267	128	233	9	303	344	410	73	0.0	26	3	6
GW9	7.06	10.2	2 860	191	87	233	8	287	223	420	147	0.02	29	4	6
GW10	7.05	10.2	3 520	265	124	234	14	406	307	442	113	0.01	19	2	6
GW11	7.33	11.0	2 310	236	128	216	11	304	220	314	52	0.0	5	1	7
GW12	7.02	10.5	2 090	182	113	221	11	242	212	254	10	0.0	20	2	7
GW13	7.16	19.8	3 100	196	108	212	11	324	410	355	98	0.0	10	1	6
GW14	7.06	20.1	1 794	131	65	220	12	207	222	299	11	0.0	29	3	7
July 2015															
GW1	7.52	11.5	1 467	140	57	221	12	187	61	329	35	0.01	19	2	7
GW2	7.08	13.4	2 360	184	82	190	13	303	167	418	10	0.0	22	3	7
GW3	7.14	16.1	1 605	175	68	180	11	242	99	342	64	0.01	18	2	7
GW4	6.97	14.6	2 730	220	97	160	10	331	52	185	22	0.1	20	3	7
GW5	7.01	11.6	2 480	196	89	221	9	300	44	303	11	0.1	21	2	7
GW6	6.96	18.3	2 640	206	97	223	7	348	96	429	19	0.0	20	2	7
GW7	6.93	18.7	2 620	204	92	229	9	338	51	403	55	0.01	20	2	7
GW8	6.86	19.5	2 630	204	92	220	8	326	22	424	28	0.0	19	2	8
GW9	6.88	10.2	2 550	195	81	223	6	317	32	403	8	0.1	18	2	8
GW10	6.98	19.9	3 370	256	123	230	14	400	54	457	15	0.02	19	2	8
GW11	7.47	18.7	2 590	140	80	211	12	455	111	297	0.0	0.0	17	1	8
GW12	7.33	18.9	1 890	125	49	225	11	230	94	329	0.1	0.04	18	2	7
GW13	6.92	22.7	2 680	228	105	212	11	344	150	356	0.0	0.0	18	2	7
GW14	7.10	20.24	1 792	127	65	212	9	198	98	298	2	0.0	29	4	7

Explanations: GW = groundwater, *T* = temperature, *EC* = electrical conductivity, BOD₅ = biochemical oxygen demand, COD = chemical oxygen demand, DO = dissolved oxygen, all values are in mg·dm⁻³, except pH and *EC* (μS·cm⁻¹).
Source: own study.

samples in the study area exceeded the WHO permissible limits (1000 μS·cm⁻¹) for drinking water. The higher values of *EC* for groundwater is indicator of higher ionic concentrations, probably due to the high anthropogenic activities in the region and geological weathering conditions acquiring high concentrations of the dissolved minerals [DINKA *et al.* 2015].

Ca²⁺ and Mg²⁺ are the 5th and 8th most abundant elements on Earth, respectively; their concentrations in the study area are high. Ca²⁺ ranged from 131 to 285 mg·dm⁻³ and Mg²⁺ ranged from 65 to 135 mg·dm⁻³ in the wet season and from 125 to 256 mg·dm⁻³, 65 to 123 mg·dm⁻³ respectively in the dry season. All samples exceeded the WHO permissible limits of Ca²⁺ (75 mg·dm⁻³) and Mg²⁺ (50 mg·dm⁻³) for drinking water. The higher contents of calcium and magnesium in water are due to gypsum and anhydrite dissolution in the circulating waters [GHORABA, KHAN 2013].

The values for the Na⁺ in the wet season ranged from 165 to 235 mg·dm⁻³ and in the dry season ranged from 160 to 230 mg·dm⁻³. Almost all samples in study area exceeded the WHO permissible limits of Na⁺ for drinking water (200 mg·dm⁻³). The K⁺ values remained almost the same during both seasons. It's concentration ranged from 6 to 14 mg·dm⁻³ and only

few samples exceeded the WHO permissible limits of K⁺ for drinking water (12 mg·dm⁻³).

The HCO₃⁻ concentration is high; its values ranged from 254 to 470 mg·dm⁻³ in the wet season and from 185 to 457 mg·dm⁻³ in the dry season. The primary source of these ions in groundwater is the dissolved CO₂ in rainwater that on entering in the soil dissolves more CO₂. HCO₃⁻ ions occur in the form of carbonate system of chemical equilibrium, usually associated with the alkalinity (pH) and hardness of water which gives an unpleasant taste to water [DINKA *et al.* 2015].

The concentrations of Cl⁻ and SO₄²⁻ in the study area are high. Cl⁻ varied from 176 to 406 mg·dm⁻³ and SO₄²⁻ varied from 167 to 410 mg·dm⁻³ in the wet season and from 187 to 455 mg·dm⁻³, 22 to 167 mg·dm⁻³ respectively in the dry season, and almost all samples exceeded the WHO permissible limits of Cl⁻ and SO₄²⁻ for drinking water (200 mg·dm⁻³). High concentrations of Na⁺, Cl⁻, and SO₄²⁻ in the area of Fesdis may be derived from lithology (dissolution of evaporate minerals), industrial effluents and agricultural activities (phosphatic fertilizers).

The nitrate concentrations in groundwater samples are higher than WHO permissible limits (50

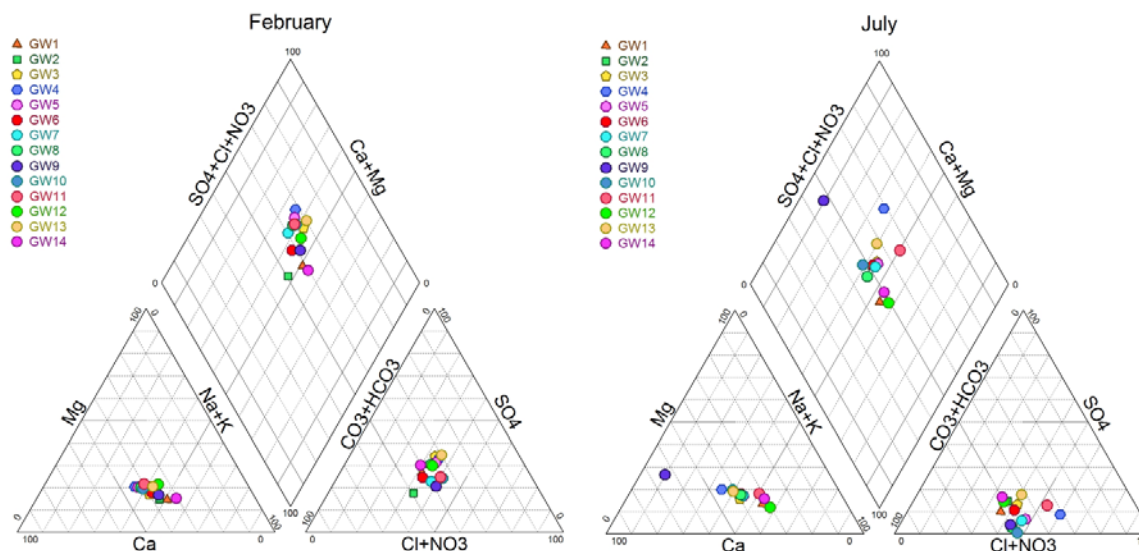


Fig. 2. Piper diagram applied to water of Fesdis aquifer; source: own study

$\text{mg}\cdot\text{dm}^{-3}$) for drinking water for 79% of cases during the wet season. NO_3^- varied from 11 to $147 \text{ mg}\cdot\text{dm}^{-3}$ during the wet season and from 0 to $64 \text{ mg}\cdot\text{dm}^{-3}$ during the dry season. The high concentration of NO_3^- is probably due to wastewater penetration, from industrial activities, urbanization and agricultural practices.

Contrary to NO_3^- the values of phosphate ions, COD and BOD_5 ranged from 0–0.02, 5–30, 1–4 $\text{mg}\cdot\text{dm}^{-3}$ respectively during the wet season and 0–0.04, 17–29, 1–4 $\text{mg}\cdot\text{dm}^{-3}$ respectively during the dry season. None of the groundwater samples in the study area exceeded the WHO permissible limits of phosphate ($0.5 \text{ mg}\cdot\text{dm}^{-3}$), and Algerian norm of COD ($30 \text{ mg}\cdot\text{dm}^{-3}$) and BOD_5 ($3 \text{ mg}\cdot\text{dm}^{-3}$) for drinking water.

HYDROGEOCHEMICAL FACIES

The different water samples have been classified according to their chemical composition using the Piper diagram. This diagram is a multifaceted plot wherein milliequivalents percentage concentrations of major cations (Ca^{2+} , Mg^{2+} , Na^+ and K^+) and anions (HCO_3^- , SO_4^{2-} , and Cl^-) are plotted in two triangular fields, which were then projected further into the central diamond field [RAVIKUMAR *et al.* 2015]. In the present study, hydrochemical diagram software was used to plot this diagram.

The chemical nature of the studied waters is shown in the Piper diagram in Figure 2, which is based on the relative concentrations of the main anions and cations. During February it is apparent that majority of the samples (78.57%; 11 GW samples) belong to $\text{Ca}^{2+}\text{-Mg}^{2+}\text{-Cl}^-\text{-SO}_4^{2-}$ demonstrating the dominance of alkaline earths over alkali (viz., $\text{Ca}^{2+}+\text{Mg}^{2+} > \text{Na}^++\text{K}^+$). Only few samples (14.28%; 2 GW samples) belong to $\text{Na}^+\text{-K}^+\text{-Cl}^-\text{-SO}_4^{2-}$ signifying the dominance of alkali over alkaline earths and 7.14% (1 GW sample) belong to $\text{Ca}^{2+}\text{-Mg}^{2+}\text{-HCO}_3^-$.

In July, it was revealed that 57.14% of the samples (8 GW samples) belong to $\text{Ca}^{2+}\text{-Mg}^{2+}\text{-Cl}^-\text{-SO}_4^{2-}$,

21.42% (3 GW samples) belong to $\text{Na}^+\text{-K}^+\text{-HCO}_3^-$, 14.28% (2 GW samples) belong to $\text{Ca}^{2+}\text{-Mg}^{2+}\text{-HCO}_3^-$ and 7.14% (1 GW sample) belong to $\text{Na}^+\text{-K}^+\text{-Cl}^-\text{-SO}_4^{2-}$.

It is known that the chemical composition of water varies in time and space due to changes in recharge composition and flow patterns and due to chemical processes between the water and the porous environment [BENCER *et al.* 2016]. Erosion of rocks (e.g. limestone and dolomite) and minerals (e.g. calcite and magnesite) are the most common source of HCO_3^- , Ca^{2+} and Mg^{2+} ions. Leaching of soil by erosion, pollution from sewage and industrial waste can also contribute [NIKANOROV, BRAZHNKOVA 2012]. The potential sources of Na^+ , Cl^- and SO_4^{2-} ions in groundwater, might be the dissolution of halite, pyrite and related mineral salts, leaching of rocks and minerals from (upper) soil layer by weathering or erosion, oxidation processes and anthropogenic activities [DINKA *et al.* 2015; NIKANOROV, BRAZHNKOVA 2012].

STATISTICAL ANALYSIS

Correlation between variables. First step in principal component analysis is the determination of the parameter correlation matrix. It is used to account for the degree of mutually shared variability between individual pairs of water quality variables [ASIF *et al.* 2011]. The correlation matrix with which we can observe the relationship between parameters was obtained and tabulated in Table 2.

Correlation studies between different variables are very helpful tools in promoting research and opening new frontiers of knowledge. The study of correlation reduces the range of uncertainty associated with decision making [JOSHI *et al.* 2009]. Electric conductivity shows a strong to moderate positive correlation (0.83, 0.72, 0.71, and 0.46) with Cl^- , Ca^{2+} , Mg^{2+} and HCO_3^- . This reflects the participation of these elements in the acquisition of saline load of groundwater in the region. Chloride (Cl^-) shows also a moderate

Table 2. Correlation coefficients for thirteen physicochemical parameters

Variable	EC	Cl ⁻	SO ₄ ²⁻	PO ₄ ³⁻	NO ₃ ⁻	BOD ₅	COD	DO	HCO ₃ ⁻	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺
EC	1.00												
Cl ⁻	0.83	1.00											
SO ₄ ²⁻	0.20	-0.06	1.00										
PO ₄ ³⁻	0.08	0.06	-0.47	1.00									
NO ₃ ⁻	0.33	0.02	0.67	-0.23	1.00								
BOD ₅	-0.06	-0.29	0.06	0.00	0.21	1.00							
COD	-0.09	-0.20	-0.13	0.02	0.01	0.82	1.00						
DO	0.08	0.36	-0.52	0.20	-0.48	-0.38	-0.22	1.00					
HCO ₃ ⁻	0.46	0.32	0.09	-0.24	0.37	0.17	0.16	-0.18	1.00				
Ca ²⁺	0.72	0.52	0.34	-0.05	0.45	-0.01	-0.09	0.01	0.44	1.00			
Mg ²⁺	0.71	0.55	0.42	-0.18	0.37	-0.09	-0.11	0.06	0.28	0.92	1.00		
Na ⁺	0.07	-0.01	0.19	-0.50	0.17	0.01	0.18	-0.23	0.11	0.12	0.23	1.00	
K ⁺	-0.05	-0.01	0.13	-0.32	0.06	-0.19	-0.21	-0.08	-0.05	-0.10	-0.05	0.30	1.00

Explanations: GW = groundwater, T = temperature, EC = electrical conductivity, BOD₅ = biochemical oxygen demand, COD = chemical oxygen demand, DO = dissolved oxygen, the bold values indicate the correlated variables. Source: own study.

positive correlation (0.52) with Ca²⁺ and a moderate negative correlation (-0.54) with Mg²⁺, indicating a probable common origin. A strong positive correlation (0.92) is observed between Mg²⁺ and Ca²⁺ with indication that most of the ions are involved in various physicochemical reactions, such as oxidation-reduction and ion exchange in the groundwater aquifer system [UDAYALAXMI *et al.* 2010]. Sulphate (SO₄²⁻) shows a moderate negative correlation (-0.47, -0.52) with PO₄³⁻ and DO and a moderate positive correlation (0.66) with NO₃⁻. Otherwise PO₄³⁻ shows a moderate negative correlation (-0.50) with Na⁺. Nitrate (NO₃⁻) shows a moderate negative correlation (-0.48) with DO and a moderate positive correlation (0.44) with Ca²⁺. This is attributed to the effect of anthropogenic pollution, which is usually identified in the urban, industry and agriculture-intensive areas due to the domestic wastewater discharge and agricultural activities [ATTOUI *et al.* 2016; BENRABAH *et al.* 2016; LAMBRAKIS *et al.* 2004]. This analysis shows also a strong positive correlation (0.82) with parameters pollution (COD, BOD₅). COD and BOD₅ were organic pollution indicators, and they could be attributed to uncontrolled domestic discharges [SU *et al.* 20113].

Principal component analysis. 28 water samples were collected and 13 physicochemical parameters were determined. This water quality data was analyzed by using PCA. The second result of this analysis is the liaison between the different variables and individuals because it is used to examine the underlying patterns for a large number of variables and then to determine the possible contributing factors in the waters samples hydrochemistry [VOUDOURIS *et al.* 1997]. The Kaiser criterion [KAISER 1960] was applied to determine the total number of significant factors. An examination of the Kaiser-Meyer-Olkin (0.705) measure of sampling adequacy suggested that the sample was factorable.

From data, four factors, explaining 75.19%, of the total variance, were estimated on the basis of Kaiser criterion [KAISER 1960] of the eigenvalues greater or equal 1 and from a Cattel scree plot [CATTEL 1966].

The eigenvalues for different factors, accounted percentage variance accounted, cumulative percentage variance, and loadings component loadings are given in Table 3. According to this criterion, only factors that eigenvalue greater than or equal to 1 have been retained as a possible source of variance in the data.

Factor 1 explains 29.51% of the total variance (Fig. 3), and has strong to moderate positive loadings on EC, Cl⁻, SO₄²⁻, NO₃⁻, HCO₃⁻, Ca²⁺ and Mg²⁺ which were 0.834, 0.618, 0.548, 0.623, 0.563, 0.882, 0.877 and 0.822 respectively. High positive loadings indicated strong linear correlation between the factor and parameters. Thus, factor 1 can be termed as salinization factor. This axis reflects the role of natural factors such as dissolution of some carbonate, dolomitic, and evaporite minerals in the aquifer. Nitrate (NO₃⁻) can originate from various sources, including municipal waste, soil erosion and fertilizer applica-

Table 3. Rotated factor loading matrix, eigenvalues, % variance and cumulative variance values

Parameter	Factor 1	Factor 2	Factor 3	Factor 4
EC	0.834	-0.342	0.215	0.053
Cl ⁻	0.618	-0.606	0.101	0.222
SO ₄ ²⁻	0.548	0.512	-0.327	-0.416
PO ₄ ³⁻	-0.288	-0.466	0.506	-0.364
NO ₃ ⁻	0.623	0.483	-0.027	-0.372
BOD ₅	-0.035	0.623	0.674	0.106
COD	-0.111	0.508	0.689	0.391
DO	-0.151	-0.779	0.009	0.275
HCO ₃ ⁻	0.563	0.134	0.277	0.237
Ca ²⁺	0.882	-0.159	0.165	-0.068
Mg ²⁺	0.877	-0.168	0.022	0.004
Na ⁺	0.283	0.395	-0.322	0.604
K ⁺	0.045	0.140	-0.640	0.312
Eigenvalue	3.83	2.70	1.97	1.26
% variance	29.51	20.80	15.17	9.71
Cumulative %	29.51	50.31	65.48	75.19

Explanations: GW = groundwater, T = temperature, EC = electrical conductivity, BOD₅ = biochemical oxygen demand, COD = chemical oxygen demand, DO = dissolved oxygen; the bold values indicate strong loadings. Source: own study.

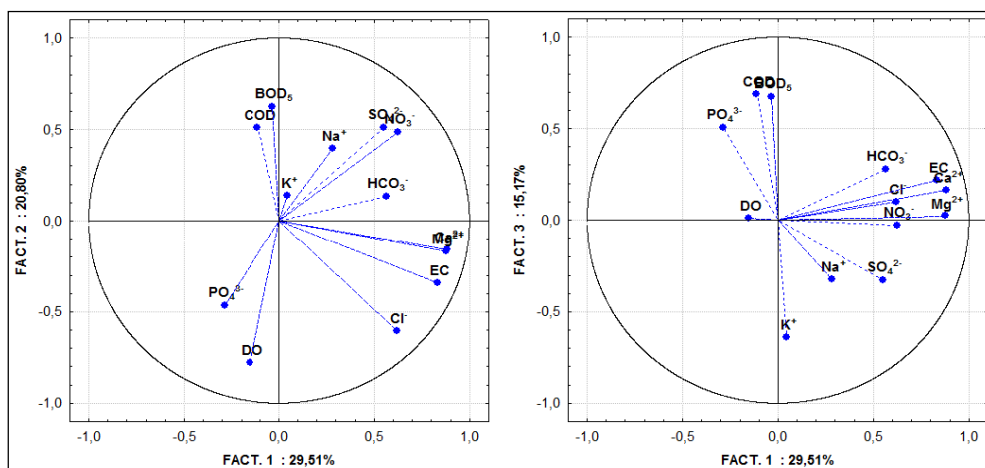


Fig. 3. Factorial plane F1–F2 and F1–F3; source: own study

tions [SU *et al.* 2011]. Factor 2 explains 20.80% of the total variance of the dataset and has strong negative loadings on DO (−0,779). Factor 3 explains 15.17% of the total variance and shows a significant bipolar characteristic. It has strong positive loadings on PO_4^{3-} (0.506), BOD_5 (0.674), COD (0.689), and the negative pole has a strong loading on K^+ (−0.640). Therefore, factor 3 is associated with an opposition between chemical fertilizers and organic pollution from domestic wastewater. Factor 3 is recognized as “anthropogenic pollution” factor, which is usually identified in the urban, industry, and agriculture-intensive areas due to the domestic wastewater discharge and agricultural activities [ATTOUTI *et al.* 2017; DRAGON 2006]. Factor 4 explains the lowest variance 9.71% and Na^+ gave most contribution with a positive loading of 0.604. The presence of Na^+ and is connected to the water-rock interaction and surface water connecting groundwater. Factors 2, 3 and 4 reflect the signatures of the anthropogenic activities, the contaminant source of the agricultural fertilizers and the domestic wastewater discharge [DRAGON 2006]. Hence the combination of factor 2, 3 and 4 is recognized as the pollution group which indicates major processes deteriorating the regional groundwater quality.

Cluster analysis (CA). The analytical results of multivariate analysis were performed for the set of 14 samples and 10 variables. Figure 4 shows the R-mode cluster analysis dendrogram of the 10 descriptors. The variables cluster into four major clusters. These four groups are controlled by the EC. Group 1 (G1) is formed by pH, K^+ and NO_3^- . This group is influenced by agricultural practices. Group 2 (G2) comprises SO_4^{2-} and Mg^{2+} , group 3 (G3) covers Ca^{2+} and Na^+ and group 4 (G4) covers Cl^- and HCO_3^- . These groups are influenced by, wastewater discharge and natural processes.

On the other hand, the Q mode was used to detect the similarity groups between the sampling sites. It yielded a dendrogram (Fig. 5), grouping all 14 sampling sites into three statistically significant clusters. The cluster 1, composed of the sampling stations assigned by numbers 1, 3, 12 and 14 and concerns

28.5% of the total water samples, corresponds to low salinity ($1682 < EC < 2090 \mu S \cdot cm^{-1}$), cluster 2 represented by sample numbers 2, 4, 5, 6, 7, 8, 9, 11 and 13, corresponds to intermediate and average salinity ($2220 < EC < 3100 \mu S \cdot cm^{-1}$). It occupies 64.5 % of the total water samples. Cluster 3 includes sample numbers 10 corresponds to highly salinity (the EC is $3520 \mu S \cdot cm^{-1}$), and concerns 7% of the total water samples. Sample number 10 presented the highest average values of most parameters, especially Ca^{2+} , Na^+ , K^+ , Cl^- and HCO_3^- .

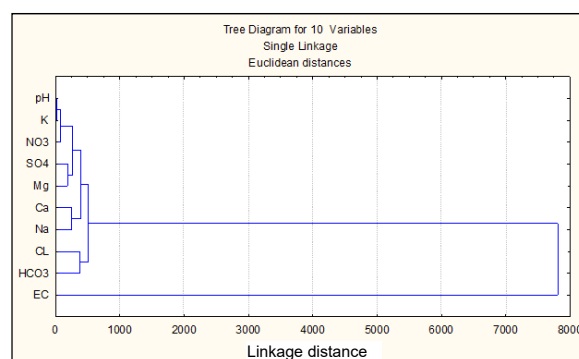


Fig. 4. Cluster dendrogram for variables; source: own study

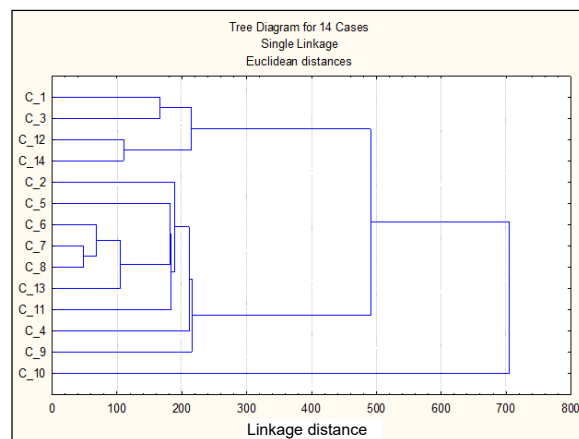


Fig. 5. Cluster dendrogram for water samples; source: own study

CONCLUSIONS

The study showed that the analysis of hydrochemical data using the multivariate statistical techniques such as principal component analysis (PCA) and cluster analysis can give some information not available at first glance and help to elucidate and define the phenomenon at the origin to the mineralization of groundwater in Fesdis Plain; Algeria. The classification of groundwater types and dominant ions for both seasons based on Piper diagram is: Ca^{2+} - Cl^- type, Na^+ - Cl^- type, Ca^{2+} - HCO_3^- type and Na^+ - HCO_3^- type, with Ca^{2+} - Cl^- , as the dominant water type. For almost all samples, the order of abundance in ions is $\text{Ca}^{2+} > \text{Na}^+ > \text{K}^+ > \text{Mg}^{2+}$, for cations and $\text{Cl}^- > \text{HCO}_3^- > \text{SO}_4^{2-}$ for anions.

Principal component analysis is an effective means of manipulating, interpreting, and representing data concerning groundwater pollutants. PCA converted the thirteen parameters in to four factors, which explained 75.19%, of the total variance. The first factor termed as salinization factor, explained 29.51% of the total variance. The second, the third and the fourth factor can be called as anthropogenic pollution factor, which explained 20.80%, 15.17% and 9.71% respectively of the total variance. Hierarchical cluster analysis in R-mode grouped the ten variables into four distinctive groups related to water-rock interaction, agriculture and anthropogenic sources. Q-mode shows 3 statistically groups where *EC* seem to be major distinguishing factors between groundwater samples. Hence, this study illustrates that multivariate statistical methods are an excellent exploratory tool for interpreting complex water quality data sets and for understanding spatial variations, which are useful and effective for water quality management.

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Safia KHELIF, Abderrahmane BOUDOUKHA

Wieloczynnikowa charakterystyka statystyczna jakości wód podziemnych w Fesdis we wschodniej Algierii

STRESZCZENIE

Przedstawione w niniejszej pracy badania stanowią przyczynek do poznania właściwości hydrochemicznych wód gruntowych na równinie Fesdis w Algierii uzyskany z wykorzystaniem wieloczynnikowej analizy statystycznej, w tym analizy głównych składowych (PCA) i analizy skupień. Dwadzieścia osiem próbek wody pobrano w lutym i w lipcu 2015 r. (po 14 próbek w każdym miesiącu). Na podstawie analizy składowych głównych zastosowanej do zbioru danych stwierdzono cztery istotne czynniki, które objaśniały 75,19% całkowitej wariancji. Metoda PCA umożliwiła wyodrębnienie dwóch zjawisk odpowiedzialnych za mineralizację wody. Głównym czynnikiem tworzenia jonów w wodzie jest kontakt wody ze skałą (czas retencji mineralizacji). Drugi czynnik jest odzwierciedleniem aktywności człowieka. W hierarchicznej analizie skupień (CA) zgrupowano 10 zmienionych w cztery skupienia w trybie *R*, a w trybie *Q* zgrupowano 14 stanowisk pobierania próbek w trzy skupienia o podobnych cechach jakości wody.

Słowa kluczowe: *analiza składowych głównych, analiza skupień, hydrochemia, równina Fesdis, statystyczne techniki wieloczynnikowe, wody podziemne*