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Application of principal component analysis (PCA) for evaluating the quality of Hammam Debagh dam water, Guelma province (north-eastern Algeria)

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Abstract

In order to better understand and manage the quality of Hammam Debagh dam water, the application of the two (2) principal component analysis (PCAs) could be beneficial, realized respectively by the physico-chemical parameters and the metallic trace elements (MTEs) In view of such an application, eighteen (18) physico-chemical parameters and four (4) metallic trace elements, coming from samples collected during eleven (11) years from 2006 to 2016, helped to provide answers to our problem. The various results contribute to make known the quality and the sources of pollution of the waters of our dam including agricultural and domestic. The Hammam Debagh dam is slightly polluted and the pollution is of agricultural and domestic origin.

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Introduction

Surface water encompasses all circulating or stored water at the continents surfaces (rivers, lakes, ponds, dams and so on.) The chemical composition of surface water is dependent on the nature of the crossed terrains by this water during its travel through the set of catchments. This composition is found to be modified as a result of intense evaporation at the free water bodies. This water is the seat, in most cases, of a microbial life development because of wastes discharged into the aquatic medium and the large surface of contact with the outer medium; this causes water to be rarely drinkable prior to treatment (ANBT, 2014). In Algeria as in most developing or industrialized countries, the degradation of both surface water and groundwater quality is increasingly becoming a matter of concern. At the scale of a functional unit (catchment), the transfer processes and interactions between water and the different (geological, pedological, climatic, anthropogenic and so on) systems are diverse and very complex. These hydrochemical phenomena lead to a facies that reflects the geochemical environment of the area (Djemai *et al.*, 2017). The use of principal component analysis (PCA) for interpreting data appears to be an interesting solution for a better comprehension of water quality (Chaouki *et al.*, 2015). This technique has also the advantage of transforming the initial quantitative variables, more or less correlated between each other, into non-correlated new quantitative variables called principal components (PCs) (Amadou *et al.*, 2014).

The aim of the present study is to make an application of PCA on physico-chemical data and metallic trace elements (MTEs) for the purpose of management and control of Hammam Debagh dam water quality, to visualize and analyze the existing correlations between different variables through their structuring and their orientations, and to identify the main factors responsible for the quality of this water during the observation period (2006-2016).

Materials and methods

Study area

The Hammam Debagh dam is located on the Bouhamdane wadi at a distance of 20 kilometers west of the Guelma province. This dam was commissioned in 1987 (Benchaiba, 2007). The main characteristics of the dam are summarized in the following Table 1.

Table 1. Main characteristics of the Hammam Debagh dam.

Hydrological characteristics	
Wadi	Bouhamdane
Initial storage capacity	200 hm^3
Last survey storage capacity	184,35 hm^3
Annual mean input	69 hm^3
Annual siltation	0,53 hm^3/year
Catchment surface area	1 070 km^2
Dam characteristics	
Type	Soil
Height	95 m
Length	430 m
Normal operating water level (NWL)	360 m
Highest water level (HWL)	370,24 m
Spillways	Funnel-shaped and free flow
Discharge capacity	2 240 m^3/s
Low-level outlet	218 m^3/s

Source: ABHCSM, 2016.

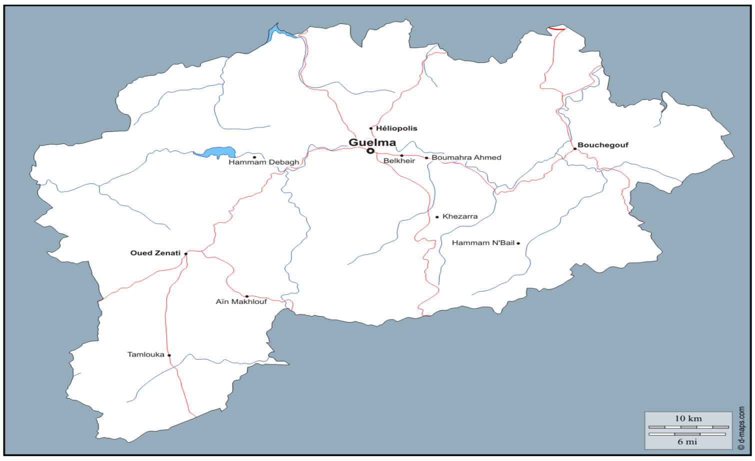

Fig. 1. Localization of the Hammam Debagh dam in the Guelma area (source Hammam Debagh report 2016).

The dam supplies drinking water (PWS) to the following agglomerations: Ain Hassainia, Hammam Debagh, Medjez Ammar, Ben Djerrah and Guelma. The population of these agglomerations is estimated at 162488 inhabitants according to the census of 2008; this population is distributed as follows in Table 2 (AGIRE and ABHCSM, 2016):

Table 2. Distribution of PWS needs according to population (Source ABHCSM, 2016).

Agglomeration	Population (in Hab)	Needs (Hm^3/Yr)
Ain Hassainia	5897	0.32
Hammam Debagh	15384	0.84
Medjez Ammar	3575	0.2
Ben Djerrah	8711	0.48
Guelma	128921	7.1

For the irrigation, the dam supplies the two perimeters: Guelma-Bouchegouf, the surface area of which stretches over 13.000 ha on the one hand and Drean-Besbès in the El-Tarf province on the other hand. The present findings for the irrigation season 2016 show that the volume extracted for the irrigation reaches 20 hm^3 (ABHCSM, 2009).

Table 3. Irrigated surface areas.

Irrigable surface area (ha)	9250
Irrigated surface area (ha)	2401
Irrigation rate (%)	26

Source: ABHCSM, 2016.

The study area is subject to humid to Sub-humid Mediterranean climate. It is marked by monthly and annual irregularities of rainfall (Louamri, 2010). The moderate mean annual temperature (T°C) at the Hammam Debagh dam is of the order of 18, 6°C. The T°C and rainfall findings define two seasons typical of the Mediterranean climate, with a dry-hot season ranging from the beginning of May to November, and a humid-cold season ranging from November to April.

The geology is made by diverse works realized in eastern Algeria. The catchment of the Seybouse is part of the alpine chain of eastern Algeria (Durand Delga, 1969). This chain is made up of the superposition of heterogeneous structural units, the geological history of which ranges from Triassic to Pliocene.

This complex edifice is partially covered by a deposition of Mio-Pliocene and/or Quaternary especially continental (Vila, 1980).

This geology can be divided into three big sets according to (Lahondère, 1987): (i) an ante- nappe set, (ii) a Mio-Pliocene set (continental, the Guelma basin) and (iii) a recent set (Pliocene and Quaternary). The Guelma area is the neritic domain of Djebel Debagh, Heliopolis and southern Guelma.

This carbonate facies and karstified unit of Jurassic-Cretaceous ageis surmounted by several thrust sheets and subject to significant tectonic events. The Guelma valley is an ancient collapse basin closed for a long time, where a varied set of deposits ranging from Miocene to Quaternary piled up.

The Plio-Quaternary tectonic movements are greatly involved in the area morphogenesis. The study area is classified as a farming sector; it is characterized by a large scale growing of different agricultural products: vegetables (323 ha), industrial cultures (1711 ha), forage (03 ha), fruit trees (353 ha) and cereals (11 ha) (ANBT, 2014).

For the industry, our study area is characterized by 15 car washandfuelstations concentrated on the axis Hammam Debagh- Bouhamdane, and an industrial unit (brickyard); they discharge into the Bouhamdane wadi (Mansouri, 2009). The major pollution sources, namely urban pollution represented by the discharges of domestic wastewaters of the study area, which are discharged without prior treatment, into the wadis, and agricultural pollution (Mouchara, 2009).

Analysis methods

Data used in the framework of this study come from the findings of monthly chemical analyses during eleven (11) years (2006/2016), provided by national agency of the dam and transfers of Algeria (ANBT). These data are concerned about the physico-chemical and MTEs parameters. The statistical study is based on the PCA. The intermediate matrices correlations, the correlations coefficients between the variables and the two axes F1-F2 and the variables projections in the space of axes F1-F2 were obtained by STATISTICA software. The PCA is performed on a matrix of data constituted of 12 monthly samples of each year during the observation series (2006-2016), in the course of which, the physico-chemical parameters were measured whereas another matrix of data constituted of 12 monthly samples of each year during the observation series (2006-2016), in the course of which, the four MTEs were measured (Chaouki *et al.*, 2015).

Results and discussion

Chemical facies

For the chemical facies, the general aspect of Piper diagram shows that the Hammam Debagh dam water is mostly chloride-magnesium type water (Fig.2).

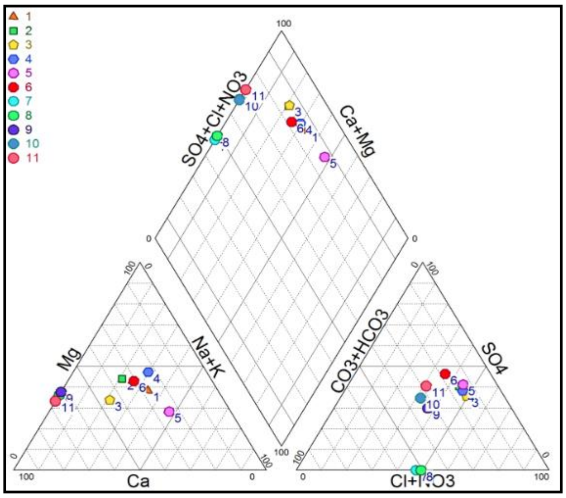

Fig.2. Graphic representation of chemical facies of Hammam Debagh dam water on Piper diagram.

Application of PCA using physico-chemical parameters

The analysis of findings allows highlighting that most of the information is explained by the two first factorial axes (Mouissi and Alayat, 2016). In the factorial design F1×F2, the eigenvalues of the two components F1 and F2 and their contribution to the total inertia are represented in Table 4. The two axes taken into account in order to describe the correlations between variables linked to the spatial structures, hold alone 60,56% of the total information, with 42,30% for the axis F1 and 18,26% for the axis F2, respectively (Table 4).

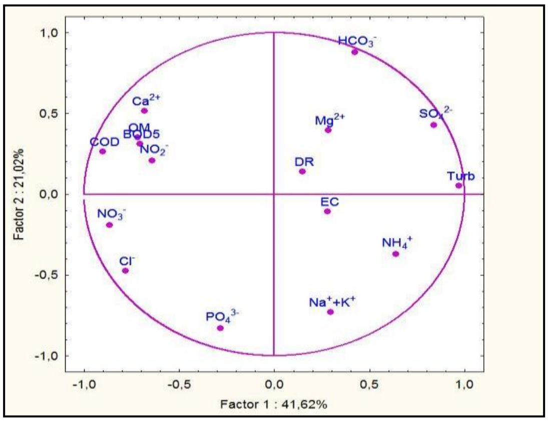

Fig. 3. Projection of variables on the factorial design (F1×F2).

The axis F1 is expressed, to its positive pole by turbidity (Turb), phosphate (PO_4^{3-}), sulfate ($SO4^{-2}$), nitrate (NO_3^-), magnesium (Mg^{2+}), sodium (Na^+), potassium (K^+) and chlorides (Cl^-) that exhibit good correlations between each other (Fig. 3), and to its negative pole by bicarbonate (HCO_3^-), organic matter (OM), chemical oxygen demand (COD), nitrite (NO_2^-) and dissolved oxygen (DO_2), whereas the axis F2 is defined by electrical conductivity (EC), T°C and ammonium (NH_4^+) to its positive pole.

Table 4. Distribution of inertia between the two axes (F1×F2) of the physico-chemical parameters measured in Hammam Debagh dam water.

Factors	F1	F2
Eigenvalues	7,61	3,28
% Variance	42,30	18,26
Eigenvalues cumulative	7,61	10,89
Cumulative variance explained %	40,30	60,56

In the correlation circle (Fig. 3), the component (F1), contributing with 42, 30% of inertia, is defined by organic pollution parameters, namely COD, OM, Turb, NO_3^-, NO_2^- and PO_4^{-3} on the one hand and the elements responsible for the most abundant chemical facies for the dam water, namely chloride-magnesium facies on the other hand. With an inertia of 18, 26%, the component (F2) is defined by EC, which is responsible for the mineralization of Hammam Debagh dam water. The typological structure generated by the design F1×F2 (Fig. 4) shows the individualization of two different groups according to their hydro-chemical quality (Amadou *et al.*, 2014):

the first groups the individuals having a significant pollution, and the second set is opposed to the first one; it is marked by the elements responsible for mineralizing water of our study area.

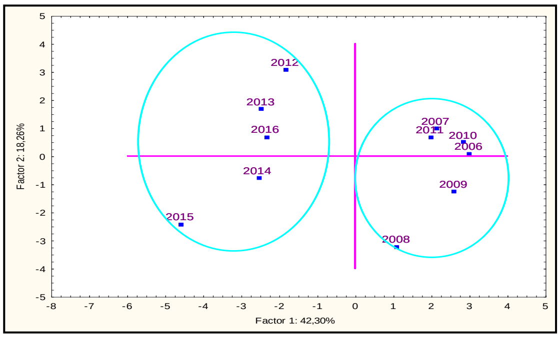

Fig. 4. Projection of individuals on the factorial design (F1×F2).

Application of PCA using MTEs

The two axes (F1×F2) taken into consideration in order to describe the correlations between variables linked to the spatial structures hold alone (Kendouci *et al.*, 2013) 83,36% of the total information, with 59,65 % for the axis F1 and 23,71% for the axis F2, respectively (Table 5).

Table 5. Distribution of inertia between the two axes (F1×F2) of MTEs measured in Hammam Debagh dam water.

Factors	F1	F2
Eigenvalues	2,40	0,95
% Variance	59,65	23,71
Eigenvalues cumulative	2,40	3,35
Cumulative variance explained %	59,65	83,36

The examination of the correlation matrix (Table 6) between variables reveals that all linear correlations are positive (which means that all variables vary, on average, in the same direction) (Khedimallah and Saidi, 2014), some are high (0, 80), namely Cu/Pb, others medium (0, 50 and 0, 56), such as those of Manganese (Mn) with Copper (Cu) and Lead (Pb).

Table 6. Correlation matrix between MTEs measured on Hammam Debagh dam water.

Variable	Cu	Mn	Pb	Zn
Cu	1,00			
Mn	0,50	1,00		
Pb	0,80	0,56	1,00	
Zn	0,13	0,40	0,28	1,00

In the factorial design F1×F2 (Fig. 5), the axis F1 describes the overload of Hammam Debagh dam water by Pb (0, 80), Mn (0, 56) and Cu (0, 50). The axis F2 describes the enrichment of this water in Zinc (Zn) (0, 40). From left to right, the axis F2 reflects, thus, an increasing gradient of a water overload with Cu, Mn, Pb and Zn. And from bottom to top, the axis F1 reflects an increasing gradient of water pollution by Zn (Fig.5).

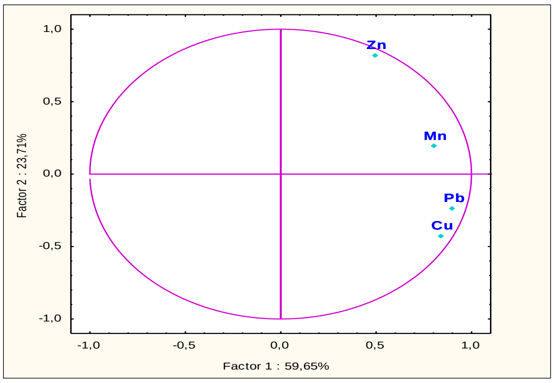

Fig. 5. Projection of variables on the factorial design (F1×F2).

The typological structure generated by the design F1×F2 (Fig. 6) (Mouissi and Alayat, 2016) shows the individualization of two point's clouds. Group I, group's water which is marked by a severe pollution by MTEs, notably Pb, Cu, Mn and Zn. In addition, group II, formed by water being marginally polluted by these elements.

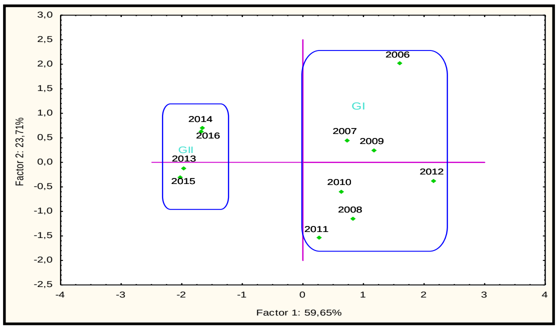

Fig. 6. Projection of individuals on the factorial design (F1×F2).

These results confirm that there is an absence of a study to quantify the pollutant loads entering the watershed and lack available data on the sources of water pollution of the Hammam Debagh dam, to contribute to the quality of these waters, so we can see that the discharges of domestic sewage from the agglomerations of Wadi Zenati and Bordj Sabat which are causing water pollution due to the lack of a treatment plant upstream of our dam.

Conclusion

This study revealed also the significance and utility of principal component analyses techniques (PCA) for obtaining information on the quality of Hammam Debagh dam water. The findings obtained on the two PCAs realized respectively by the physico-chemical parameters and MTEs highlighted the existing correlation between the different parameters and the distribution during the observation period (2006/2016). These two PCAs allowed evaluating the quality of Hammam Debagh dam water. The quality of this water varies from one year to another according to pollution degree. In fact, the graphical representation of PCA of the physico-chemical parameters and MTEs of Hammam Debagh dam water in the factorial space F1×F2 allowed highlighting two classes of water: the first class groups water which is highly mineralized, with similar chemical facies, the second class encompasses polluted water with high Pb, Cu, Zn and Mn contents. The following recommendations are necessary to safeguard this resource:

- The installation of a wastewater treatment plant for the wastewater treatment of the cities of Zenati and Bordj Sabat Wadis.
- Installation of automatic monitoring stations for the quality of dam water to prevent any pollution.
- The use of biological treatment through the seeding of bacteria assimilating the excess OM and the stocking with silver carp and large mouth.
- The use of release and hunting operations studied to limit the siltation of the reservoir.

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