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Hydrochemical characteristics and water quality assessment of Lake Dayet Erroumi – Khemisset, Morocco

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Abstract

The objective of this paper is to study the hydrochemical characteristics of Lake Dayet Erroumi (Khemisset, Morocco). Three sampling campaigns were carried out in April, July and November 2019. The temperature, pH and electrical conductivity were measured *in situ* using Hanna Instruments HI 98280. Concentrations of calcium, magnesium, carbonate, bicarbonate and chloride were analysed by the volumetric method. The atomic absorption technique was used to determine sodium, potassium, nitrate and sulphate. The physico-chemical analysis of the water indicates that the pH is basic. The nitrate and sulphate concentrations show that the water is of good quality according to Moroccan surface water guidelines. Furthermore, the hydrochemical facies of water is of the sodium-chloride type according to the Piper diagram. The value of the electrical conductivity indicates that the lake water has high salinity. The high mineralization of water is explained by the leaching from evaporitic rocks in the region. The principal component analysis shows that the spatial and temporal variation in salinity constitutes the major phenomenon of the hydrochemical characteristics of this lake. Salinity varies inversely with the pH value. The salinity of the water is controlled by abiotic factors (rain and evaporation). However, other parameters (pH, nitrate, carbonate and bicarbonate) depend on biotic factors. Evaporation plays a crucial role in the seasonal variation of the water chemical composition. During wet seasons, the mineralization of water decreases due to dilution by rainwater and the water level of the lake rises (high water period). During dry seasons, lake water evaporates and consequently the mineralization of the water increases, which explains the increase in salinity during the low water period.

Key words: *Dayet Erroumi, hydrochemical characteristics, Morocco, salinity, water quality*

INTRODUCTION

Lakes are dynamic systems in constant evolution which adapt to changes in their environment. Each lake is characterized by a specific and diversified flora and fauna which reflect the prevailing environmental conditions.

The lakes have always attracted different anthropogenic activities (agriculture, fishing, tourism, etc.). These activities can lead to severe environmental impacts: pollution, proliferation of invasive species, climate change, etc.

Studies of lakes have attracted the attention of scientists around the world. Several studies have examined the quality of lake water [ASTEL *et al.* 2016; GIARDINO *et al.* 2007; JIRSA *et al.* 2013; URBANSKI *et al.* 2016; WORQLUL *et al.* 2015; ZHAO *et al.* 2012]. A large number of authors have studied the phenomenon of eutrophication. Other researchers have investigated the impact of climate change on lake functioning [BURNETT *et al.* 2011; CHERKAUER, SINHA 2010; CROSSMAN *et al.* 2013; FENG *et al.* 2012; SHIMODA *et al.* 2011; SHRESTHA *et al.* 2012; YE *et al.* 2013]. In

Morocco, various studies have been carried out on the lakes [ABBA *et al*. 2008; BOUIH *et al*. 2005; ETEBAAI *et al*. 2008; 2012; NASSALI *et al*. 2001; SADANI *et al*. 2004; SAYAD *et al*. 2011].

The aim of this paper is to investigate the hydrochemical characteristics of the lake in order to: (i) assess the physicochemical quality of water, and (ii) determine which processes control the chemical composition of water.

MATERIAL AND METHODS

STUDY AREA

Lake Dayet Erroumi represents the only permanent natural low-lying continental lake in Morocco. It is a shallow lake (maximum 14 m) of 90 ha in area located 15 km southwest of Khemisset (Fig. 1). It is an elongated lake (Fig. 2) in the WSW-ENE direction, 1.6 km in length and a 400 to 700 m in width. The climate in the study area is Mediterranean [CEIBM 2019].

Fig. 1. Geographic location of Lake Dayet Erroumi in Morocco; source: own elaboration based on Google Earth (2019)

Fig. 2. Location of sampling sites of Lake Dayet Erroumi; source: own elaboration based on Google Earth (2019)

STUDY METHODS

The samples were taken 3 times a year, in April, July and November 2019 to cover spring, summer and autumn seasons. Six samples, from S1 to S6, were taken all around the lake from the banks. The location of the sampling points is shown in Figure 2. Samples of water collected have been placed in 1 litre sterile polyethylene bottles and transported to the laboratory in a cooler at 4°C. The temperature (T), pH and electrical conductivity (EC) have been measured in situ using Hanna Instruments HI 98280. The chemical composition has been determined in the laboratory of the Regional Office for Agricultural Development of Gharb (Fr. Office Régional de Mise en Valeur Agricole du Gharb – ORMVAG). The concentrations of calcium (Ca^{2+}), magnesium (Mg^{2+}), carbonate (CO_3^{2-}, bicarbonate (HCO_3^-) and chloride (Cl^-) have been analysed by the volumetric method. The atomic absorption technique has been used to determine sodium (Na^+), potassium (K^+), nitrate (NO_3^-) and sulphate (SO_4^{2-}). The data obtained have been processed using an Excel spreadsheet 2016 and the XLSTAT 2016 software, which supports a principal component analysis (PCA), in order to determine similarities or dissimilarities between parameters.

RESULTS AND DISCUSSION

TEMPERATURE

Temperature is a parameter of great ecological importance [IOUNES *et al.* 2016]. It plays an essential role in the solubility of salts and gases [CHEIKH *et al.* 2011]. In fact, the physicochemical and biological processes in water depend on temperature [BHATERIA, JAIN 2016; SHARMA, WALIA 2015]. It also influences the distribution of living organisms in an aquatic environment [IOUNES *et al.* 2016]. Temperature affects the degree of evaporation that controls the salinity of water [GOUAIDIA 2008]. Water temperature has varied between 18.5 and 31.5°C (Fig. 3).

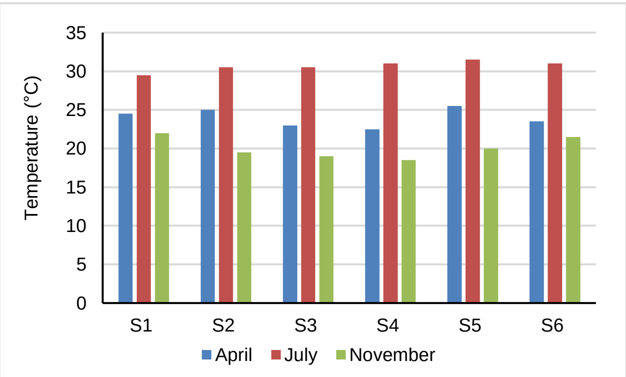

Fig. 3. Spatio-temporal variations of temperature of all the studied water samples; S1–S6: sampling sites; source: own study

HYDROGEN POTENTIAL (pH)

pH is a measure of hydrogen ions (H^+) concentration. It depends much on chemical and biological mechanisms [DJABOURABI *et al.* 2014; PURI *et al.* 2010] and plays an important role in the physico-chemical balance of water [BELGHITI *et al.* 2013]. It is linked to the buffer system developed by carbonate and bicarbonate [IOUNES *et al.* 2016]. It depends on the origin of water, geological nature of the rocks, and the catchment area [BELGHITI *et al.* 2013; GRIBA *et al.* 2019].

Results show that the pH is alkaline and varies between 8.44 and 10.2 (Fig. 4). High values recorded during a high water period (April) may be due to an increase in the photosynthetic assimilation of dissolved CO_2. In fact, the photosynthesis process contributes to the increase in the consumption of CO_2 which increases the pH value [ANDERSEN *et al.* 2017; DJABOURABI *et al.* 2014; OSSEY *et al.* 2008].

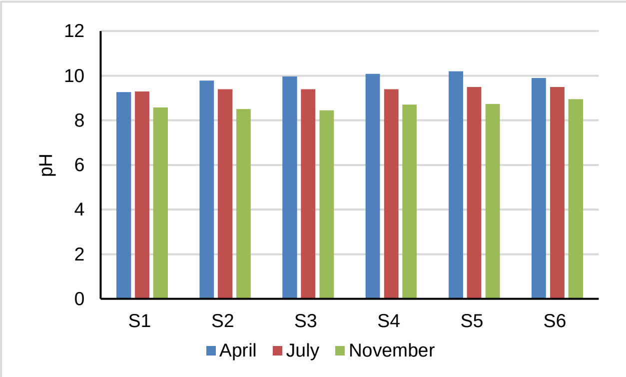

Fig. 4. Spatio-temporal variations of pH of all the studied water samples; S1–S6: sampling sites; source: own study

ELECTRICAL CONDUCTIVITY

The electrical conductivity reflects the salinity level and the degree of overall mineralization of water [LAKHILI *et al.* 2015; MALEK *et al.* 2019]. This is a parameter that represents the total concentration of water-soluble salts [PURI *et al.* 2010]. The electrical conductivity depends on the evaporation as well as the geological substrate crossed [BELGHITI *et al.* 2013].

The value of the electrical conductivity has been between 3230 and 4460 $\mu S \cdot cm^{-1}$ in the study area (Fig. 5). The highest values are recorded during the low water period in November. Evaporation is the process responsible for the variation in electrical conductivity.

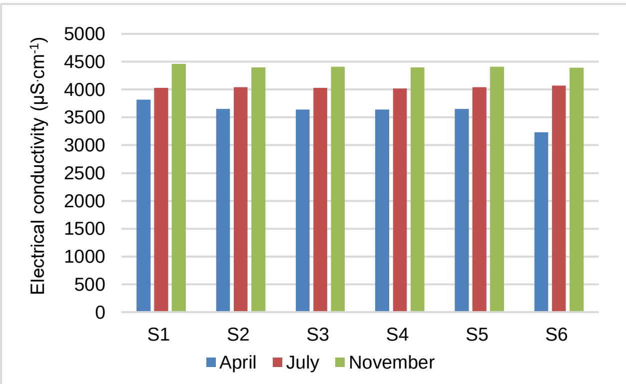

Fig. 5. Spatio-temporal variations of electrical conductivity of all the studied water samples; S1–S6: sampling sites; source: own study

SODIUM AND CHLORIDE

Sodium results from the dissolution of halite (NaCl) or the decomposition of silicates [RODIER *et al.* 2009]. The sodium value varies between 632.5 and 805.0 mg·dm^{-3} (Fig. 6).

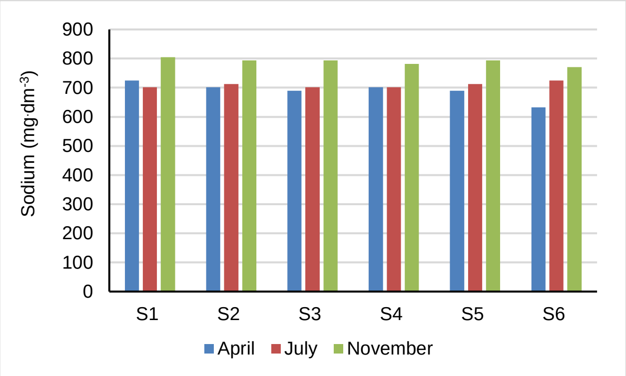

Fig. 6. Spatio-temporal variations of sodium concentration of all the studied water samples; S1–S6: sampling sites; source: own study

Chloride is widely distributed in nature, usually in the form of sodium and potassium salts [NECHAD *et al.* 2014]. They have an influence on aquatic organisms as well as on plant growth [LAKHILI *et al.* 2015]. The chloride concentration is high. It is between 844.9 and 1207 mg·dm^{-3} (Fig. 7).

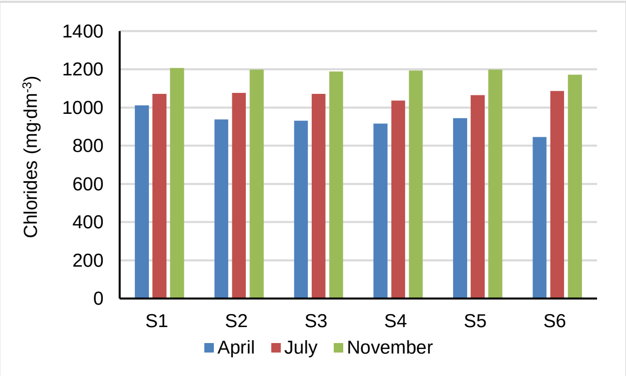

Fig. 7. Spatio-temporal variations of chloride concentration of all the studied water samples; S1-S6: sampling sites; source: own study

Chloride and sodium prevails in the chemical composition of water. These two ions evolve in linear correlation (Fig. 8). All these results show that the origin of these two major ions is the dissolution of halite. In fact, the study area is located in the Khemisset plateau, which is characterized by the presence of the evaporitic formations of the Mesozoic Age [ET-TOUHAMI 2000].

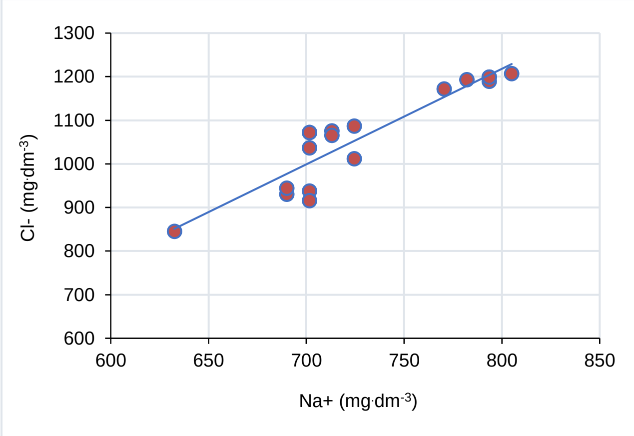

Fig. 8. Linear correlation between chloride and sodium of all the studied water samples; source: own study

CALCIUM AND MAGNESIUM

These elements are responsible for the hardness of water [COUTURE 2006; NECHAD *et al.* 2014; TFEILA *et al.* 2016]. Calcium comes from the dissolution of carbonate rocks [EL BADAOUI 2016; EL MOSTAFA HASSOUNE *et al.* 2006] and gypsum rocks [KAHOUL, TOUHAMI 2014], while magnesium is derived from dolomitic rocks [MALEK *et al.* 2019].

The calcium and magnesium content varies from 35.6 to 65·2 mg·dm^{-3} (Fig. 9a) and from 40.58 to 86.99 mg·dm^{-3} (Fig. 9b) respectively.

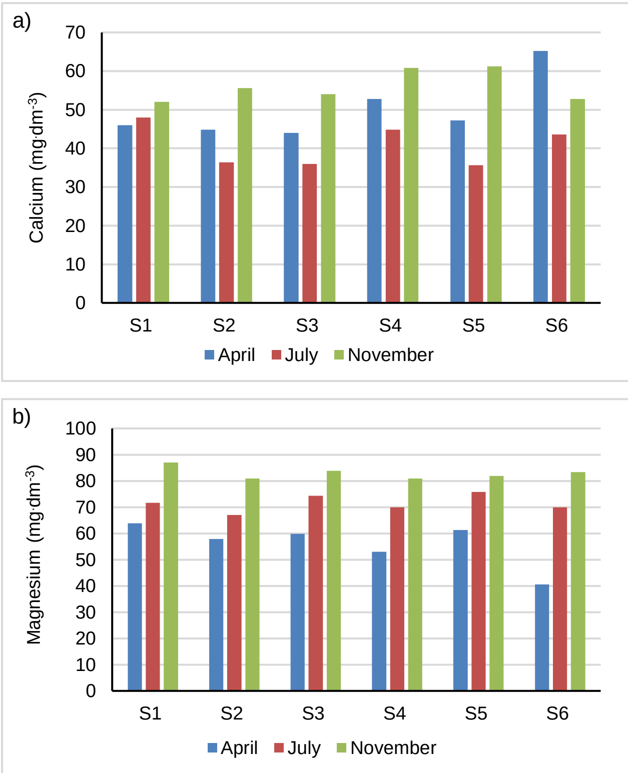

Fig. 9. Spatio-temporal variations of calcium (a) and magnesium (b) concentration of all the studied water samples; S1–S6: sampling sites; source: own study

POTASSIUM

Potassium results from the weathering of clay minerals and the dissolution of chemical fertilizers [GOUAIDIA 2008]. Its content varies between 7.82 and 9.38 mg·dm^{-3} (Fig. 10). This is the lowest concentration of major ions. There is little variation between sampling stations.

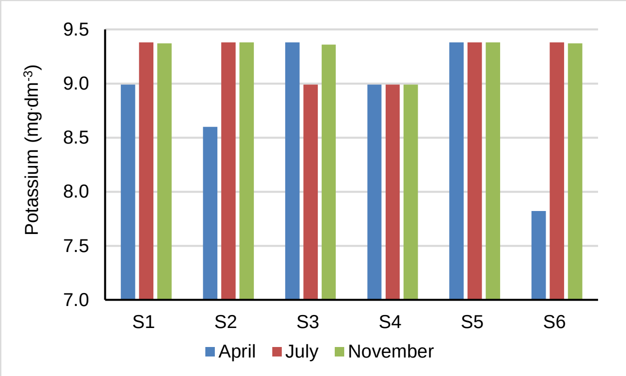

Fig. 10. Spatio-temporal variations of potassium concentration of all the studied water samples; S1–S6: sampling sites; source: own study

NITRATE

Nitrate results from the oxidation of organic matter [TFEILA *et al*. 2016] where it constitutes the final stage of nitrogen oxidation [LAKHILI *et al*. 2015]. It is one of the factors responsible for the degradation of water quality [IOUNES *et al*. 2016]. Agriculture remains the main source of nitrate [GOUAIDIA 2008; LALAMI *et al*. 2011].

The presence of nitrate in lake water can overstimulate the growth of algae and plants [TAMOT, SHARMA 2006], which can induce eutrophication [ZENG *et al*. 2019]. This can negatively affect the diversity of aquatic organisms [TAMOT, SHARMA 2006].

The nitrate content is between 5.58 and 19.84 mg·dm^{-3} (Fig. 11). The water is of good quality according to Moroccan surface water guidelines [2002]. High values at various sampling stations are recorded during the month of November. The spatiotemporal variation of nitrate can be explained by the combined action of climatic (rain and evaporation) and biological factors (absorption of nitrate by aquatic vegetation and decomposition of organic matter). Furthermore, the lake is surrounded by agricultural land. Nitrate from fertilizers can be brought to the lake by rainwater and runoff.

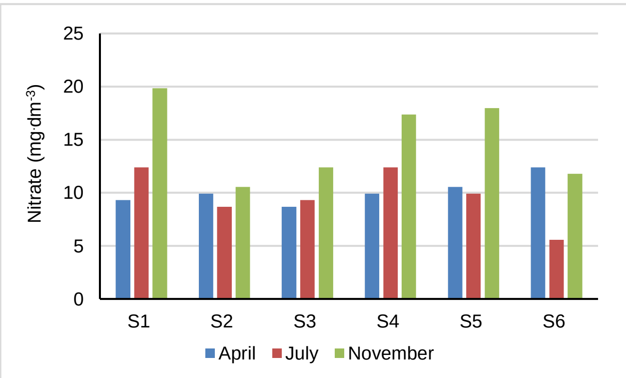

Fig. 11. Spatio-temporal variations of nitrate concentration of all the studied water samples; S1–S6: sampling sites; source: own study

SULPHATE

Sulphate comes from the solubilisation of gypsum and pyrite [GHAZALI, ZAID 2013]. Its origin can be anthropogenic, such as industrial discharges [OSIBANJO *et al*. 2011], and the use of chemical fertilizers [IOUNES *et al*. 2016]. Sulphate also results from the activity of certain bacteria that can oxidize toxic hydrogen sulphide (H_2S) to sulphate [BELGHITI *et al*. 2013]. The sulphate concentration varies between 149.76 and 218.88 mg·dm^{-3} (Fig. 12). High values at the different sampling stations are recorded in April. This result indicates good water quality according to Moroccan surface water guidelines [2002].

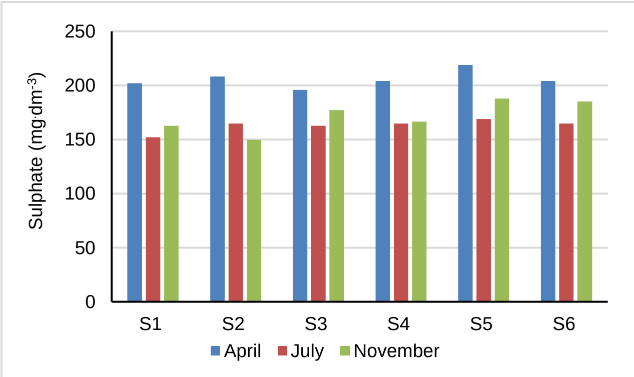

Fig. 12. Spatio-temporal variations of sulphate concentration of all the studied water samples; S1–S6: sampling sites; source: own study

CARBONATE AND BICARBONATE

The presence of carbonate and bicarbonate in water is due to the dissolution of carbonate rocks [GOUAIDIA 2008]. The concentration of carbonate and bicarbonate is partly regulated by the photosynthesis, respiration and solubilisation processes of carbon dioxide [ZHANG 2014]. The carbonate and bicarbonate content varies from 24 to 213.6 mg·dm^{-3} (Fig. 13a) and from 97.6 to 280.6 mg·dm^{-3} (Fig. 13b) respectively.

The equilibrium of the carbon dioxide-bicarbonate-carbonate system is controlled by the following reactions [FEKRACHE 2015]:

1) $H_2O + CO_2 \rightleftharpoons H_2CO_3$
2) $H_2CO_3 \rightleftharpoons HCO_3^- + H^+$
3) $HCO_3^- + H^+ \rightleftharpoons 2H^+ + CO_3^{2-}$

Carbonate and bicarbonate evolve according to the pH of water, which is itself linked to the photosynthetic activity [ABBA *et al*. 2008]. In fact, photosynthesis reduces the concentration of dissolved CO_2, increases the pH and changes carbonate and bicarbonate concentrations [ZENG *et al*. 2019].

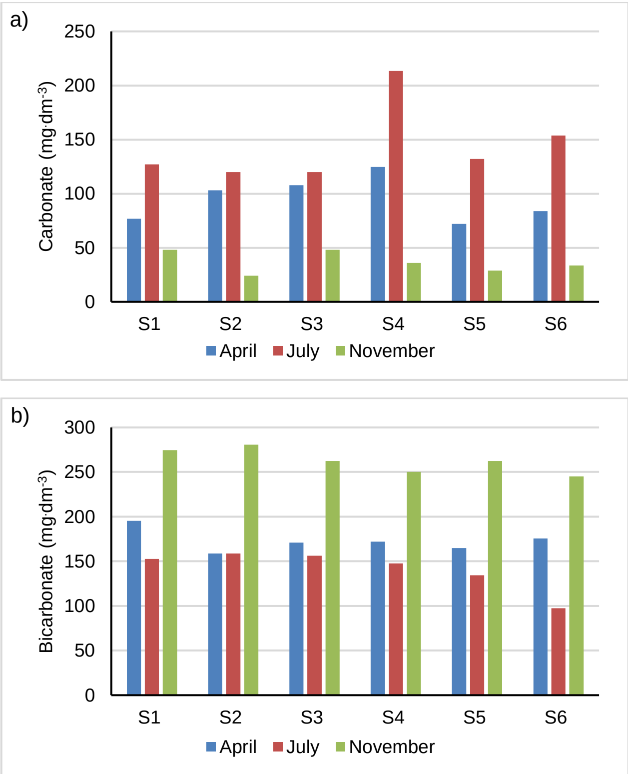

Fig. 13. Spatio-temporal variations of carbonate (a) and bicarbonate (b) concentration of all the studied water samples; S–S6: sampling sites; source: own study

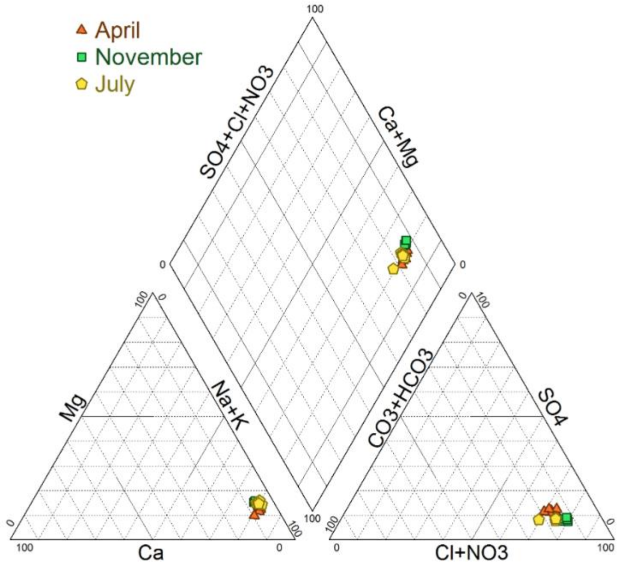

Fig. 14. Piper diagram showing the chemical composition of all samples of the lake water; source: own study

HYDROCHEMICAL FACIES

Hydrochemical facies are frequently used in determining the composition and chemical quality of ground and surface water [KUMAR 2013]. In this study, the chemical characteristics of water were assessed by the Piper diagram. This diagram is widely used to interpret hydrogeochemical data [KARMEGAM *et al*. 2011] and to compare chemical compositions of water. The Piper diagram was drawn by the Avignon Hydrogeology Laboratory using the "Diagrammes" software [SIMLER 2014]. The representation of samples from the three campaigns on the Piper diagram (Fig. 14) has shown that the hydrochemical facies is of the sodium chloride type. The Piper diagram shows no evolution, the facies remain the same with a little change.

PRINCIPAL COMPONENT ANALYSIS

Principal component analysis was applied to 12 variables and 18 observations (6 observations x 3 campaigns). The PCA is a multivariate analysis technique widely used in environmental studies [BENGRAÏNE, MARHABA 2003; LU *et al*. 2010]. The method contributes to data reduction [BENGRAÏNE, MARHABA 2003; PRIMPAS *et al*. 2010; SHRESTHA *et al*. 2008]. The purpose of this method is to represent similarities between observations and linear correlations between variables [ALAYAT, LAMOUROUX 2006]. The results of the PCA are shown in Figure 15.

Electrical conductivity, sodium, magnesium and chloride are highly positively correlated with the F1 axis. These parameters indicate the mineralization of water, and depend

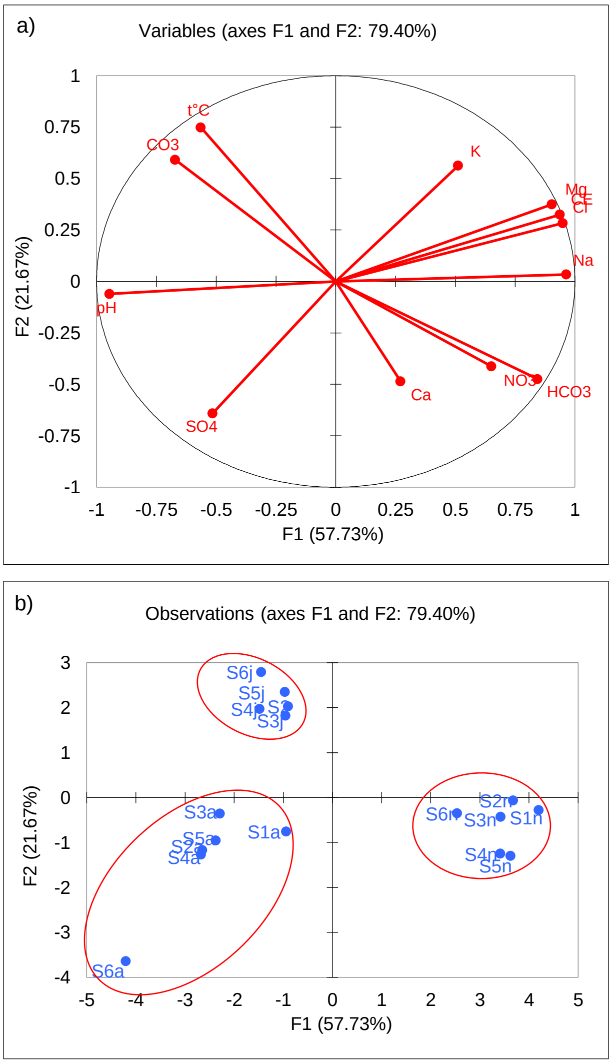

Fig. 15. PCA results of all the studied water samples: a) correlations between variables, b) position of the sampling points in the first factorial plane (Sa for April, Sj for July and Sn for November 2019); source: own study

on abiotic factors (climatic factors). The first factorial axis F1 represents 57.73% of the total variance. It is an axis of water mineralization which indicates the increase in the concentration (salinization) of the waters with the drop in pH (negative correlation between pH and F1 axis). The second factorial axis F2 explains 21.67% of the information and distinguishes warm waters with low nitrate from less hot waters which contain more nitrate. This component separates the waters of July from those of the other months.

The projection of the observations in the factorial plan highlighted three groups which reflected the seasonal variation of the water chemical composition. The waters of November are more mineralized compared to waters of other months. Thus, the spatial and temporal variations of salinity constitute the major phenomena of the physico--chemical characteristics of the water in the lake. Evaporation plays an essential role in the variation of salinity. However, certain parameters (pH, nitrate, carbonate and bicarbonate) depend on biotic factors (photosynthetic activity). The results confirm also that the salinity varies inversely with the pH value.

CONCLUSIONS

The physicochemical analysis of the lake water shows that the pH is alkaline ($8 < pH < 11$). The salinity of the water is high with a dominance of chloride and sodium. This mineralization results from the dissolution of evaporitic rocks in the region. The nitrate and sulphate content shows that the water is of good quality according to Moroccan surface water guidelines. The hydrochemical facies of water is of the sodium-chloride type.

The principal component analysis revealed the presence of a significant positive correlation between electrical conductivity, sodium and chloride. These parameters reflect the water mineralization and depend on abiotic factors (rainfall and evaporation). The first component F1, which represents more than half of the total variance, constitutes an axis of water mineralization. However, other parameters (pH, nitrate, carbonate and bicarbonate) are controlled by biotic factors. The equilibrium between carbonate and bicarbonate depends on the change in pH. When the pH drops, the carbonate turns into bicarbonate. The results also show that the pH value changes inversely with salinity.

In this study, the lake water level fluctuates with seasons. April is a period of high water and November represents a period of low water, while July is an intermediate water level period. Evaporation plays a crucial role in the seasonal variation of the chemical composition of water. Indeed, after a period of rain, the water level of the lake rises (high water period) causing dilution. During dry seasons, evaporation causes an increase in the salinity of water, which is typical in arid or Mediterranean areas, and the drop of the lake water level (low water period).

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