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EVALUATION OF SOIL SALINITY OF THE FETZARA LAKE REGION (NORTH-EAST ALGERIA)

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Abstract: *Fetzara lake, located at 18 km southwest of Annaba city, is one of the largest lakes in the extreme northeastern Algeria. In 2002, the Ramsar convention classified it among the wetlands of international importance. In this study, we aim to evaluate soil properties of Fetzara lake region, which are very sensitive to salinization phenomena, and their evolution according to depth. A sampling companion was carried out on the first two superficial levels 0 to 25 cm and 25 to 50 cm. A total of 24 samples, gathered from 12 sites distributed around the lake perimeter, were analyzed for their physical and physico-chemical properties. Results show that the majority of the soils samples are classified as saline soils (ESP ≤ 15%, EC > 4 mS cm^{-1}), with a highly variable electrical conductivity (6.52 to 24.3 mS cm^{-1}), reaching its maximum in both northeastern (Wadi Zied town) and southeastern part of the lake (Cheurfa town). Moreover, the soil solutions are characterized by the abundance of ions such as Cl^-, SO_4^{2-}, Na^+ and Mg^{2+}, giving a dominant sodium chloride facies in most of the analyzed samples.*

Keywords: *sodization, ionic exchanges, alkalinity, saline soils, soil quality, wetlands*

1. Introduction

Soil salinity becomes a major problem in global agriculture when soil and environmental factors contribute to the accumulation of salts in soil layers to a level that negatively affects crop production. Worldwide, more than 800 million hectares of land are estimated to be affected by salt [1-2]. This is usually due to natural processes such as the accumulation of salt by rainfall or by the weathering of rocks, known as primary salinization. Secondary salinization can result from human activities such as urbanization, agricultural practices and irrigation of cultivated land [3-9]. In the Mediterranean region, salt accumulation is a process favoured by the ecological conditions of the region, controlled above all by soil and climate variability and the expected increase in irrigated areas and the scarcity of good quality water [10-13]. This accumulation and modification of the sorption complex (exchange phenomena) leads to a substantial degradation and transformation of the physical and chemical properties of soils, resulting in a reduction the productivity of many agricultural crops, including most vegetable crops, which present low tolerance to soil salinity [9, 14-16]. In Algeria, several wetlands concentrated mainly in the northeastern part of the

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country, along the Mediterranean coastal suffer from soil salinization [17]. The Fetzara lake region is one of the most important wetlands in northeast Algeria and has been classified as a Ramsar Wetland since 2002. Its vast surface and its relatively temporal character make it a typical wetland of the Mediterranean region [18] and an important ecosystem that requires surveillance of both its quality and quantity. Several studies [7, 17, 19-24] have generally mentioned the salinization problem in Fetzara lake region, especially in the northeastern and southeastern parts, but without providing details about the mechanisms controlling this phenomenon. Therefore, a suitable study on the soil salinity of this region seems very useful and provides more information about this problem.

The assessment of soil quality and salinization requires the determination of their physico-chemical properties, which are quantitatively measurable providing a complete description of the major processes of their functioning [16, 25-26]. The risk of soil degradation can be assessed by two important criteria, namely: the soluble salt content that reflects salinity in the strict sense while the percentage of exchangeable sodium in the soil reflects sodization [8-9, 14]. The sodization phenomenon is the process of sodium exchange on the sorption complex of clays and their progressive saturation in sodium ion [27].

The objective of this research is to study the quality and salinization of soils in the Fetzara lake region, by interpreting the results obtained from the analysis of physicochemical parameters using analytical and statistical approaches (PCA) as well as calculating indexes relating to the soil classification, i.e. the exchangeable sodium percentage (ESP) and the sodium adsorption ratio (SAR).

2. Matherials and methods

2.1. Study area

Fetzara lake is located in north-east Algeria and distant of 18 km south-west of Annaba city (Fig. 1), covers an area of about 18600 ha stretching for 17 km long from East to West and 13 km wide from North to South [23]. The lake collects water from an important watershed of about 515 km^2, it plays a major role in flood control, sediment and nutrient retention and recharge of the water table [28-29]. Throughout the year, a main canal drains the water from the lake, which is evacuated into the oued Meboudja, then into the oued Seybouse, which in turn flows into the Mediterranean Sea.

Geologically, the Fetzara region is characterized by two distinct lithologies, metamorphic and sedimentary. Metamorphic formations outcrop in the Edough Massif and its surroundings area, they consist mainly of gneiss and metapelites (Alumaceous Shale Unit). Sedimentary formations occupy the rest of the study area and consist of marls, clays, cretaceous sandstone (Cretaceous Flysch), and Oligo-Miocene sandstone [30-31].

Several studies on agricultural development have been carried out on the soils of the Fetzara region [7, 20-21, 28]. These studies classified soils into four classes: poorly developed soils, vertisols, hydromorphic soils and halomorphic soils.

2.2. Procedure

The great variability of salt content in soil from one point to another has made more delicate both sampling and laboratory analyzes to study their spatial distribution. In the present case, soil sampling was carried out on the first two surficial levels (0 to 25 cm and 25 to 50 cm) where the most important ionic exchanges take place.

A total of 24 samples were taken from twelve (12) points around Fetzara lake (Fig. 2). They were air dried, crushed and sieved to 2 mm to obtain the fine soil that will be object for all chemical, physicochemical and physical analyzes, namely: specific density, total porosity, total organic carbon (TOC) and organic matter (OM), pH, electric conductivity (EC) and soluble salts (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, HCO_3^{-}, SO_4^{2-}, CO_3^{2-}) (Table 1).

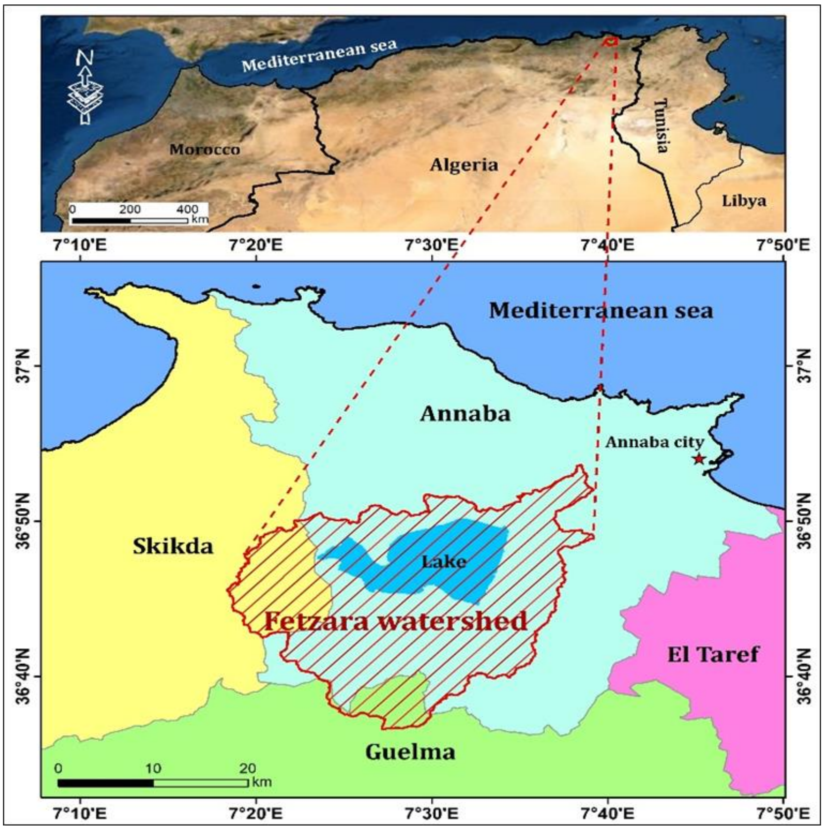

Fig. 1. Location map of Fetzara lake watershed

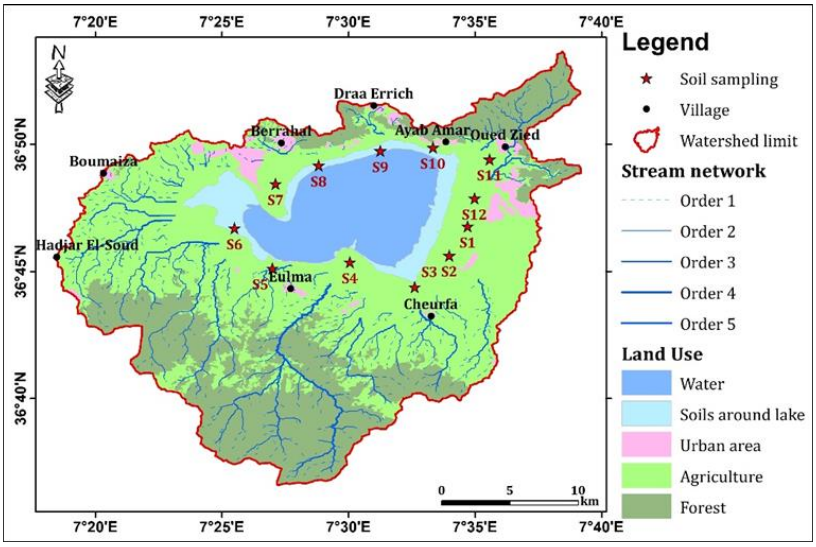

Fig. 2. Soil sampling inventory map

Table 1

Physico-chemical soil analysis methods [32]

Parameters	**Symbols**	**Unit**	**Méthods**
pH	pH	/	pH meter
Electrical conductivity	EC	mS cm^{-1}	Conductimeter
Total organic carbon	TOC	%	Modified Anne method
Organic matter	OM	%	OM = % TOC * 1.72
Specific density	D	g cm^{-3}	Paraffine
Total porosity	P	%	P = (1- Da / Dr) * 100
Calcium, Magnesium	Ca^{2+}, Mg^{2+}	meq dm^{-3}	Complexometry
Chlorides	Cl^-	meq dm^{-3}	Mohr with $AgNO_3$.
Sulfates	SO_4^{2-}	meq dm^{-3}	Gravimetry with $BaCl_2$
Bicarbonates, Carbonates	HCO_3^-, CO_3^{2-}	meq dm^{-3}	Sulfuric acid (H_2SO_4).
Sodium and Potassium	Na^+, K^+	meq dm^{-3}	Flame emission spectrometry

Particle size measurement is one of the classical ways of studying soils, defining the texture, which in turn determines in part the physical and physicochemical properties of the environment [33]. The soil texture is the reflection of the proportion of sand particles, silt and clay found there [34-35]. These proportions determine the pores size and, largely, the ability to retain moisture and nutrients. Soil particles less than 2 mm in size are divided into three categories: sand (the largest particle), silt and clay (the smallest). They are classified according to the ratios between different particles. For example, soils classified as "sandy" consist of more than 50 to 55% of sand, while "clayey" soils have a clay content of 20% or more [36].

The soil capacity to exchange cations is called cation exchange capacity (CEC), arises because of the charge associated with clay particles and other soil components [34]. In this study, since the CEC was not measured, an empirical equation proposed by US Salinity Laboratory [37] was used, the latter expressing a correlation between the percentage of exchangeable sodium (ESP) and the values of the sodium adsorption ratio (SAR) of soil solutions. It has been used by several authors [38-40] and can be written by the following formula (Eq. 1):

$$ESP(\%) = \frac{100(-0.0126 + 0.01475 * SAR)}{1 + (-0.0126 + 0.01475 * SAR)}$$

This empirical equation satisfies the theoretical limit condition for high SAR and ESP values. However, the data used in the calculation of this ratio was SAR < 65 and ESP < 50.

The sodium adsorption ratio (SAR) was developed to describe empirically the imbalance between divalent cations (calcium and magnesium) and sodium for assessing the sodization risk of the sorption complex [8, 41]. It was calculated according to the following formula (Eq. 2) where all concentrations are expressed in (meq dm^{-3}):

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}}$$

There are different methods for classifying the saline soils; The American, French, Russian and FAO classification. Among these classifications and the most used is the classification of USSL [37] (Table 2), since it is based on easy-to-obtain parameters like electrical conductivity (EC) and exchangeable sodium percentage (ESP).

Table 2
Classification of saline soils according to USSL [37]

Parameters	**EC ≤ 4 mS cm^{-1}**	**EC > 4 mS cm^{-1}**
ESP ≤ 15%	Non-Saline and non-Alkaline soils	Saline soil
ESP > 15%	Alkaline soils	Alkaline-Saline soils

3. Results and discussion

3.1. Physical and chemical properties of soils

Soils in the Fetzara region are weakly alkaline to acid pH (5.97 to 8.10) containing 0.4 to 3.47% of organic matter. They are characterized by an electrical conductivity ranging from 6.52 to 24.3 mS cm^{-1}. Total porosity shows an average value of 23% and 22% for the first and second level respectively, while the permeability coefficient is less than 2 cm hr^{-1}.

3.1.1. Particle Size

The obtained results of particle size analysis carried on soils from the Fetzara lake region are plotted into the triangular diagram (Fig. 3) in order to determine their textures. The majority of samples with average values of 69.34% for the first level (0-25 cm) and 58.67% for the second (25-50 cm) show the dominance of silt fraction. This excess of silt fraction and clay deficiency conducts to a massive structure formation, and therefore the mediocre physical properties of soils [34-35, 42].
The sandy fraction shows an average of 26.46% and 35.83% for the first and second level respectively.
However, sandy fraction is greater than 50% in both the sample S4 (level 0-25 cm) located in the southern part of Fetzara lake, near of wadi El Hout, and S'4, S'8 (level 25-50 cm). Soils with sandy fraction > 50% are generally, well ventilated, of low coherence, not or very weakly structured, poor in nutritive elements, and have a weak capacity of cationic exchange [34-35, 42]. The clay fraction shows low averages, 4.2% for the first level and 5.5% for the second level where the maximum value is registered in the south of Berrahal town (18% sample S7). These clayey soils are chemically rich, but exhibit mediocre physical properties (impervious and weakly aerated soil) [34-35, 42].

3.1.2. Soil pH

Hydrogen potential (pH) is one of the most important properties of the soil solution [34], it reflects the content of free acid hydrogen ions in a soil solution generated either by pure water (pH_{H2O}) or potassium chloride-rich water (pH_{KCl}).
The values of pH_{H2O} for the upper level (0-25 cm) vary between 6.37 and 7.67 with an average of 7.27. However, they oscillate between 7.02 and 8.10 with an average of 7.44 for the lower level (25-50 cm). Accordingly, with reference to Gaucher [43], these pH values could be qualified as weakly acidic to alkaline.
The maximum values of pH_{KCl} reach 7.08 to 7.33, and 6.67 to 6.83 for the minimums for the first and second level respectively. Obviously, $pH_{KCl} < pH_{H2O}$, the value of the difference indirectly reflects the biological state of the soil; (1) a difference of 0.2 to 0.4 indicates a heavy soil with a weakness of microbial activity. (2) a difference of 0.4 to 0.6 indicates normal microbial activity. (3) a difference of 0.6 to 0.8 indicates an excellent structure, conducive to a rapid organic matter transformation [32].

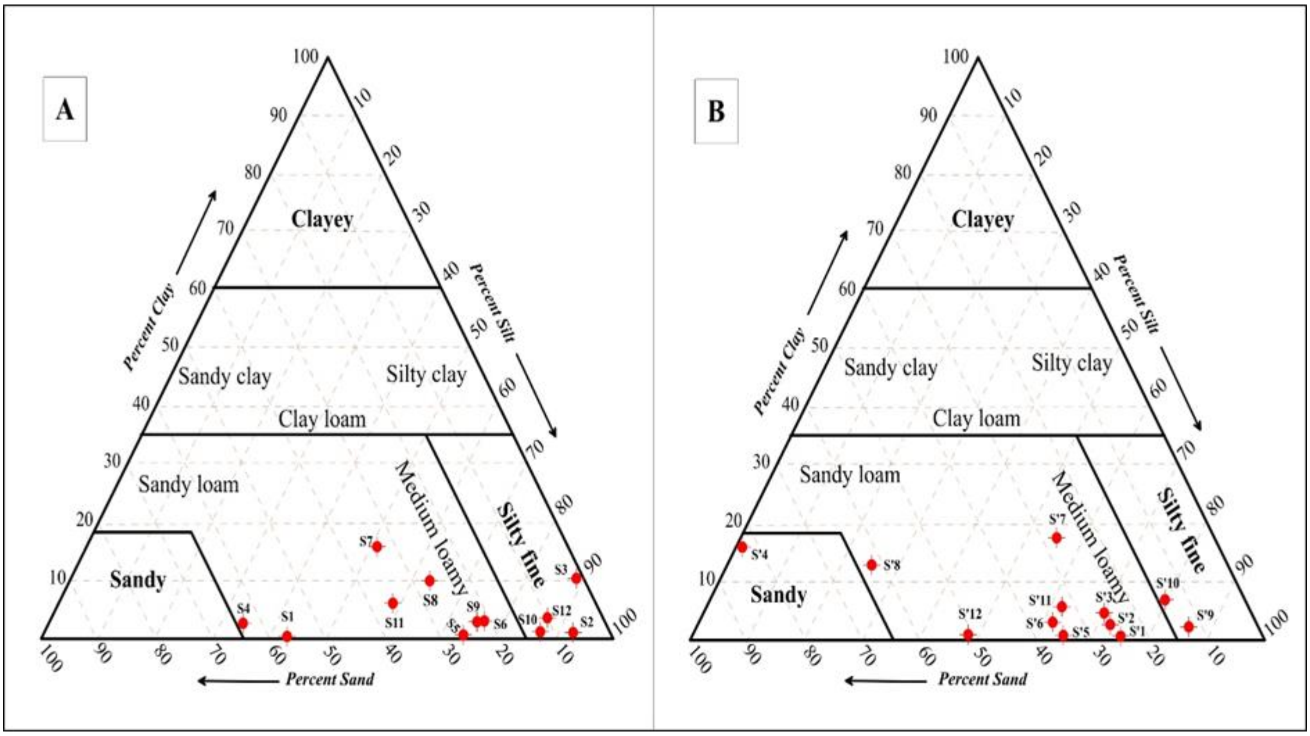

Fig. 3. Soil texture of Fetzara lake region: A - first level, B - second level

For soils of the Fetzara lake region, this difference fluctuates from one point to another, it varies from 0.3 to 0.8 (an average of 0.6) for the 24 samples, which shows that these soils are characterised by low to normal microbial activity. Acidic or alkaline reaction of a soil is controlled by the preponderant presence of acidic salts, contained particularly in the humus, relative to basic salts outcome from limestone; it would be neutral when acids and bases equilibrate each other.

3.1.3. Electrical Conductivity (EC)

Measured electrical conductivities on the saturated paste extract (soil solution) vary between 6.52 and 24.3 mS cm^{-1} (average of 11.54 mS cm^{-1}, n=12) for the first level (0-25 cm), and from 8.03 to 20.2 mS cm^{-1} (average of 13.96 mS cm^{-1}, n=12) for the second (25-50 cm). The highest values exceeding 16 mS cm^{-1} are recorded at the stations 3, 6, 9 and 10 (Fig. 4). The increase of the electrical conductivity according to depth has been observed in the majority of samples, except sample (S10), due to the trapping of salts in the silty parts of the upper level (Fig. 4).

Soil classification proposed by USSL [37], enabled us to identify the distribution of samples by class (Table 3). Since the majority of soils in the Fetzara lake region are affected by salinity with an evolution of the latter depending on the depth, three classes have been highlighted: 25% of samples are moderately saline soils ($4 < EC \leq 8$ mS cm^{-1}), 41.67% are saline soils ($8 < EC \leq 16$ mS cm^{-1}) and 33.33% are very salty soils ($EC > 16$ mS cm^{-1}).

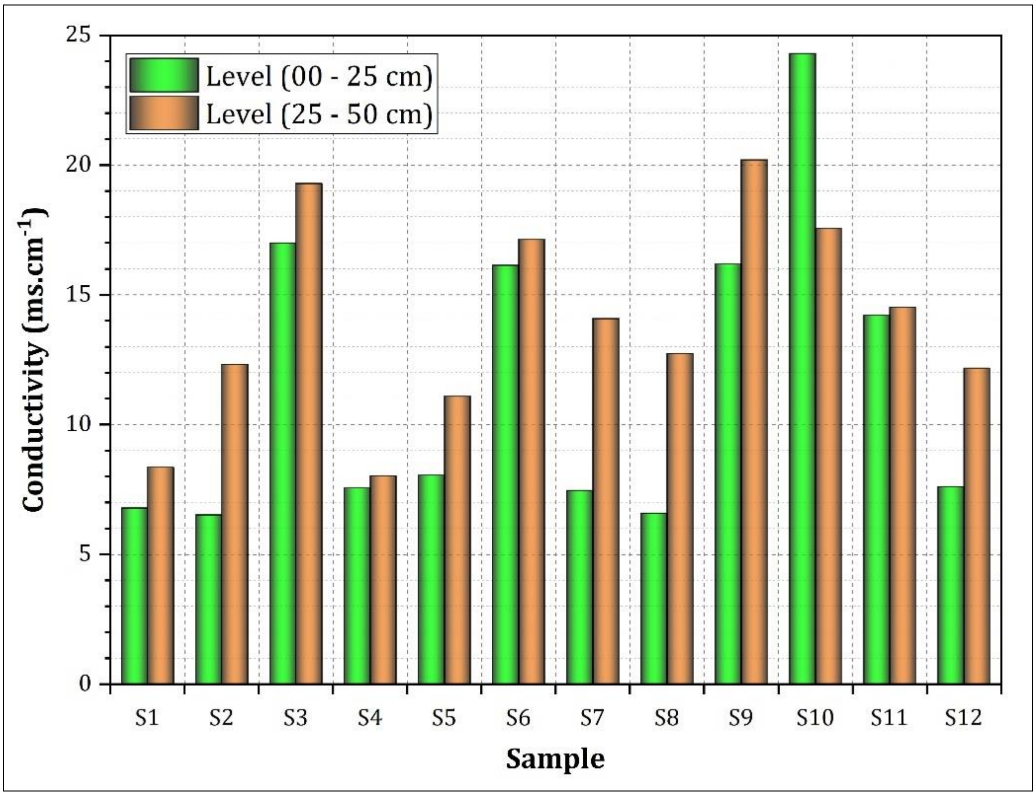

Fig. 4. Variation of soil electrical conductivity (EC)

Table 3

Soil classification as a function of electrical conductivity

EC (mS cm^{-1})	**Level (*0 – 25 cm*)**	**Level (*25 – 50 cm*)**	***Appreciation***
EC ≤ 2	/	/	Soils are not salty
2 < EC ≤ 4	/	/	Soils are slightly salty
4 < EC ≤ 8	S1, S2, S4, S7, S8, S12	/	Soils are moderately salty
8 < EC ≤ 16	S5, S11	S1, S2, S4, S5, S7, S8, S11, S12	Soils are salty
EC > 16	S3, S6, S9, 10	S3, S6, S9, S10	Soils are very salty

3.1.4. Soluble Salts

Soil salinity reflects an excessive concentration of soluble salts (saline soils), sodium adsorbed (sodium or alkaline soils) or alkaline-saline soils. The soluble salts concerned are mainly Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, Cl^{-}, SO_4^{2-} and HCO_3^{-}. The dynamic of these salts in soil is related to the hydrous and structural functioning of soils, to the water and geochemical conditions at the soil profile limits, to the supply of irrigation water and the fluctuations of the water table [44]. The main results of the chemical analyze performed on the extract of the saturated paste are summarized in the table below (Table 4).

Table 4

Chemical analyzes of soil solutions of the Fetzara lake region

Levels	Soluble salts (meq dm^{-3})	Maximum	Minimum	Average	Standard deviation
0-25 cm	Ca^{2+}	14.40	2.80	6.18	3.51
	Mg^{2+}	31.00	0.60	13.27	10.61
	Na^{+}	29.90	1.24	13.86	7.10
	K^{+}	3.66	0.64	1.88	0.90
	Cl^{-}	240.00	40.00	105.00	67.27
	SO_4^{2-}	61.25	6.25	26.24	20.85
	HCO_3^{-}	4.00	1.20	2.13	0.72
25-50 cm	Ca^{2+}	16.50	3.00	6.09	3.89
	Mg^{2+}	34.40	1.40	14.54	10.19
	Na^{+}	24.29	2.49	16.35	6.13
	K^{+}	7.32	1.00	2.33	1.64
	Cl^{-}	220.00	60.00	139.17	49.74
	SO_4^{2-}	61.98	14.50	31.09	15.96
	HCO_3^{-}	3.60	0.60	2.29	0.82

3.2. Chemical facies of soil solutions

The most dominant chemical facies of the soil solutions in the Fetzara lake region have been determined using the piper's triangle diagram (Fig. 5), where the following remarks have been highlighted:
On the anion's triangle, the chlorides are dominant, plotted samples are grouped closely to chlorinated pole. They show 79.29% and 80.74% of the total sum of anions respectively for the two levels (0-25 cm and 25-50 cm). The sulphates are less important than chlorides, they exhibit 18.59% for the first level and 17.78% for the second. However, bicarbonates have the lowest percentage with a maximum of 4.5%.
On the cation's triangles, sodium is the most important ion, reaching 47.81% and 50.51% of the total sum of cations for the first and second level respectively. Magnesium has percentages of 31.52% and 32.70%, while calcium exhibits the lowest percentages with 20.67% and 16.79% for the first and second level respectively.
As a result, the soil solutions are characterized by a dominance of the sodium chloride facies for most soil samples (Fig. 5), with the exception of samples S6, S'6, S9 and S'9 where the facies become magnesian chloride (Fig. 5-A). This character of the soil solutions allows to the successive precipitation of minerals, which modifies its composition and determines different soil evolution pathways as a function of the relative abundance of the different major ions in the starting solution.

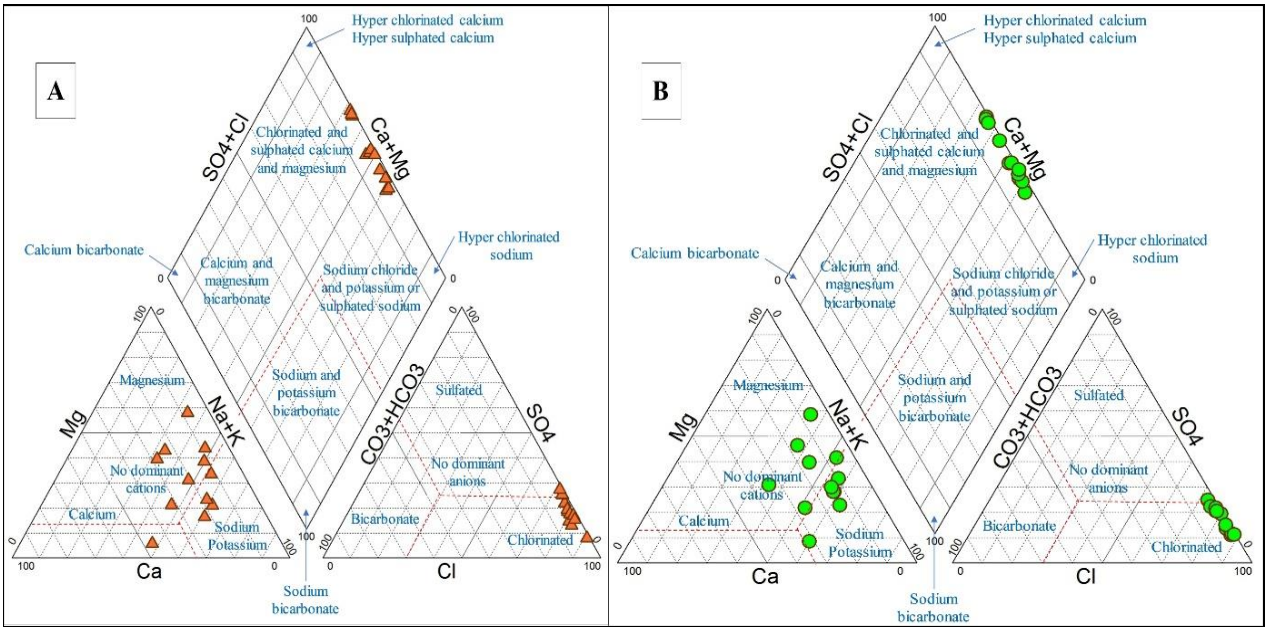

Fig. 5. Chemical facies of soil solutions: A - first level, B - second level

3.3. Statistical study of chemical analyzes of soil solutions

The Principal Component Analysis (PCA) was performed on 12 variables (EC, pH, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, HCO_3^{-}, SO_4^{2-}, moisture (H%), total organic carbon (TOC) and organic matter (OM)) from 24 samples (individuals). Soil analysis has been interpreted by the software (SPAD version 5.5). For statistical data processing, the first three factorial axes (F1, F2 and F3) reach 74.53% of the total variance: F1= 45.89%, F2=18.01% and F3=15.14%.

- First factorial plane F1F2: The observation of the correlation circle formed by the two factorial axes F1 and F2 is presented in figure 6. The first axis groups the soluble salts (Ca^{2+}, Mg^{2+}, Na^{+}, Cl^{-}, SO_4^{2-} and HCO_3^{-}) on its positive part; those are well correlated with the electrical conductivity (EC) while all the latter are opposed to the pH, which represents the soil acidity.

According to Mcgeorge [45-46], the pH decreases with increasing concentrations of NaCl. He speculated that the pH of the soil increased as the salt concentration of the soil solution was reduced, due to increased hydrolysis of the sodium clay complex. Salinity increases the ionic strength of the soil solution and consequently suppresses the activity coefficient of ions in solution. This would increase the pH values, but increasing ionic strength mainly decreases the pH values because salinity decreases the junction potential. As a result, this first axis reflects the salinization phenomena affecting some types of soil influenced by water intake of salt irrigation, climate type or specific hydrological conditions (low leaching near the aquifer water table).

The second axis F2 (18.01% of the variance) contrasts carbon and organic matter with pH and potassium K^{+}. This could be explained by two phenomena: (1) the dissolution of carbonates, which leads to CO_2 consumption causing the rise in pH. This type of mechanism allows the transient increase in pH leading to the dissolution of organic matter [47]. (2) the fixation of K^{+} by certain types of fine textured soils (clay texture, clay-silt ... etc.) [48]. The distribution of individuals on the plane (F1F2) allowed the discrimination of two groups of associations (Fig. 6-B).

The first group (G1) is characterized by highly mineralized solutions that oppose the second group (G2) which represents soil solutions of less mineralized basic character.

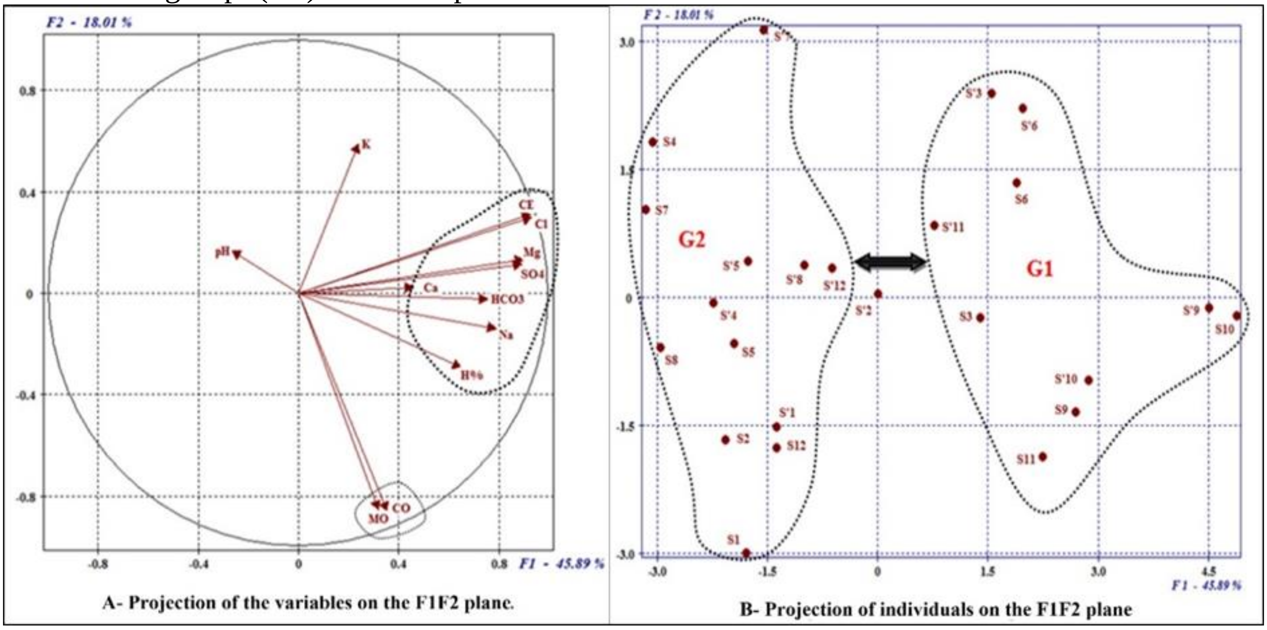

Fig. 6. Principal Component Analysis of soil solutions according to plane F1F2

- Second factorial plane F1F3: (61% of the variance) (Fig. 7), the first axis has been discussed above, reflects the overall concentration of soil solutions (axis of mineralization). The third axis represents in its positive part the soil solutions rich in potassium and an alkaline character. Potassium could be fixed in soils by certain clay minerals (Fig. 7-A).

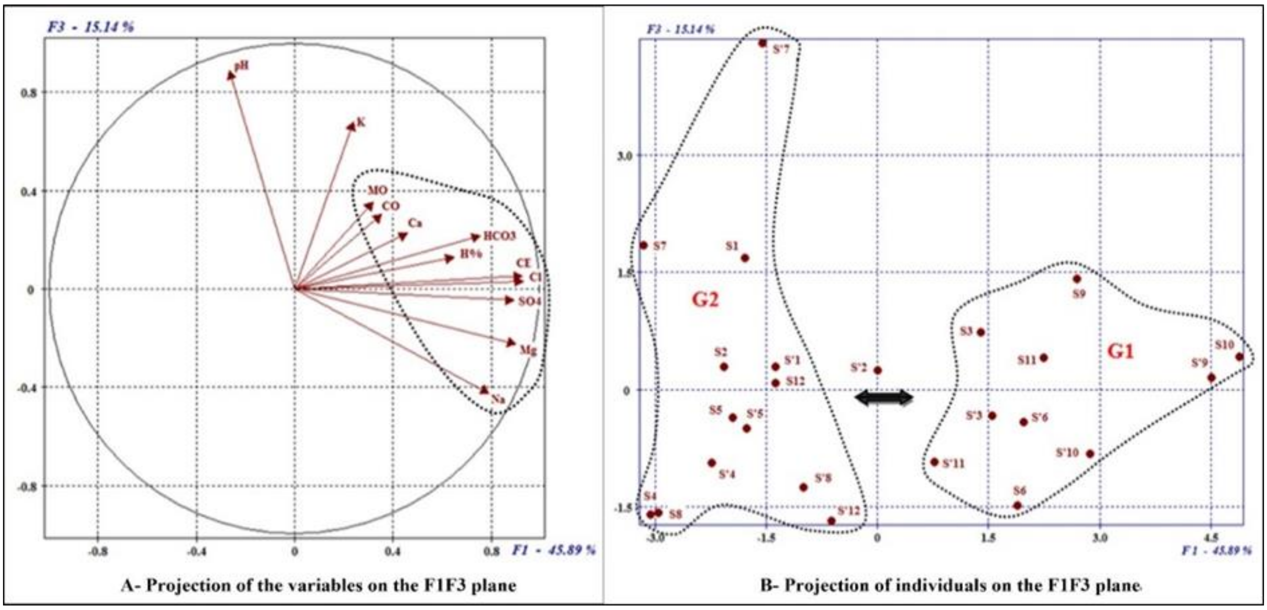

Fig. 7. Principal Component Analysis of soil solutions according to plane F1F3

3.4. Typology of saline soils

The variation of the exchangeable sodium percentage (ESP) as a function of the electrical conductivity measured on the saturated paste extract and according to the classification proposed by the USSL [37] is represented graphically in the following figure (Fig. 8).

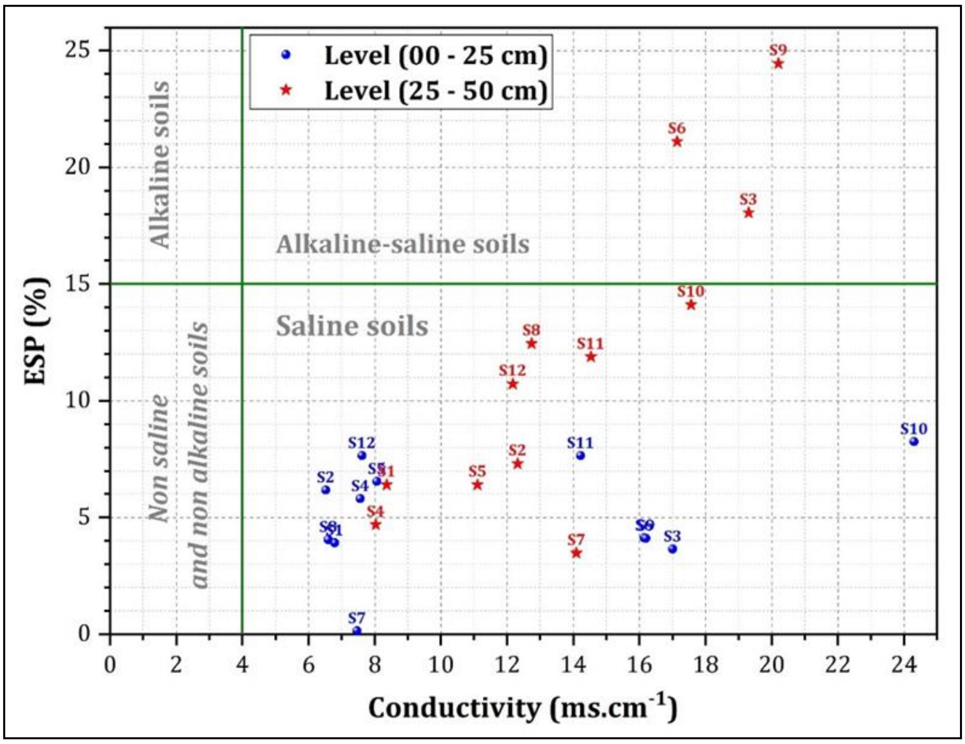

Fig. 8. Classification of saline soils according to USSL [37]

The majority of the soils analyzed from the Fetzara lake region (about 87.5%), are classified as saline soils (ESP ≤ 15%, EC > 4 mS cm^{-1}) (Fig. 8), these soils are characterized by a high content of salts [14, 47, 49-51], and are generally flocculated, which contributes to maintain a good soil structure and a good water and air circulation [14]. They are characterized by an electrical conductivity of the saturated paste extract > 4 mS cm^{-1}, pH < 8.5 and an exchangeable sodium percentage < 15%.
Three samples of the lower level (25-50 cm) are part of the alkaline-saline soils (ESP > 15%, EC > 4 mS cm^{-1}) and are characterized by an electrical conductivity of the saturated paste extract > 4 mS cm^{-1} and pH > 8.5. According to Marlet and Job [47], they contain enough soluble salts and exchangeable sodium > 15%. This leads to low structural stability of the soil [48, 50-52].

4. Conclusions

Pedological studies carried out on the soils of the Fetzara lake region have led to identify four classes namely: poor soils, vertisols, hydromorphic soils and halomorphic soils. Analytical results and their interpretation by the different methods led to the conclusion that the soils in the Fetzara region are weakly alkaline to acid pH (5.97 to 8.10) containing 0.4 to 3.47% of organic matter. Their average total porosity is about 23% for the first level (0-25 cm) and 22% for the second

(25-50 cm), while the permeability coefficient is less than 2 cm hr^{-1}. The particle size analyzes show the dominance of the silty fraction in the majority of the samples, with an averages value of 69.34% and 58.67% for the first and second level respectively.

The majority of soils are classified as saline soils (ESP ≤ 15%, EC > 4 mS cm^{-1}), with a very variable electrical conductivity (6.52 to 24.3 mS cm^{-1}), reaches its maximum in the northeastern and southeastern parts of Fetzara lake. The Soil solutions are characterized by the abundance of ions (Cl^-, SO_4^{2-}, Na^+ and Mg^{2+}) conducting to a dominance of sodium chloride facies in the most samples analyzed.

The principal component analysis (PCA) indicates a strong correlation between soluble salts (Ca^{2+}, Mg^{2+}, Na^+, Cl^-, SO_4^{2-} and HCO_3^-) and electrical conductivity (EC), which corresponds to the salty soils of the south-east (Cheurfa town) and the north-east (Wadi Zied town) of the lake. While the ensemble is opposed to the pH, which represents the soil's acidity, mainly observed in the north-west (Berrahal town). This soil salinity would be mainly controlled by the seasonal variation of the lake water level, the strong evaporation of the water, particularly in summer, which causes the precipitation of mineral salts, and the phenomena of ion exchange between the sorption complex and the soil solutions.

Finally, in order to protect the soils of the Fetzara lake region against salinization and to minimise their degradation, a continuous monitoring of the irrigation water quality and an improvement of the drainage system of the agricultural land around the lake are recommended.

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