GeoScience Engineering

IRRIGATION WATER IMPACT ON SOIL PROPERTIES IN ARID OUED-SOUF REGION, SOUTHEAST ALGERIA

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ABSTRACT

The perimeters of the Oued-Souf region are irrigated by salty water coming from the phreatic water and thus progressive salinization of the soil occurs. This study aims at a qualitative analysis of the evolution of the salinity in the soils irrigated by pivot irrigation for several years. For this, three plots were irrigated by pivots in each agricultural region. The choice of these 3 plots is justified by the number of years of their cultivation: plot 1 has been cultivated and irrigated for 2 years (2016–2017), plot 2 has been cultivated and irrigated for 5 years (2016–2020) were studied and compared to the controlled soil not irrigated. The irrigation is done by sprinkling with mineralized water from the phreatic water. The results obtained showed that the irrigation water is characterized by high salinity and low sodium adsorption ration (SAR). Sodium and chloride contents are excessive in sprinkler irrigation mode. The evolution of salinity in irrigated soils between 2 and 5 years was very significant compared to the control (non-irrigated). The salinity goes from 0.38 dS/m in the control site classified as low salinity to 1.54 dS/m in the cultivated site for the 5 years classified as high salinity soil. The geochemical facies at the three study regions after irrigation are sulfate-calcium. A significant correlation is observed between calcium and sulfate with electrical conductivity (EC), so the salinity of our soils is dominated by sulfate. These results are confirmed by statistical analysis of the data (PCA), which revealed that salinity is heavily influenced by Mg^{2+}, Ca^{2+}, SO_4^{2-} in the topsoil.

Keywords: Hydrochemical; Irrigation water; Oued-Souf area; Phreatic aquifer; Salinity; Soil; Statistical analysis.

1 INTRODUCTION

In the Saharan areas, the soil has a low level of fertility, the organic balance is deficient, water reserves are large, non-renewable, and diversely mineralized, and crop water requirements are high due to high climatic demand. In these areas, organic outflows greatly exceed inflows [1,2]. Vegetable crops, which are the main crop in the new schemes, are considered salinity tolerant and grow well in sandy textured soils. However, the cumulative effect of irrigating with irrigation water with a high salinity hazard and under a highly evaporating climate leads to an accumulation of soluble salts on the surface that affects crop yields [3]. In this study, we are aiming to analyze the evolution of salinity at different ages: 2 and 5 agricultural years.

2 MATERIALS AND METHODS

2.1 Study area

The study area is part of the province of El-Oued that is located (Figure 1) in the South East of Algeria and surrounded by the provinces of Biskra, Khenchela, and Tebessa in the North, Djelfa in the North-West, Ouargla

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in the South and South-West and Tunisia in the East; it occupies an area of 220 km^2, and it is located UTM coordinates: X = 290000 E / 315000 E, and Y = 36000000 N /3700000 N [4].

The region is part of the Great Eastern Erg, which is characterized by a set of dunes of Continental origin and Quaternary age. The slope of the study area is generally oriented south-north, with altitude values ranging from 64 to 120 m. We point out here the existence of artificial funnels, dug by the inhabitants to plant palm groves and vegetables, locally called “Ghout”. The climate of the region is of the Saharan type. The average interannual temperature is about 28.4 °C, and rainfall is rare, with an interannual average of about 70.03 mm [5].

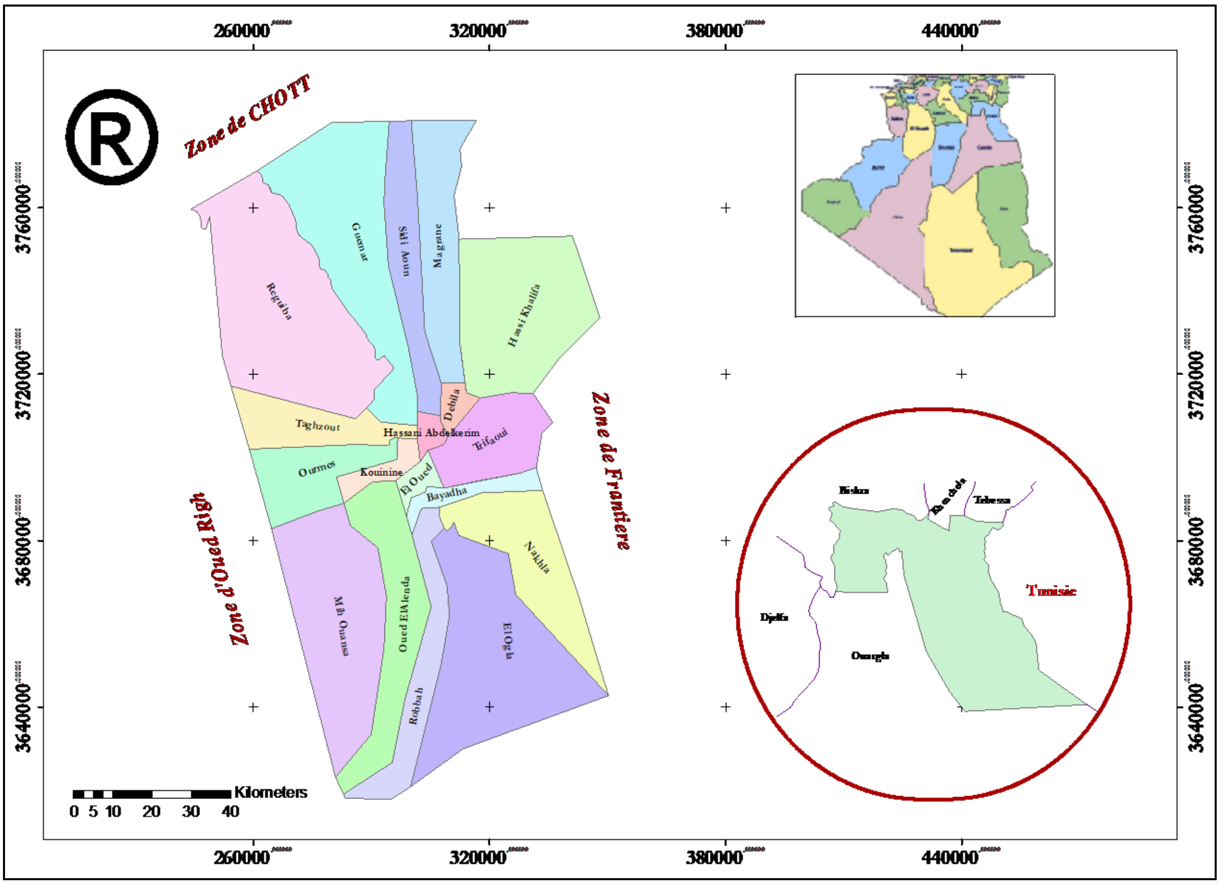

Figure 1. Location map of the study area (Oued-Souf area)

2.2 Experimental regions

2.2.1 Reguiba region

Reguiba region is located 35 km northwest of the city of El Oued, whose spatial coordinates are 33°34’14” N; 06°43’6” E (Figure 2). It is characterized by horticulture and potato cultivation, whose area is 5500 hectares (DSA, 2019) [5].

2.2.2 Trifaoui region

Trifaoui region is located 10 km north-east of the city downtown, whose spatial coordinates are 33°25’24” N; 06°56’09” E (Figure 3). It is characterized by plasticultures and potato cultivation, with an area of 4578 hectares (DSA, 2019) [5].

2.2.3 Ourmes region

This region is located 18 km northwest of the city downtown, whose spatial coordinates are 33°24’19” N; 06°46’23” E (Figure 4). It is characterized by plasticultures and potato cultivation, with an area of 5529 hectares (DSA, 2019) [5].

Figure 2. *The sampling location in the Reguiba region; (Photo: Zaiz, 2020)*

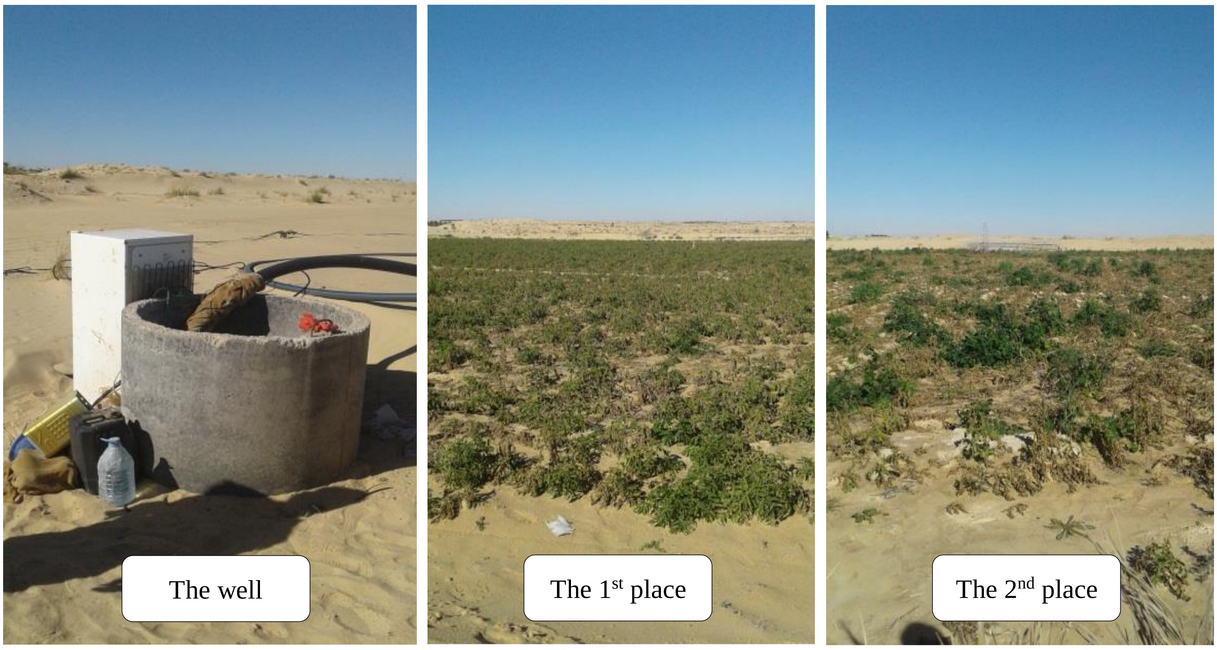

Figure 3. *The sampling location in the Trifaoui region; (Photo: Zaiz, 2020)*

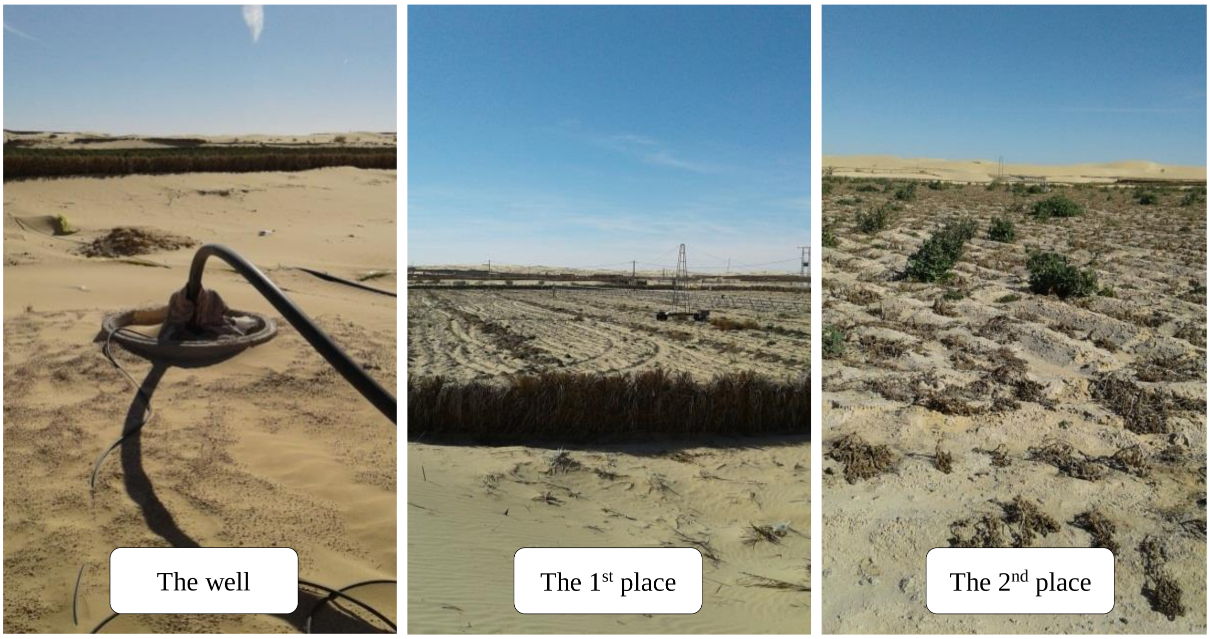

***Figure 4.** The sampling location in the Ourmes region; (Photo: Zaiz, 2020)*

2.3 Soils sampling

The study uses 9 soil samples which were collected from 3 regions in the Oued-Souf area from the upper horizon (0–30 cm) during July 2020. Three plots were irrigated by pivots in each agricultural region. The choice of these 3 plots is justified by the number of years of their cultivation: plot 1 has been cultivated and irrigated for 2 years, plot 2 has been cultivated and irrigated for 5 years. One plot was used as a control and the results of the control soil (no-irrigated) cultivated with potatoes were compared with those irrigated with water from the phreatic (Figure 5).

The sampling method basically consists of digging a hole with a shovel or trowel at depths ranging from 0 to 30 cm, and taking the desired volume of soil. The hole should have a good surface with stable walls to prevent surface soils from falling to the bottom and being collected [6,7].

2.4 Irrigation water sampling

The study included 3 water samples collected in July 2020 from regions wells. The study region is irrigated by a traditional well tapped into the phreatic water for irrigation at a depth of 60 m and a flow rate of 5 l/s. The irrigation system adopted is localized sprinkler irrigation (local pivot) [8,9]. The water samples were taken at the same time as the soil samples. The water samples were collected in labelled plastic bottles that bear the date and the number of the site (Figure 5).

Figure 5. *Soil and irrigation water sampling method; (Photo: Zaiz, 2020)*

3 RESULTS AND DISCUSSION

3.1 Granulometry

From the results obtained by the particle size analysis (Figure 6), it can be seen that the texture of the non-irrigated soil is dominated by sand. Moreover, the different samples of the study area are surrounded by dunes whose wind effect causes the accumulation of sand for several years, which explains the high dominance of the sandy texture.

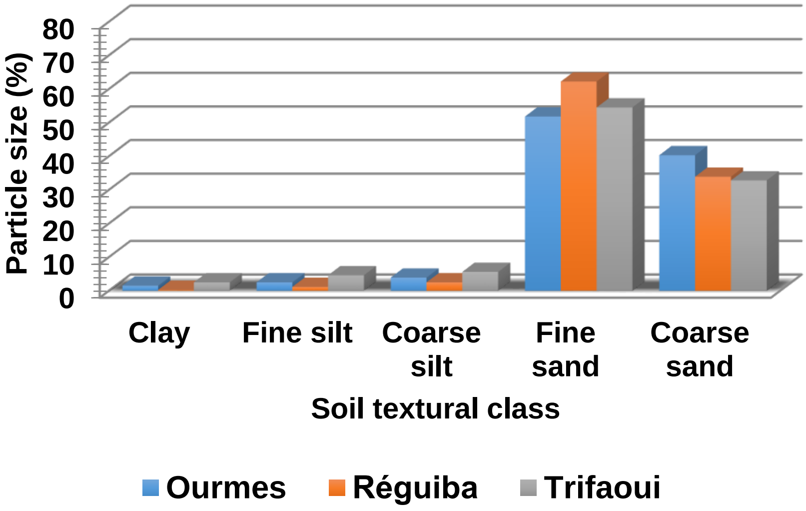

Figure 6. *Granulometric composition of soil samples in the three regions*

3.2 Irrigation water characteristics

According to the analytical results of the waters shown (Table 1), the borehole water has neutral pH, high salinity (EC electrical conductivity > 3 dS·m 1), and low sodicity risk (SAR). Cations and anions are distributed in the following order: Na^{+}>Ca^{2+}> Mg^{2+} and SO$_4^{2-}$>Cl^{-}> HCO$_3^{-}$. On the other hand, the groundwater has a low alkalinity pH with values between 7.87 and 7.95.

Table 1. *Statistical summary of measured parameters of irrigation water in the study area*

Parameter	Minimum	Maximum	Mean	Standard deviation
CE (µs/cm)	3658.00	5549.00	4405.67	1005.68
PH	7.87	7.95	7.90	0.04
HCO$_3^-$ (mg/L)	404.80	561.12	494.32	80.60
Cl$^-$ (mg/L)	53.47	252.80	155.56	99.75
SO$_4^{2-}$ (mg/L)	87.88	636.30	348.79	275.18
Na$^+$ (mg/L)	14.60	30.30	20.50	8.55
Ca^{2+} (mg/L)	63.40	153.72	106.53	45.30
K$^+$ (mg/L)	80.03	142.94	114.16	31.79
Mg^{2+} (mg/L)	389.98	943.10	654.71	277.32

The projection of major element concentrations (cations and anions) on the PIPER diagram (Figure 7) has shown that the irrigation water is the facies: Cl$^-$, SO$_4^{2-}$, Ca^{2+} and Mg^{2+}.

According to the RIVERSIDE irrigation water classification diagram modified by DURAND, the water from the three wells is class C$_4$S$_1$, C$_4$S$_2$, C$_4$S$_3$. (Figure 8)

- Class (C$_4$-–S$_1$): Water of mediocre to poor quality, used with caution for heavy soils and sensitive plants, the use of light and well-drained soils requires a dose of leaching and/or gypsum contribution.
- Class (C$_4$–S$_2$): Very bad quality water used only for light and well-drained soils and for resistant plants with the necessity of leaching doses and/or gypsum contribution.
- Class (C$_4$–S$_3$): Very bad quality to be used only in exceptional circumstances.

These waters can be used on coarse-textured soils, and with great care.

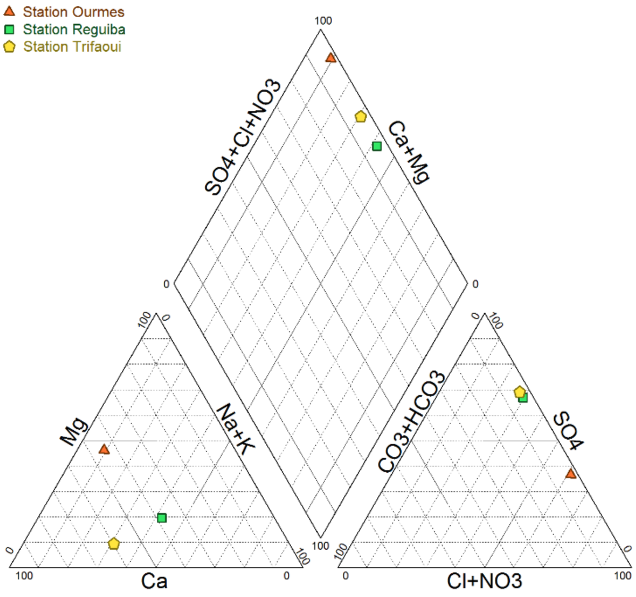

Figure 7. *The Piper trilinear plot describing the distribution of the categories of irrigation water samples*

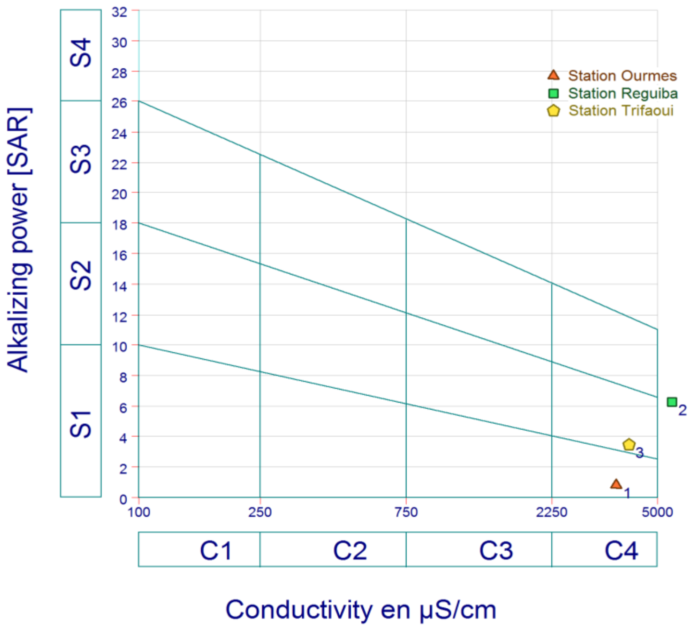

Figure 8. *The Riverside diagram plot describing the salinization of irrigation water samples*

3.3 Irrigation water mineralization

The correlation matrix established between the parameters (Table 1) shows a high correlation between the ions Na^+, K^+, HCO_3^-, NO_3^-, SO_4^{2-}, Cl^- and electrical conductivity (EC) with a coefficient $R > 0.80$. This shows that the high mineralization of the phreatic water is induced by the high concentrations of these elements.

Sulfates SO_4^{2-} are highly represented in irrigation water, and they come from the dissolution of some minerals such as gypsum ($CaSO_4$ $2H_2O$), anhydrite ($CaSO_4$), or from agricultural activity (sulfate fertilizers). The dissolution is favoured in the presence of water that is rich in NaCl, $NaSO_4$, $MgSO_4$, $CaHCO_3$, justified by the presence of ions Na^+, Cl^-, Mg^{2+}, K^+, and HCO_3^-.

Nitrates are introduced into the system either by leaching from applied fertilizers or by wastewater discharge, which translates into an essentially anthropogenic origin.

3.4 Soil samples characteristics

3.4.1 Electrical conductivity (EC)

The results of the analysis of EC which are represented in Figure 9 show a significant increase in EC in the topsoil (0-30 cm), which is comparable to that of the control (non-irrigated). For the three regions cultivated for 2 and 5 years, as the values oscillate between (0.81 to 8.63) dS/cm, they reduce the effect of agricultural activity through the use of fertilizers and irrigation.

According to AUBERT (1978), the 2 years of irrigation of the three regions, the EC of aqueous extracts (1/5) varies between 0.40 and 1.45 dS/m. It corresponds to the saline classes. During the 5 years of the three regions, the EC varies from 1.13 to 1.90 dS/m. It corresponds to the high salinity classes. The comparison of this state of salinity with the control (not irrigated), which is varied between 0.19 and 0.58 dS/m, corresponds to the not salted classes and gives a significant difference in EC.

Irrigation of the cultivated soils for 2 and 5 years causes significant salinity; the EC values obtained are comparable to those of the control (no-irrigated)

Soil salinity for all three regions increases with increasing temperature. This increase in salinity is due to evaporation and consequently an increase in the soil solution concentration of salt deposits on the soil surface.

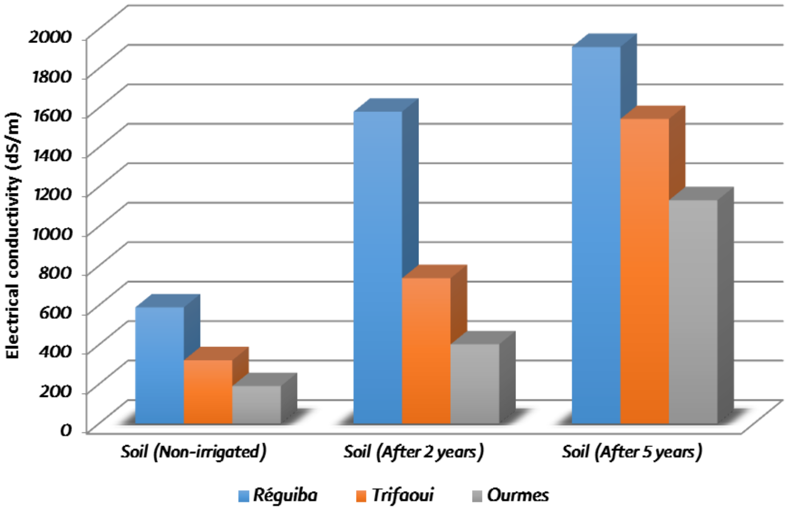

Figure 9. *Electrical conductivity (EC) evolution of soil samples in the three regions*

3.4.2 Soil PH

The results of the pH analysis are represented in (Figure 10) showing that the majority of the soils studied have medium basic pH with alkaline tendency. They vary from (7.04 to 8.20). The pH values seem to agree with the level of alkalinity encountered in the soils studied, which is generally low. The saline soils have a pH that does not rise above 8.2 for saline soils. The accumulation of soluble salts reduces the pH of saline soils. This small change in pH is due to the buffering effect exerted by calcium and magnesium ions that saturate the adsorbent complex and the liquid phase of the soils in these regions [10].

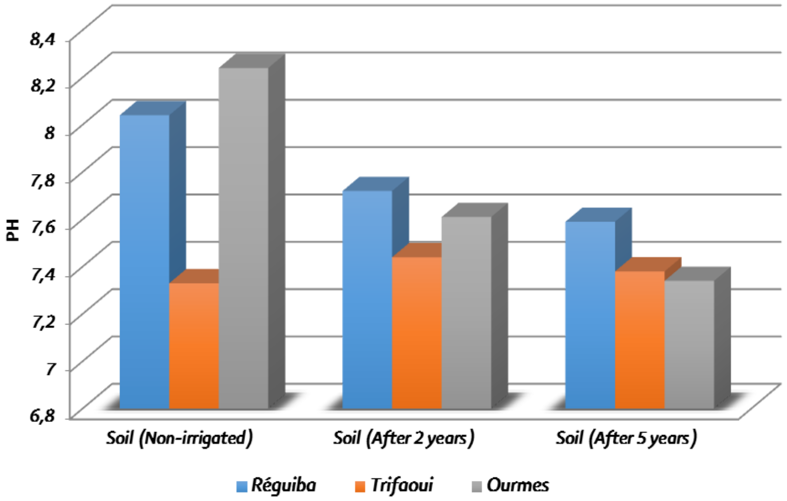

Figure 10. *PH evolution of the soil samples in the three regions*

3.4.3 Soil samples chemical composition

As for the cationic balance in the three regions, it is marked by the dominance of calcium with the other cations (Ca^{+2}> Mg^{+2}>Na^{+}> K^{+}) with a value of Ca^{+2} (36.07 to 456.91) mg/l and from (3.6 to 75.5) mg/l for magnesium and potassium (K^{+}). For the anionic balance, the soil is loaded with sulfates with respective values of 105.10 to 1150 mg/l, and for HCO_3^- and Cl^- observes a low content (Figs. 11, 12 and 13).

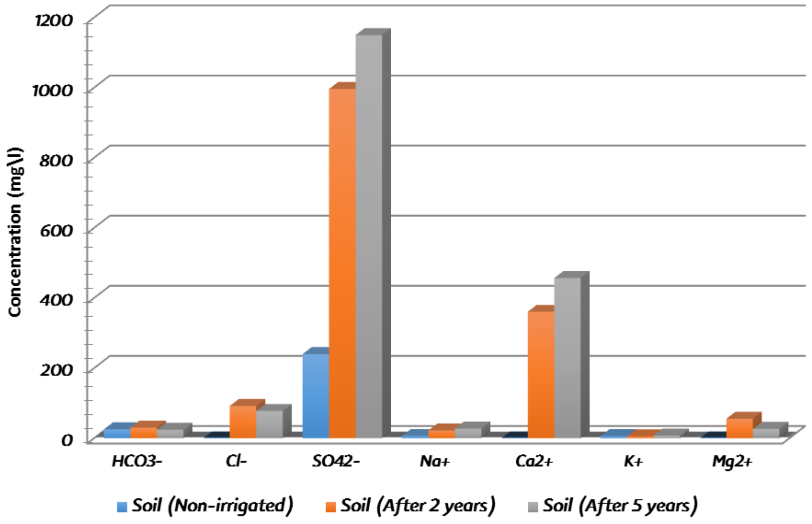

Figure 11. *Ion concentration evolution (mg\l) of soil samples in the Reguiba region*

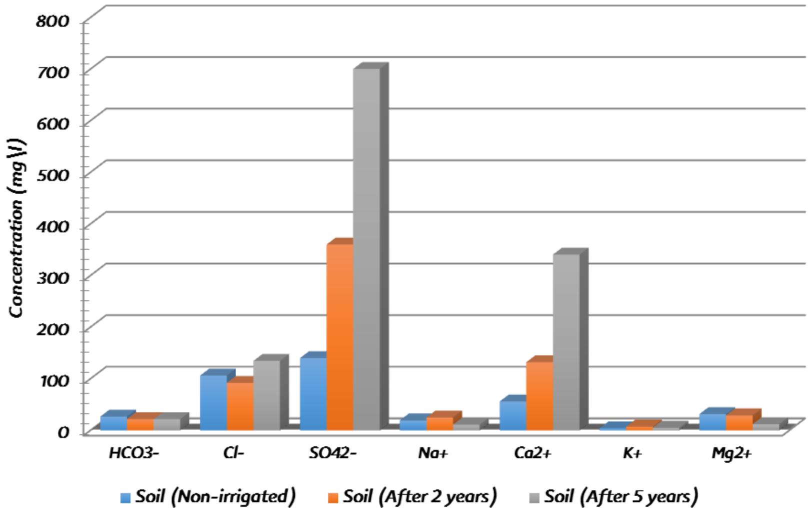

Figure 12. *Ion concentration evolution (mg\l) of soil samples in the Trifaoui region*

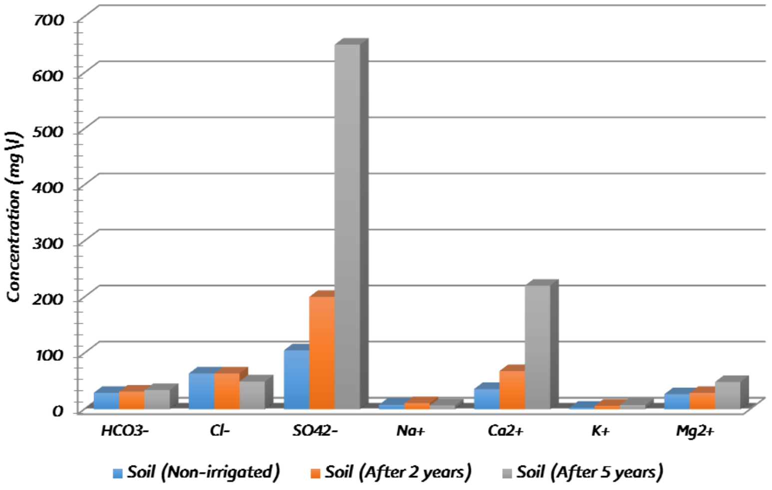

Figure 13. *Ion concentration evolution (mg\l) of soil samples in the Ourmes region*

3.5 Ion source diagnosis

Multivariate statistical analysis was also used as a tool to identify ion sources. The correlation matrix (CM) and principal component analysis (PCA) were performed by STATISTICA7.1. Correlation between different parameters was used to measure the relationship between two quantitative variables. PCA was used to study the correlations between anions and cations and their grouping into some factors (Tables 2, 3 and 4).

Table 2. *Correlation matrix between chemical parameters of topsoil solution no-irrigated in the study area*

Parameter	**CE**	**PH**	**HCO$_3^-$**	**Cl$^-$**	**SO$_4^{2-}$**	**Na$^+$**	**Ca^{2+}**	**K$^+$**	**Mg^{2+}**
CE	1								
PH	0.6010	1							
HCO$_3^-$	0.1290	0.8701	1						
Cl$^-$	0.7194	-0.1228	-0.5960	1					
SO$_4^{2-}$	0.9961	0.6692	0.2159	0.6553	1				
Na$^+$	0.5845	-0.2972	-0.7292	0.9841	0.5107	1			
Ca^{2+}	0.9976	0.6549	0.1973	0.6696	0.9998	0.5269	1		
K$^+$	-0.4540	-0.9850	-0.9421	0.2923	-0.5308	0.4576	-0.5146	1	
Mg^{2+}	0.9612	0.7981	0.3974	0.5000	0.9818	0.3382	0.9780	-0.6820	1

Table 3. *Correlation matrix between chemical parameters of topsoil solution irrigated after 2 years in the study area*

Parameter	**CE**	**PH**	**HCO$_3^-$**	**Cl$^-$**	**SO$_4^{2-}$**	**Na$^+$**	**Ca^{2+}**	**K$^+$**	**Mg^{2+}**
CE	1								
PH	-0.0146	1							
HCO$_3^-$	-0.9263	0.3901	1						
Cl$^-$	0.1370	-0.9925	-0.5000	1					
SO$_4^{2-}$	0.9972	0.0599	-0.8958	0.0629	1				
Na$^+$	-0.2852	-0.9542	-0.0968	0.9104	-0.3557	1			
Ca^{2+}	0.9964	0.0703	-0.8910	0.0524	0.9999	-0.3655	1		
K$^+$	0.9962	-0.1017	-0.9557	0.2228	0.9869	-0.2006	0.9852	1	
Mg^{2+}	-0.8206	-0.5595	0.5449	0.4538	-0.8608	0.7818	-0.8661	-0.7676	1

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Table 4. *Correlation matrix between chemical parameters of topsoil solution irrigated after 5 years in the study area*

Parameter	**CE**	**PH**	**HCO_3^-**	**Cl^-**	**SO_4^{2-}**	**Na^+**	**Ca^{2+}**	**K^+**	**Mg^{2+}**
CE	1								
PH	0.6010	1							
HCO_3^-	0.1290	0.8701	1						
Cl^-	0.7194	-0.1228	-0.5960	1					
SO_4^{2-}	0.9961	0.6692	0.2159	0.6553	1				
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Ca^{2+}	0.9976	0.6549	0.1973	0.6696	0.9998	0.5269	1		
K^+	-0.4540	-0.9850	-0.9421	0.2923	-0.5308	0.4576	-0.5146	1	
Mg^{2+}	0.9612	0.7981	0.3974	0.5000	0.9818	0.3382	0.9780	-0.6820	1

The correlation coefficients for the three regions cultivated for 2 and 5 years and soil (no-irrigated) are presented respectively in (Tables 2, 3 and 4). The results indicate very high correlation coefficients of Ca^{2+}, SO_4^{2-} and Mg^{2+} with the salinity indicator EC, which are the main ions influencing the salinity of our soils. Calcium and sulfate are the ions that correlate highly with EC, so the salinity of our soils is dominated by sulfate.

The sulfate ions were highly associated with magnesium and calcium, indicating that sulfate salts could be present in the soil like CaSO4 and $MgSO_4$ However, due to the saturation of the exchange site with calcium, the predominant salt is probably $CaSO_4$. This is due to the common ion effect or a common ion source.

4 CONCLUSION

The soils of the Oued Souf valley region have a low level of chemical, physical and biological fertility because of their sandy texture. They are not very salty, but poor in organic matter, relatively rich in total limestone, permeable, and shallow.

The cumulative effect of irrigation with poor quality water and a very evaporative climate leads to the salinization of the agricultural land. Indeed, the results obtained concerning the chemical characteristics of the irrigation water of the phreatic water highlight a high risk of salinity and a low risk of sodicity. The sodium and chloride contents in these waters are excessive in sprinkler irrigation mode. The evolution of soil salinity in the three plots shows a significant accumulation of soluble salts in the soil after 5 years of irrigation. Indeed, on the surface horizon, salinity increased from 0.38 dS/m in the control site to 1.54 dS/m when they cultivated it for 5 years. Salinity increases with the number of years of irrigation at the surface horizon.

Sustainable improvement of agricultural productivity in saline soils is now a goal that must be achieved to motivate farmers to produce in these soil conditions.

1. Management techniques include land leaching and irrigation by efficient modes. For example, drip irrigation, a method that can play an important role in controlling salts in the root zone, and any practices that reduce evaporation from the soil surface.
2. Proper irrigation has a significant effect on optimizing yields and controlling soil salinity and water loss. Excess water can be detrimental by reducing starch richness and promoting the development of mildew and rot. [11].
3. Organic amendment which will help the farmers store water in the soil to minimize the adverse effects of water stress caused by salts.
4. Windbreaks also act to limit the loss of useful water through evaporation and drying of the soil by evapotranspiration of the plants.

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