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Study of soil salinity from geological, endorheic and anthropic origin in the Timimoun region (Algeria), and their impacts on soil pollution

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ABSTRACT

Soil and water salinization is among the most pressing environmental challenges in arid and semi-arid regions, an issue further intensified in Saharan zones with a dry continental climate such as the Timimoun region, Algeria. This study aims to diagnose the geochemical origin of soil and irrigation-water salinity in the Charouine area (El Waha Well, Bakou), by analyzing the ionic composition of soluble ions and relating it to the area's parent rock formations, based on field soil and water samples subjected to physico-chemical laboratory analyses.

Results showed relatively high concentrations of calcium (6.28 $cmol.kg^{-1}$), magnesium (3.6 $cmol.kg^{-1}$), and sodium (0.52 $cmol.kg^{-1}$) in the soil, together with a high concentration of sulfates (16.34 $cmol.kg^{-1}$) and a lower concentration of chlorides (3.5 $cmol.kg^{-1}$), reflecting the influence of the parent rock — mainly dolomitic limestone ($2CaMg(CO3)2$) at the base of the Eocene, along with rock salt, calcium carbonate, and gypsum ($CaSO4 \cdot 2H2O$). Irrigation-water analyses further revealed marked enrichment in sodium and potassium, with high sulfate (2500 mg/L) and chloride (1900 mg/L) concentrations attributable to evaporite deposits. The use of this water for irrigation, combined with intense evaporation, has led to soil contamination by soluble salts and intensified secondary salinization.

These findings highlight the pivotal role of geological and geochemical factors in determining water quality and the source of soil salinity in the Charouine area, contributing to the database needed for effective soil and water resource management in oasis regions and for mitigating land degradation in similar arid environments at both the regional and global levels.

KEYWORDS: secondary salinity, soil degradation, alkalinity, irrigation water for Charouine Timimoun- Algiers.

1. Introduction

A large percentage of agricultural land in the world, especially in Algeria, suffers from the problem of salinity. Data from the Food and Agriculture Organization of the United Nations indicate that salt-affected soils now cover approximately 1.381 billion hectares worldwide, equivalent to about 10.7% of total land area (FAO, 2024), the areas affected by salinity have increased from 48 million hectares to 265 million hectares of cultivated land worldwide, including 3.2 million hectares in Algeria (Bellaredj & Hamidi, 2018). The percentage of land affected by secondary salinity ranges between 10 % and 15 % (Cheverry & Robert, 1998; Piper, 1944; Robert & Alain, 2006)). Where high concentrations of soluble salts in soil solution affect the growth and development of plants, especially in arid regions (Kaouritchev, 1983), leading to a decrease in agricultural land productivity and farmers abandoning the land after it becomes saline. The charouine area is among the regions affected by the phenomenon of rising salinity in most emerging agricultural investments, which has clearly impacted the soil and the agricultural yield that most of the region's residents rely on for their livelihood. Therefore, our goal with this work is to contribute to the study of the salinization phenomenon in the charouine area of Timimoun Province, which is classified as a dry region threatened by this phenomenon. We aim to investigate its sources, causes, and development over time, as well as to identify its negative effects on soil and agricultural production, and to propose proactive solutions to mitigate these effects. This study also contributes to understanding the dynamics of salinization in dry regions, which helps in developing sustainable soil management strategies in these areas.

To achieve this, field samples were collected from open profiles of salt-affected soils and samples of irrigation water, and we analyzed them in the laboratory by measuring electrical conductivity and identifying the types of cations and anions present in order to determine their sources.

2. Materials and methods

2.1 Materials

In this work we used the following tools: MAGELLAN-MERIDIAN GPS device, axe, pickaxe, soil scoop, plastic bags for carry soil, small plastic bottles for carrying water, sensitive electronic scale, electromagnetic mixer, sieves, glassware (beakers, funnels, test tubes), water bath, conductivity meter, pH meter equipped with a thermometer.

3. Methods

3.1 Study area

To study soil salinity in the Timimoun region, the "Charouine" area located in the northwestern part of the Timimoun province was chosen. It is classified as one of the Algerian desert arid regions and is famous for its oases, which are known for producing the finest dates in Algeria. Its geographical location is defined as follows: longitude 0° 14' East and latitude 29° 3' North on the map .

3.2 Collecting soil and water samples

We opened profiles in the soil of several agricultural investments from the study area. Samples were taken from six open profiles at the level of agricultural investments affected and most affected by the salinity phenomenon, including profiles P1 and P2, which were opened in a new agricultural investment less affected by the salinity phenomenon. Profile (P1) was opened in unirrigated soil, while profile (P2) was opened in irrigated soil.

The necessary analyses were conducted on the horizons of the two profiles to compare the phenomenon of salinization between irrigated and non-irrigated soils on one hand, and saline and less saline soils (on their way to salinization) on the other hand, In order to determine the true causes of soil salinity in the Charouine area of Timimoun. Samples were taken from the six profiles whose locations are precisely specified in (Annex 3), and the analyses were conducted at the National Institute of Soil, Irrigation, and Drainage (INSID) in Adrar to perform the physical and chemical soil analysis (Annex 1). Samples of irrigation water were also taken from six wells used for irrigation in the aforementioned affected agricultural investments. The analyses were conducted at the regional laboratory of the National Agency for Water Resources (ANRH) in Adrar for analysis (Annex 2).

3.3 Methods of conducting physical and chemical analysis of soil samples.

We performed physical and chemical analyses of soil samples according to the method adopted by (AFNOR, 1987). The analyzes included measuring the following values:

1. pH (H2O) for soil solution by mass ratio (m / m) 2.5 at temperature $\theta = (20 \pm 2)$ C°
2. Measure the value of the pH (KCl) of the soil solution by mass ratio (m/m) 2.5 at temperature $\theta = (20 \pm 2)$ C°
3. Electrical conductivity (CE) (mS / m) by using the metering device at temperature $\theta = (25 \pm 0.1)$ C °
4. Measure the percentage of lime by using "Bernard calcimeter" at (0 C °, 1 atm)
5. Measuring the percentage of active chlorine by DROUINEAU method
6. Measurement of cation exchange capacity (CEC) using method acetate (METSON) ($cmolkg^{-1}$)
7. Measure the amount of dissolved bases (Na^{+}, K^{+}) using flame photometry and Ca^{++}, $Mg^{++,}$ using atomic absorption spectrophotometry.
8. Estimating the amount of solvents SO4-BaCl2 gravimetric (meq / 100g)

9. Determination of chlorine Cl^- by silver nitrate and by using potassium chromate (meq / 100g)
10. Determination of carbonate CO^{-3} and bicarbonate HCO^{3-} (meq / 100g)
11. Measuring soil granularity using ROBINSON de Robinson pipette
12. Measuring the amount of phosphor assimilable (P2O5) in Joret-Hebert (ppm)
13. Measuring percentage of organic matter (MO%)
14. Identification of soil texture Based on the proposed graph of strength proposed by USDA texture, in [11].

3.4 Methods of conducting irrigating water samples.

The physical and chemical analyses of irrigation water samples were conducted based on the work of the American Salinity Laboratory (USSL, 1954: Szabolcs, 1994). These works allow us to determine the quality of irrigation water and have been adapted to Algerian soils to include five profiles according to FAO (2024). Where a degree value was added to the alkalinity (SAR) vertical scale (S4) specific to the very high sodium elevation, and a degree value to the horizontal scale (C5) when the water (excessively saline water - C5) has an electrical conductivity value ranging between (5000 < EC < 20,000 µS/cm at 25°C). As in the Diagram of water alkalinity classes (Annex 4), that clearly defines the relationship between electrical conductivity and the percentage of sodium adsorption ratio (%) SAR for irrigation water. This Diagram consists of two scales as follows:

- The horizontal scale (C) shows the salinity hazard in terms of electrical conductivity (0-20 mS /m) at a temperature of 25°C.
- -The vertical scale (S) carries SAR values from (0 to 30) that represent the risk of alkalinity. the inter profiles points of the horizontal and vertical scales precisely determine whether the water is dominated by salinity or alkalinity.
- Several authors have expressed the dangers of alkalinization of irrigation water by taking into account the electrical conductivity (EC) measured at 25°C and the SAR and sometimes all the dissolved salts as indicated in Table 1.

Table 1. Assessment of the quality of irrigation water (Daoud & Halitm, 1994)

Electrical conductivity (dS/m) at 25°C	**Concentration (g/l)**	**U.S. Assessment**	**Evaluation Russian**	**Evaluation de Durand for Algeria (1958)**
EC < 0.25	< 0.2	Low salt	Good quality	Non-salt

0.25 < EC < 0.75	0.2 – 0.5	Medium salty		Medium salinity
0.75 < EC < 2.25	0.5 – 1.5	Highly salty	Risk of salinization	High salinity
2.25 EC < < 5.00	1.5 – 3.0	Very heavily salted		Very high salinity
5.00 EC < < 20.00	3.0 – 7.0	Excessive salinity	Can not be used without leaching	Excessive salinity

3.5 Method of collecting samples and measuring the electrical conductivity of soil solution and irrigation water

3.5.1 -Method of preparation of the soil solution

Weigh (10 g) dry soil using a sensitive balance and placed in a 100 ml beaker. Then, 50 ml of distilled water is added, resulting in a ratio of 1 gram of soil to 5 ml of water. Then, the mixture is stirred using an electromagnetic mixer for one hour, and then left to settle. Finally, it is filtered to obtain the soil solution extract, which is used to measure electrical conductivity according to the aforementioned method

3.5.2 Experimental conditions for measuring electrical conductivity and pH of soil extract and irrigation water

For the soil solution extract: After preparing the soil solution extract for each sample, these extracts are placed in test tubes and then put in a water bath to maintain the temperature at $\theta = (25\pm0.1)$ °C. The electrical conductivity (mS/m) is measured.

- For the irrigation water: We take 25 ml of irrigation water extracted from the wells, place it in test tubes, and put them in a water bath to adjust the temperature to $\theta = (20\pm 2)$ °C. We measure the water's salinity according to the mass ratio of 1/2.5 (mS/m).

4. Results and discussion

4.1 Electrical conductivity (EC) and soil pH for soil solution

The results of electrical conductivity (EC) and soil pH were represented using Excel software (Figures 1, 2).

4.1.1 Electrical conductivity (EC)

Through the representation of the histogram (Figure 1), it is evident that the electrical conductivity is low in the two profiles P1 and P2 opened in the new investment (less than 4 mS/cm), where we can classify the soil as non-saline according to the USSL (1954) and FAO (1984) standards, especially in the surface horizons. Electrical conductivity measurements in the irrigated profile indicate that it is slightly lower than in the non-irrigated profile, which may be due to several reasons related to salt balance and ion concentration in the soil solution as a result of the dissolution of these salts and their dilution with water, leading to a decrease in the electrical conductivity of the soil solution (Rhoades et al., 1992). Additionally, the increase in sodium adsorption ratio (SAR) in irrigation water leads to a decrease in water conductivity in the soil, which is related to changes in the composition of the soil solution and its effect on soil particles and porosity. It can also be attributed to the high water mobility through the sandy soil pores characteristic of the surface horizons. These soils are prone to salt loss, and thus, with excessive irrigation, they can lose their salts to the lower horizons (Madani, 2008). However, they quickly rise again by capillary action with the upward movement of water during dry periods when evaporation increases, leading to the accumulation of salts on the surface and resulting in surface soil salinization. While in the other profiles (P3-P4-P5-P6), the electrical conductivity of the soil horizons is high, ranging between (6 and 18.1 mS/cm), and they are classified as saline to highly saline, making them unsuitable for most crops except for salt-resistant or highly salt-resistant crops according to the previous classifications. The salinity is attributed to excessive irrigation with saline or highly saline water, which initially does not affect the soil salinity but over time, salts accumulate in the soil solution, increasing its electrical conductivity and thus leading to secondary salinization (Douaoui et al., 2006؛ Ben Hassine, 2005)

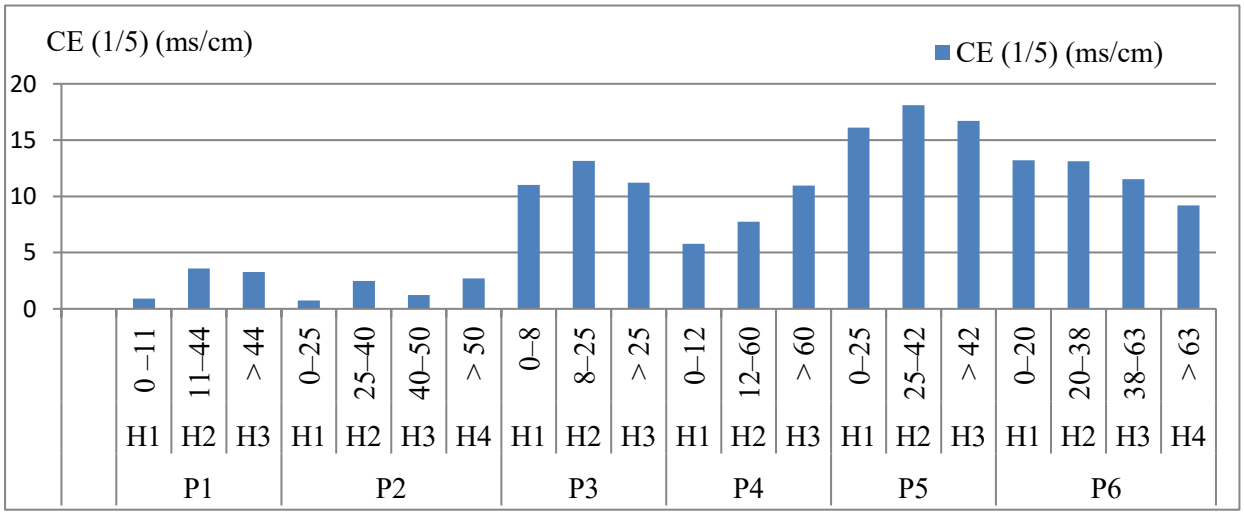

Fig. 1 Representation of the electrical conductivity (EC) results of the soil solution.

4.1.2 soil pH

To obtain a comprehensive picture of the soil condition, the actual pH (pH H2O) currently affecting the

plant and the potential pH (pH HCl) that may affect the plant in the future were measured. The results are shown in the histogram depicted in (Figure 2), which indicates that the actual and potential soil acidity in the study area tends towards alkalinity, ranging approximately between (7.61- 8.74). Consequently, this acidity will cause a deficiency in the absorption of some essential nutrients for the plant, such as phosphorus and micronutrients like manganese, iron, and zinc, and will reduce microbial activity, weakening soil fertility and causing changes in its structure. All of this affects crop quality. Therefore, acidic materials like sulfur or organic materials should be used to improve soil acidity and restore its balance, as alkaline soil may lead to soil salinization in the future (Al-Shalash et al., 1985).



Fig. 2 Representation of soil pH results of the soil solution

4.2 Discussion of the results of chemical analysis of the soil samples of the study area (Charouine)

According to the classification provided by (Kaouritchev, 1983), the ratios of anions and cations were calculated to determine the characteristic salts of the soil horizons in the previous profiles P1 and P2. The results are as shown in (Table 2) below:

Table 2. The chemical composition of the soil solution in terms of cations and the types of salts present in the soil P1, P2

Type of saline by cations	Cation ratio			Cation, (meq)/100 g of soil (cmol / kg of soil)					Depth of the horizon (cm)	horizon Code	profile Code
	$\frac{Mg+}{Ca++}$	$\frac{Na+}{Ca++}$	$\frac{Na+}{Mg++}$	∑ cations	Mg++	Ca++	K+	Na+			
Calcium-sodium	0.72	4.30	5.9	6.29	0.7	0.96	0.5	4.13	11 - 0	P1H1	P1 Outside the land of the invested Before irrigation
Soda - Magnesian	2.40	1.83	0.76	8.17	3.2	1.33	1.2	2.44	44 -11	P1H2	
Magnesium-sodium	1.91	2.01	1.05	11.1	3.4	1.78	2.34	3.58	> 44	P1H3	

Magnesium - Calcium	0.52	0.28	0.55	3.24	0.8	1.53	0.47	0.44	25 - 0	P2H1	P2 Within the land of the invested After irrigation
Calcium-sodium	0.65	1.14	1.73	9.27	2.07	3.14	0.46	3.6	40 -25	P2H2	
Calcium - Magnesium	1.17	0.07	0.06	7.33	3.6	3.06	0.45	0.22	50 -40	P2H3	
Magnesium - Calcium	0.55	0.43	0.78	13.03	3.5	6.28	0.49	2.76	> 50	P2H4	

169

170 4.2.1 Type of salinization with cation

171 Based on the results of Table (2), we conclude that the cation salinity type in the unirrigated soil (P1) is carbonic -
172 sodic in the surface horizon, and sodic - magnesic, and magnesic - sodic in the lower horizons. As for the type of
173 salinity in the irrigated soil (P2), it is salinity with almost all cations (magnesium-calcium, calcium-sodium, calcium-
174 magnesium, magnesium-calcium) (Qadir et al., 2007). This indicates that there are multiple sources of salinity in the
175 soil of this section, and in this case, saline irrigation water could be the reason for the accumulation of various cations,
176 especially sodium, which affects the soil structure and its dispersion, particularly in heavy and alkaline soils. This
177 reduces its fertility and makes it susceptible to salinization, especially after water evaporation due to the prevailing
178 drought conditions in the region (Al-Shalash et al., 1985).

179 4.2.2 Type of salinization with Anion

180 **Table 3.** The chemical composition of the soil solution in terms of Anions and the types of salts present in the soil P1, P2.

Type of saline by anions	Anion ratios			Anions (meq) / 100 g of soil (cmol / kg de sol)				Depth of the horizon (cm)	horizon Code	profile Code
	HCO3- / SO42-	HCO3- / Cl-	Cl- / SO42-	∑ Anions	HCO3-	Cl-	SO42-			
Sulfate chlorure	2	0.008	1,24	2.53	0.02	2.50	2.01	11 - 0	P1H1	P1 Outside the land of the invested Before irrigation
Sulfate	0.001	0.008	0.15	18.63	0.02	2.50	16.11	44 -11	P1H2	
Sulfate	0.001	0.005	0.22	18.82	0.02	3.50	15.30	> 44	P1H3	
Chlorory Sulfate	0.008	0.015	0.55	2.80	0.015	1.00	1.79	25 - 0	P2H1	P2 Inside the land of the invested After irrigation
Sulfate	0.0009	0.007	0.12	18.35	0.015	2.00	16.34	40 -25	P2H2	
Sulfate	0.006	0.006	1.15	4.67	0.015	2.50	2.16	50 -40	P2H3	
Sulfate	0.0009	0.006	0.13	12.63	0.01	1.50	11.12	> 50	P2H4	

181

Through the results of Table (3), it is clear that the predominant type of anions in profile P1 is chlorosulfate anions in the surface horizon, and sulfate anions in the lower horizons. As for profile 2P, the predominant type of anions is chlorosulfate anions in the surface horizon P2H1, and sulfate anions in the lower horizons (P2H2, P2H3, P2H4). This distribution is attributed to the effect of saline irrigation water and the properties of soil components from naturally occurring salts. In the soil profile irrigated with saline water, the entry of sodium and chloride ions from the water leads to the accumulation of chloride and chlorosulfate ions in the upper horizons due to their high solubility and rapid movement, making them less likely to precipitate or interact with the soil exchange complex. As a result, they gather in the surface layers, while sulfate ions move deeper due to chemical reactions and water movement, and they can precipitate there as a result of their chemical interactions with soil minerals. This explains their presence in the lower horizons (Chach-Bouaziz, 2021). The source of ions in unirrigated soils often comes from the natural salts present in the soil, which may contain varying proportions of these ions (Chach-Bouaziz, 2021).

Therefore, the distribution of ions between the upper and lower horizons of the profiles may be attributed to the movement characteristics of these ions in the soil and the effect of saline irrigation water on the transport and deposition of these ions.

4.3 Comparison of the chemical analysis results of the soil solution, P1, P2

Through the graphical representation of Piper shown in figures (3,4), it is evident that the total cations and anions increase in the soil solution of the irrigated profile (P2) compared to the non-irrigated soil profile (P1). Additionally, the dominant cations and anions in the soils of profiles P1 and P2 can be arranged as follows:

$$Ca+2 > Mg+2 > Na+ > K+, SO4-2 > Cl- > CO3- > HCO3-$$

This confirms the impact of saline irrigation water, primarily rich in cations and anions, in increasing the accumulation of various salts in the soil, leading to salinization with increased irrigation over time. Therefore, irrigation should be organized and controlled according to the needs of the plants to protect the soil from salinization and salt pollution (Mansouri et al., 2014).

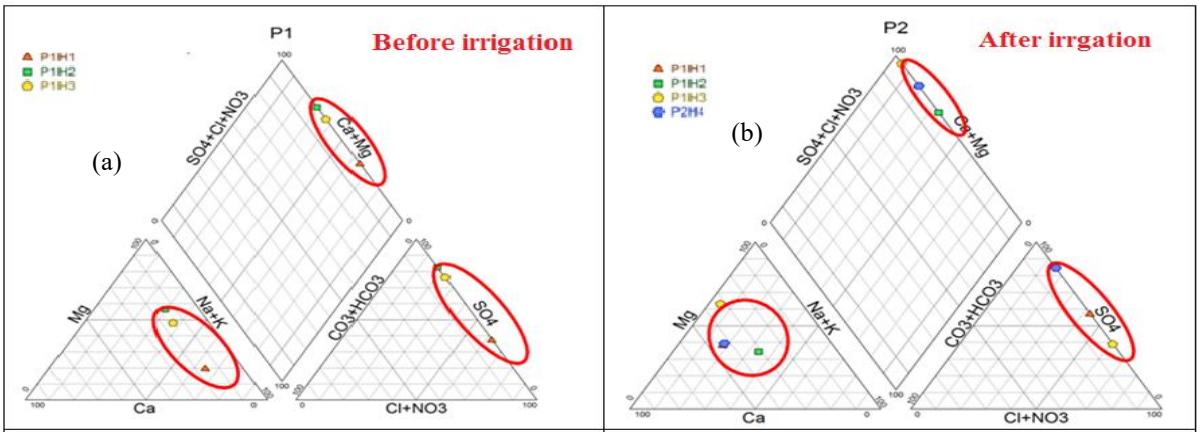

Fig. 3 Sample analysis results of (a) soil profile P1, (b) soil profile P2

205 4.4 Discussion of the results of the physical analysis of soil samples from the study area (Charouine)

206 The results of the granulometric analysis of soil samples according to the USDA soil texture classification indicate that
207 the soil in the charouine area is characterized by a sandy texture in the surface layers and a nearly balanced texture in the
208 lower layers (Table 4) (Madani, 2008). This makes them more susceptible to salinization in their lower horizons compared
209 to their surface horizons, which are characterized by a sandy texture and high drainage capacity due to low drainage and
210 increased water retention capacity in the soil. The surface layers can also become saline in dry conditions and high
211 evaporation in arid regions due to the upward movement of salts accumulated in the lower soil layers towards the surface
212 through the capillary action of the high porosity of sandy soil, increasing the concentration of salts in the root zone
213 (Rhoades et al., 1992), This reduces the plant's ability to utilize water and mineral salts due to the low water potential,
214 negatively affecting its growth and reducing its productivity, especially if irrigated with highly saline water and excessively
215 (Grattan & Grieve, 1999).

216 **Table 4**: Results of the granulometric analysis and soil texture determination based on the USDA soil texture triangle

Textures	Coarse Sand (%) Sg	Fine Sand (%) S f	Silt coarse (%) L g	Fine Silt (%) L f	Clay (%) L g	Depth of the horizon (cm)	horizon Code	profile Code
Sandy silty (sandy)	12.39	74.72	3.07	1.00	8.80	11 - 0	P1H1	P1 Outside the land of the invested Before irrigation
Sandy silty (sandy)	45.81	28.10	9.10	9.42	7 .55	44 -11	P1H2	
Silty Clay sandy (balanced)	40.19	29.60	10.24	15.44	4 .50	> 44	P1H3	
sandy	8.10	84.44	2.93	0.89	3.62	25 - 0	P2H1	P2 Inside the land of the invested After irrigation
silty Clay sandy (balanced)	20.28	48.17	15.06	9.73	6. 74	40 -25	P2H2	
silty sandy (balanced)	15.98	51.53	7 .99	11.27	13.01	50 -40	P2H3	
Sandy silty (sandy)	44.60	31.18	9.32	6.85	8.01	> 50	P2H4	

217

218 4.5 The mineral elements and soil fertilizing elements in the horizons of profiles P1 and P2

219 Through the results of the physical and chemical analyses of the nutrients and fertilizers in the soil of profiles P1 and
220 P2 (Table 5), it is evident that the total calcium in the soil is high compared to other elements, especially in the non-
221 irrigated soil in profile P1, due to the significant deposition of calcium in the lower soil layers in the form of calcium
222 carbonate ($CaCO_3$) as a result of the prevailing dry conditions in the region, making the soil more alkaline and prone to
223 salinization. This element alone is insufficient for soil fertilization, especially if the soil is highly sandy, porous, and has
224 low retention of chemical elements.

While the percentage of active lime (CaCO3), the amount of available phosphorus, organic matter, and cation exchange capacity (CEC) are low in the horizons of profiles P1 and P2, which reduces their ability to retain water, indicating low soil fertility (Asmat et al., 2025).

Table 5. The ratio of nutrient elements and fertilizing elements in the soil at the horizons of soil profiles P1, P2

Organic matter OM (%)	Available phosphorus P2O4 (ppm)	Cation exchange capacity (cmol /Kg)	Effective lime CaCO3 (%)	Total lime CaCO3 (%)	Depth of the horizon (cm)	Code horizon	Profile Code
0.51	85.82	4.33	1.25	5.38	11 - 0	P1H1	P1
0.51	70.83	6.23	4.25	26.93	11 44 -	P1H2	Outside the land of
0.43	37.49	5.49	2.25	24.12	44>	P1H3	the invested Before irrigation
0.68	70.83	2 .23	0	3 .83	25 - 0	P2H1	P2
0.68	83.33	2 .23	3.25	11.84	25 40 -	P2H2	Inside the land of
0.51	129.16	4.75	2.75	7.89	40 50 -	P2H3	the invested
0.60	45.83	3.51	4.75	12.93	50>	P2H4	After irrigation

4.6 The risk of salinity and alkalinity of irrigation water

Many authors confirm that discussing the risks of alkalinity in irrigation water requires taking into account the electrical conductivity (EC_W) measured en µS/cm at 25 degrees Celsius, the sodium adsorption ratio (SAR), and sometimes all soluble salts, and studying the relationship between them. Based on that, the soil salinity classification diagram proposed by the U.S. Salinity Laboratory (U.S.S.L) was chosen and adapted to Algerian soils, where the SAR values for irrigation water samples were calculated according to the following formula:

$$r\text{^}2SAR = Na^{+} /[\,(Ca^{++} + Mg^{++})\,.\,0{,}5\,]1/2$$ (Nasri et al., 2018)،

Ca^{++}, Mg^{++}, Na^{+} : $en\ meq/L$ (U.S. Salinity Laboratory Staff, 1954)

- After plotting the electrical conductivity values of irrigation water (CE_W) and SAR values on the water classification diagram (Figure 4), it is clear that most irrigation water in the study area (Charouine) is classified within the (C4-S4) category, where the risk of alkalinity is very high, and some within the (C4-S3) category, where the risk of alkalinity is high. This indicates that the irrigation water contains significant amounts of dissolved salts, especially sodium salts, in addition to calcium and magnesium salts, and some anions such as sulfates and chlorides.

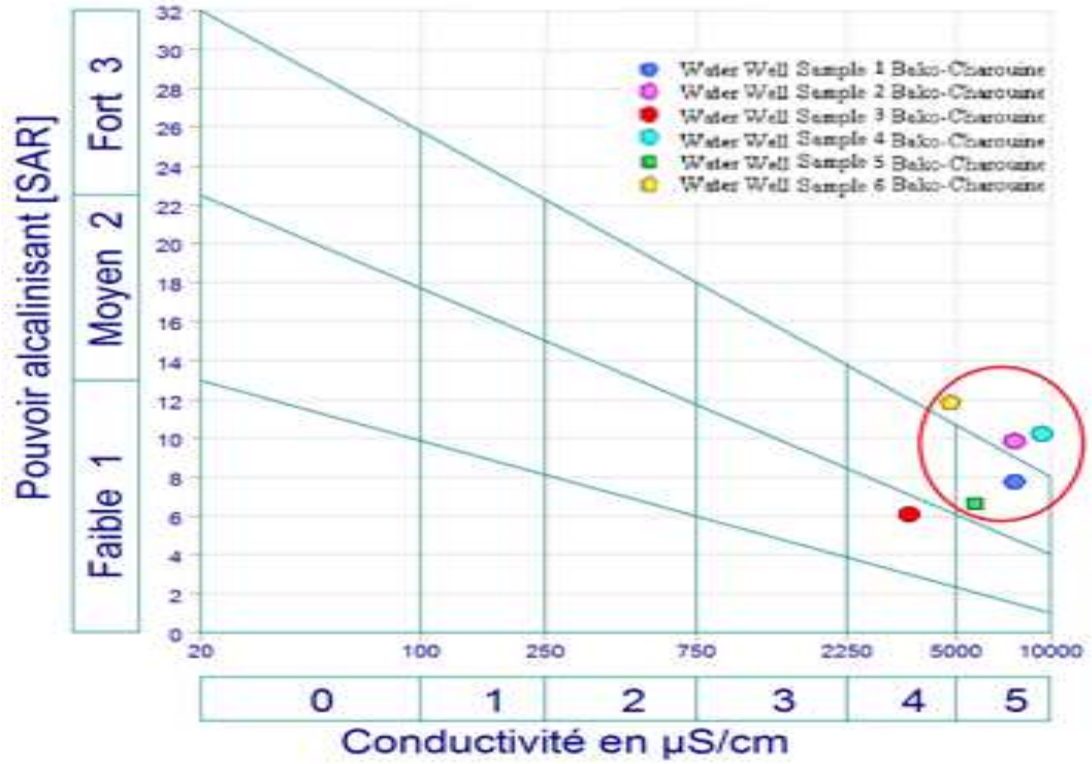

Fig. 4 Diagram of water alkalinity classes

5. Conclusion and suggestions

The results of this study have shown that the unirrigated soil in the study area contains limited amounts of sodium cations (Na^{+}), magnesium (Mg^{++}), calcium (Ca^{++}), as well as anions, sulfates (SO_4), and chlorides (Cl^{-}). The source of these ions is the soil itself (the parent rock), especially in areas close to depressions where the rocks are subjected to chemical and physical weathering, leaving behind residues rich in salts. The parent rock in the region consists of limestone from the Eocene layers. at the base of the Eocene epoch. Additionally, we find evaporitic rocks and gypsum limestone alternating with anhydrite (Ca SO_4) and gypsum ($CaSO_4$ $2H_2O$) in the upper Eocene epoch, which can produce magnesium and calcium ions on one hand and chloride and sulfate ions on the other due to the erosion and weathering conditions in the area. As for the soils of agricultural investments in the region, the source of their salinity is due to the irrigation water used, which has high levels of sodium ions (Na^{+}), potassium (K^{+}), sulfates ($SO4^{--}$), and chlorides (Cl^{-}).

Where its salinity is attributed to the presence of evaporite rocks such as halite (NaCl) and anhydrite ($CaSO_4$), which alternate with limestone in the Eocene, Cretaceous, and Albian strata. Additionally, gypsum ($CaSO_42H_2O$), which forms the Pliocene and Miocene formations of the modern era (Cenozoic) (Ben Hamza, 2013), is also a source of soil and water salinity.

Based on the above and through the study we conducted, we can identify the source of soil salinity in the charouine area of Timimoun, where we record two types of saline and sodic soils that differ in their salinity levels, the types of salts present in them, and their sources of salinity, which are as follows:

As for the highly saline soils, we find them characterized by areas close to closed saline depressions (sabkhas). It is classified as highly saline, as its salinity source is the saline groundwater (internal salinization) due to the nature of the parent rock storing it underground, which is considered a source of dissolved salts in water (alkaline elements). During dry periods, the water laden with those salts rises to the surface layers of the soil, where the water evaporates and the salts precipitate on the surface, forming a white crust. Only plants that can withstand high salinity grow in this soil.

Saline soil is mostly the result of the unconsidered use of irrigation water (human-induced salinization) that does not take into account the physical and chemical properties of the soil and the climatic conditions of the area, leading to secondary salinization of the soil. This has negatively affected agricultural production, which has become limited in some agricultural investments in the Baku- charouine area, restricted to the productivity of salt-resistant plants only (Madani, 2008) . We also recorded, through this study, the absence of geological salinity in the sandy agricultural areas of the charouine region due to the generally low levels of salts in the sandy soil, especially in the surface horizons, except for areas near closed saline depressions (sabkhas) where physical and chemical weathering of rocks occurs, depositing their residues in weathering sites, which may increase the salt concentration in the soil of those areas (Omouri, 2009).

The results of this study confirm that the soil in the charouine area is originally non-saline, especially in its surface horizons, which mainly consist of sandy soil with high permeability and are poor in essential mineral and nutrient elements for plants, as seen in the profiles (P1, P2). But the region's water is saline, having acquired its salinity from the parent rock. When farmers use it without considering the plant's needs for saline irrigation water and overuse it, it will raise the salinity of the agricultural soil, making it saline due to the high concentration of alkaline salts in the well water used for irrigation. This is confirmed by the high electrical conductivity measurements in the other profiles (P3, P4, P5, P6), which have become highly saline due to being irrigated with large amounts of saline water during their use (Ziza, 1992;Omouri, 2009). With the increase in evaporation rates due to the prevailing aridity in the region, pure water is lost from the soil column, especially from the surface horizon, while the carried salts accumulate on the surface, increasing the secondary salinity of the soil.

Due to the significant expansion of saline lands caused by human activities in the study area and its surroundings in the Algerian desert, classified as arid regions, it is essential to seriously consider how to maintain soil sustainability for agriculture and protect it from salinization. This can be achieved by taking all necessary measures to reduce the risk of alkalinity resulting from saline irrigation water, which is the main factor in the expansion of saline lands in the region. Among the proposed solutions, the use of effective and low-cost drainage techniques can be considered by establishing

292 good drainage networks to remove the impact of saline groundwater and the water resulting from soil leaching of salts
293 accumulated due to continuous irrigation. This aims to remove sodium and harmful ions away from the root zone to prevent
294 the formation of highly saline alkaline soil (Houshan, 2022; Rhoades et al., 1992). We also recommend adding chemical
295 amendments such as agricultural gypsum rich in calcium sulfate to introduce calcium ions into the soil, which play a role in
296 replacing sodium in the absorption complex, or adding sulfuric acid to reduce alkalinity (pH) in the soil solution.
297 Additionally, well-decomposed organic fertilizers can be used to improve soil structure and enhance its chemical balance,
298 thereby increasing its fertility and resistance to salinity (Mas'ad Al-Sayrafi & Al-Ghamri, 2010).

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305 ## Author Contributions

306 The corresponding author, Boushaba Abdeldjebar, carried out the analyses, formulated and analyzed the results, drew the
307 conclusions, and drafted the manuscript. Co-authors Toumi Mohamed and henni Bachir contributed to the supervision,
308 monitoring, verification, and discussion of the results.

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312 ## Data Availability

313 The data supporting this study is available from the corresponding author upon reasonable request.

314 ## Declarations

315 All authors acknowledge and agree to the publication of this work.

316 ## Competing interests

317 The authors declare no conflict of interest.

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