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THE IMPACT OF SALINE IRRIGATION ON SOIL SALINIZATION IN THE ARID REGION OF ALGERIA

SUMMARY

Water and soil salinity are among the most important challenges facing the agricultural sector in arid and semi-arid regions. In water-scarce areas, the use of saline water for irrigation is a widespread practice. This study aimed to assess the quality of irrigation water in the arid region of Messaâd and evaluate its impact on soil salinity. The analysis revealed that the electrical conductivity (EC) of irrigation water ranged from 0.595 to 24.8 mS/cm, while the sodium adsorption ratio (SAR) values ranged from 1 to 12.37 mEq/L. In soil, EC values ranged from 0.117 to 13.69 mS/cm and SAR values ranged from 1.46 to 12.26 µmol/litre. According to the Piper plot analysis, the irrigation water in Al Messaâd is mainly of the calcium chloride and chloride type. The soil texture classification indicates that the soils in the vicinity of irrigated Al Messaâd are mostly sand, sandy loam, sandy loam, and sandy loam. The results indicate that there is a clear influence of irrigation water salinity on soil salinisation, especially in the eastern parts of the region where salinity levels are significantly higher.

Keywords: Soil salinity, Irrigated Perimeter, PCA, Messaâd, Piper plot, Algeria

INTRODUCTION

Food self-sufficiency is challenged in semi-arid and arid regions due to limited fertile land, irrigation water, and the salinity or brackishness of available water sources, hindering agricultural production. The use of saltwater for crop irrigation in these regions has led to soil salinisation. This has reduced agricultural productivity by as much as 27 billion dollars per year (Singh, 2022). In some regions, agricultural production has decreased by up to 97%. Also, according to Wang *et al.* (2021), global food production has already decreased by

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50% in the twenty-first century due to soil salinization. Although the relationship between soil salinity and irrigation water has been the subject of several studies on the five continents (Gholami *et al.*, 2025; Demo *et al.*, 2025; Nicolas *et al.*, 2023; Tedeschi and Xue, 2025).

In Algeria, the studies of this phenomenon touched just the Algerian Sahara area, where the annual rainfall is almost null, such as: Zaiz and Boutoutaou (2022) in Oued Souf, Abdennour *et al.* (2020, 2021) in Biskra, Selmane *et al* (2024) in Ourgla, and Benslama *et al.* (2020) and Kraimat *et al.* (2025) in Ghardaia. These areas are located in the saharian part of Algeria and are characterized by a very harsh arid climate, high evapotranspiration, and an increasing salinization of soils. Due to drought and the lack of surface water, farmers rely on groundwater as the sole source of irrigation.

However, there aren't still number of studies in the high plateaus region of Algeria (northern part of the Algerian desert) such as the province of Djelfa, that treat the soil salinization problem. Recognize as a transition zone from a semi-arid to an arid climate where the local geology, specifically the presence of marls, gypsum, and evaporite formations in the soil profile affects the soil salinity. It's also influenced by surface water dynamics, particularly in the Messaad region. Therefore, it would be very interesting to focus research on assessing water quality for irrigation using indicators such as Sodium Absoption Ratio (SAR) and Electrical Conductivity (EC).

The aim of this work is to identify the quality of irrigation water in the Messaad area in Djelfa province, to detect if this water has an impact at soil and it is to propose crops that are adapted to this irrigation water.

MATERIAL AND METHODS

Study area

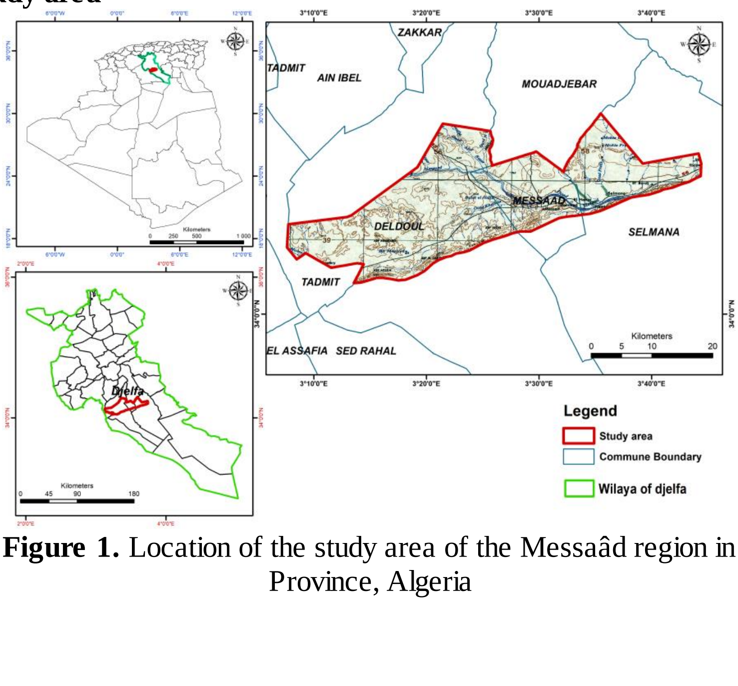


Figure 1. Location of the study area of the Messaâd region in Djelfa Province, Algeria

This work was performed in the arid area of Messaâd, which located 400 km south of Algiers (Algeria). At an altitude ranging from 600 to 859 meters above sea level, the area spans 657.37 square kilometers. It's located between 34° 17' 48'' and 34° 2' 54'' North latitude, and 3° 7' 42'' and 3° 44' 30'' East longitude (figure 1). This region has an arid climate, with an average maximum temperature of 36° C and an average minimum temperature of 7° C. The mean annual rainfall is 180 mm (DPSB, 2018; DSA, 2021).

Field work

Messaâd has 76 farms (DSA, 2021). An inquiry regarding soil salinity was conducted with 67 of the 76 farmers in the study area. After the inquiry, soil and water samples are taken once in the irrigation season in September 2023 from the farms and were collected at a 20 cm depth. Using a GPS Venture HC receptor, coordinates (latitude and longitude) were recorded for each of the 67 sampling locations (figure 2). Whereas, water samples were taken from the irrigation borehole on the farms. One-litre bottles were used to collect water samples.

Laboratory work

Soil samples were prepared for laboratory analysis by air drying, crushing and sieving using a 2 mm sieve. The EC, calcium, magnesium, sodium, and particle size were determined in the soil, while in the irrigation water, calcium, magnesium, sodium, chloride, bicarbonate, potassium, sulfate, and electrical conductivity were analyzed.

The EC was measured with a conductivity meter AZ86021 (equipped with a temperature correction device, allowing a direct reading at the reference temperature of 25°C, and using the soil extract with a ratio of 1/5 soil/water. The SAR parameter was also determined by preparing soil extracts (for soil) and using collected water samples, measuring ion concentrations (Na+, Ca2+, Mg2+). The calculation of SAR from these values using the formula:

$$SAR = \frac{\left[Na^{+}\right]}{\sqrt{\frac{Ca^{++}+Mg^{++}}{2}}} \text{.........................} eq(1)$$

Statistical analysis

The Principal Component Analysis (PCA) was used to identify homogeneous irrigated perimeters in the study region in terms of salinity. After laboratory analysis, the collected water and soil data was processed to classify homogeneous boreholes and soils in the irrigated perimeters using the following parameters:

-For borehole water: ECw, SARw, pH, Na, K, Ca, Cl, SO4 and HCO3,

-For soil: ECs, SARs, pH, limestone, Organic Matter (OM), Moisture, Na and Ca+Mg.

It should be noted that the statistical analyses were made with Statistica 12.

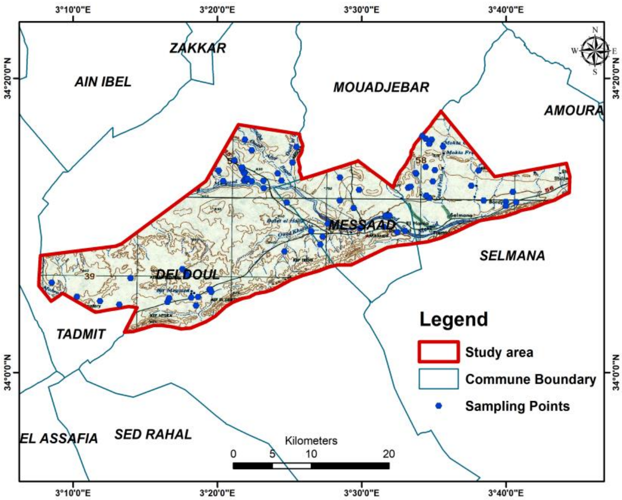


Figure 2. Map of sampling sites

RESULTS AND DISCUSSION

Survey results

The results of the survey of farmers in the Messaâd region are presented in Table 1. We divided the study region into three zones: East, Centre and West.

Table 1. Surveying zones characteristics of the study area

Zone	Number of farmers	Surface area (ha)	Irrigation technique	Crop type	Salinity problem
Center	15	1 - 30	By spraying	1-2	2
West	35	70 - 80	By spraying	1-2-3-4	3
East	17	1 - 140	By spraying	1-2-3-4	6
total	67				11

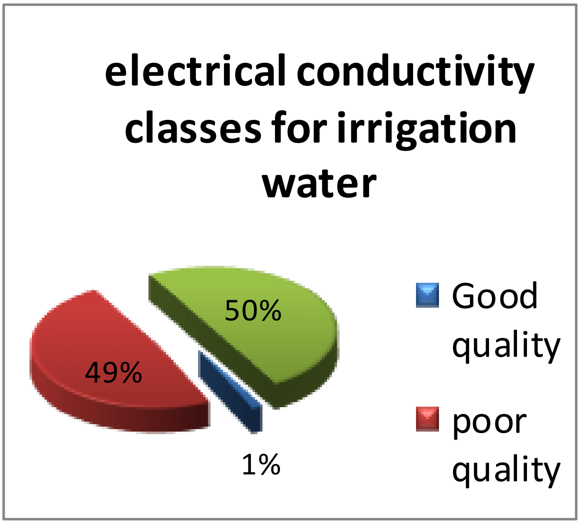
(1) Fruit growing; (2) Vegetable growing; (3) Cereal growing; (4) Olive growing

The number of farms surveyed in the study area was 67. The area cultivated by each farmer ranged from one hectare to 140 hectares. Agriculture in Messaâd area is based on family farming, which explains the small and medium-sized cultivated areas. On the one hand, the irrigation system used on the farms is sprinkler irrigation, and on the other hand, the predominant crop is fruit trees (apricots and pomegranates). According to the survey results, 11 farms reported salinity issues in these farms, mostly in the east.

We observed that, according to the respondents, the choice of this type of crops is related to the adaptation of the cultivated varieties to the climatic conditions of the region on the one hand, and on the other hand to the age of planting trees in the region, a tradition that is passed down from generation to generation.

Chemical analysis of irrigation water

The results of the chemical analysis of the water used for irrigation allow us to classify the boreholes, used in irrigation, according to their EC and SAR values (figure 3).



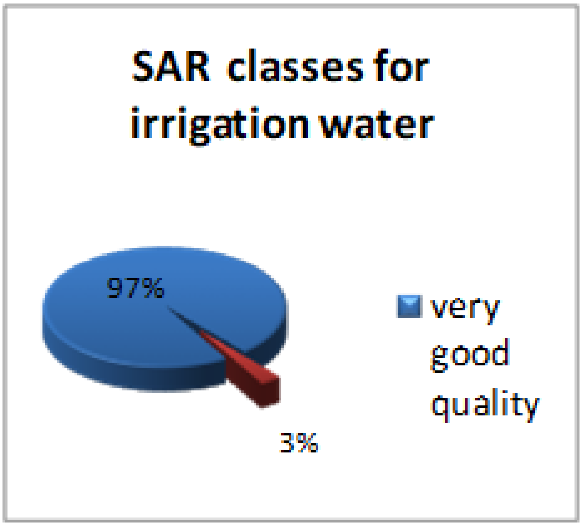


Figure 3. Classification of irrigation water of according to the EC index and the SAR index

The Messaâd irrigated area is represented by 67 irrigated perimeters, where 33 boreholes are highly saline (0.75<EC<2.25 m/cm) and 34 very highly saline with average EC values above 2.25 m/cm (Daoud and Halitem. 1994; Benaissa and Bessati 2017).

Whereas, according to the SAR index, 33 boreholes have very good water quality (SAR<10) and only two boreholes have good water quality (Richards, 1954).

Irrigation water in the eastern part of the study area has a higher salinity level compared to the western part and the center of Messaâd.

Classification of irrigation water using Piper's method

The Messaâd center

The analysis of irrigation water from boreholes in the Messaâd center has shown the dominance of magnesium over other cations, while the triangle of anions is dominated by chlorine. Irrigation water in the central irrigated perimeters is therefore of the hyper-chloride-calcium type (Figure 4).

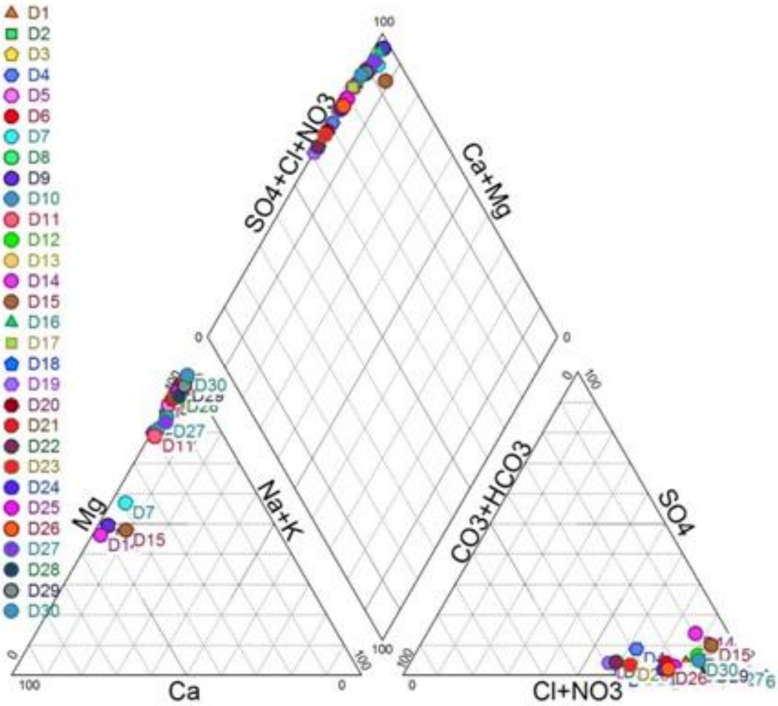


Figure 4. Classification of Piper water from irrigation boreholes in the Messaâd irrigated perimeters

The western Messaâd perimeter

We found from the Piper classification of water from the western Messaâd boreholes that chlorine is the most dominant anion on the right-hand side of the diagram, while magnesium is the most dominant cation on the left-hand side. All the western boreholes are of the calcic hyperchloride type (Figure 5).

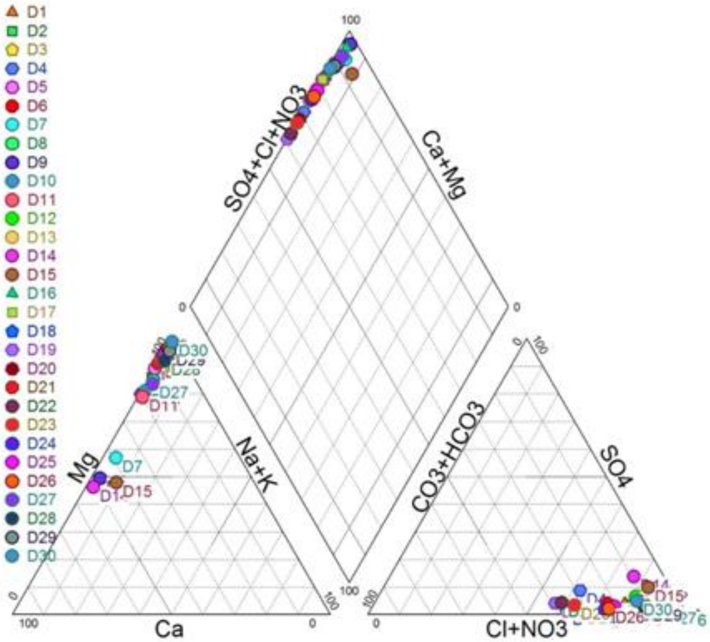


Figure 5. Piper's water classification of irrigation boreholes in irrigated perimeters - west of Messaâd

Eastern Messaâd perimeter

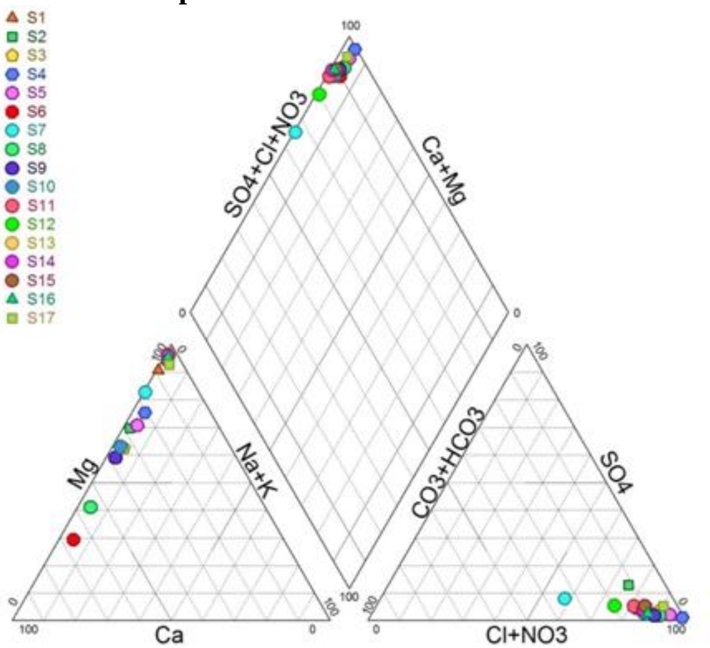


Figure 6. Piper's water classification of irrigation boreholes in irrigated perimeters - east of Messaâd

The agricultural perimeters to the east of Messaâd are irrigated with water of the hyper-chloride-calcium type. On the one hand, in 15 boreholes, the dominant cation is magnesium and in the other boreholes (two) no dominant cations; on the other hand, the dominant anion is chloride in 17 boreholes (Figure 6).

Soil salinity classification in the Messaâd irrigated perimeters

The results of the EC and the SAR index for irrigated soils are shown in the figure 7.

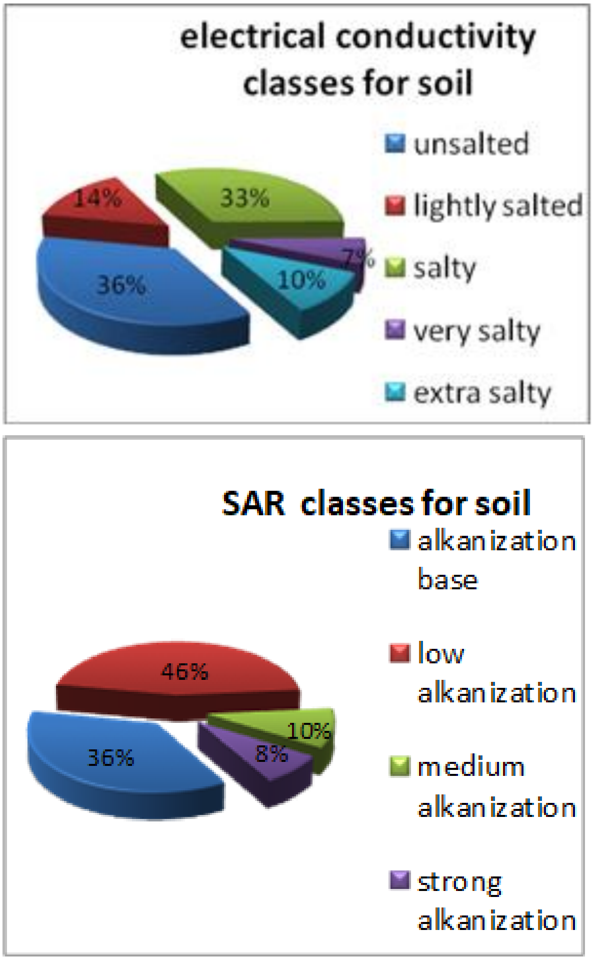


Figure 7. Classification of Messaâd perimeters according to EC values and SAR index

At the Messaâd center perimeters, we noticed that: the soil of two sites is not salty (CE <0.6 ms/cm), four sites with a slightly salty soil (0.6 <CE <1. 2 ms/cm), six sites are characterized by salty soil (1.2 <CE <2.4 ms/cm), two sites recorded a CE between: 2.4 and 4 ms/cm, which represents very salty soil and only one site extremely salty (CE=5.32 ms/cm).

The majority of soils on farms in the western part of the study region are classified as non-salty (32 sites), where EC values are below 0.6ms/cm, the soil on one farm is slightly salty (EC<1ms/cm), the soil on five farms is salty (1<EC<2 ms/cm) and the soil on just one farm is classified as very salty (2<EC<4 ms/cm). Whereas, and according to standards, the majority of irrigated perimeters in the East (14 perimeters out of 22), are classified as very salty and extremely salty where the EC value (4.55<EC<13.69 ms/cm), the soil at three sites is no salty (CE<0.6 ms/cm), the soil in two perimeters is slightly salty (0.6<CE<1ms/cm) and the soil in three perimeters is salty (1<CE<2 ms/cm) (Mathieu and Pieltain., 2009; Aubert., 1960).

We classified the soils in our study area according to the criteria mentioned by Servant and Servat (1966), who classified saline soils according to the SAR index. On farms located on the perimeter of Messaâd, we found that over 85% of farm soils were weakly alkaline (4<SAR<SAR<8 meq/L).

Soil texture classes in the Messaâd region

The particle size analysis of the studied soils revealed textural classes ranging from sandy to sandy-loam and loamy-sand, indicating a dominance of coarse particles over fine ones. These textural types are typical of arid environments and significantly influence the physical behavior of the soil, particularly in terms of permeability and water retention (Figure 8).

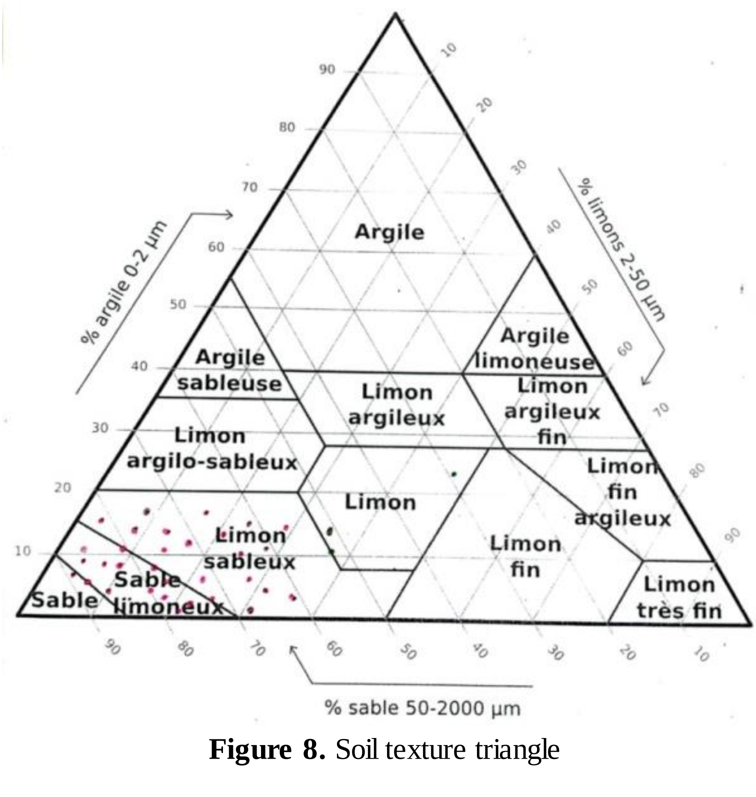


Figure 8. Soil texture triangle

The arid zone soils are generally saline, alkaline, gypsiferous and calcareous, especially in the north. Exchange capacity is limited and water holding capacity is very low. Desert soils are low in organic matter, generally less than one per cent, and lack nitrogen (Pouget, 1977; Halitim, 1988).

After analyzing the obtained results (EC and SAR), we observed that salinity is higher in irrigated soils in the eastern part of the study area, where over 63% of agricultural soils were classified as highly saline and very saline (EC>4 m/cm). These results showed a highly significant difference between the soils of the eastern perimeter and those of the other perimeters. The salinity phenomenon is associated with highly saline irrigation water and climatic conditions (arid bioclimatic phase) (Daliacopoulos *et al.* 2016; Wu *et al.* 2019; Jiang *et al.* 2019; Bensalama *et al.* 2020).

It should be noted, that the findings of EC values recorded in the Messaâd region were in good agreement with those obtained by Azlaoui *et al.* (2021), Ben Amara *et al.* (2024) and Rabouh (2025) in ain Oussara Plain located in the same province. Also, they are lower than those found in the soil of El Ghrous, an arid region in Biskra, which ranged from 36 mS/m to 854 mS/m, and the EC values noted by (Bradai *et al.,* 2022), in the arid plain of Mina (Algeria), where the average (EC) of soil samples ranged from 135 to 2842 mS/m (Berkane *et al.*, 2021).

Concerning SAR index values, soils from irrigated perimeters in the Messaâd region recorded similar values to those found in the arid region of Zelfana (southern Algeria), in an irrigated farm where SAR values ranged from 1.33 to 16.98 meq/l (Benslama *et al.,* 2020).

These results show that soil salinity levels increase with irrigation, which is confirmed by numerous studies in Algeria (Berkane *et al.*, 2021; Abdennour *et al.,* 2020; Abdennour et al., 2021; Benslama *et al.*, 2020; Semar *et al.*, 2019; Mostefa et al., 2022) and in different countries(Lhissoui *et al.,* 2014; Gorji *et al.*, 2015; Asfaw *et al.*, 2018).

Homogeneous irrigated perimeters according to the PCA analysis

Principal Component Analysis (PCA), a more in-depth statistical analysis, was used to examine the effect of irrigation water on soil salinity and their relationship. It should be noted that we have used abbreviations to make the results easier to read: B: borehole; F: farm.

Homogeneous borehole irrigation water in terms of salinity in the study area

The results of the PCA of the borehole irrigation water in the irrigated perimeters of Messaâd are represented in figure 9.

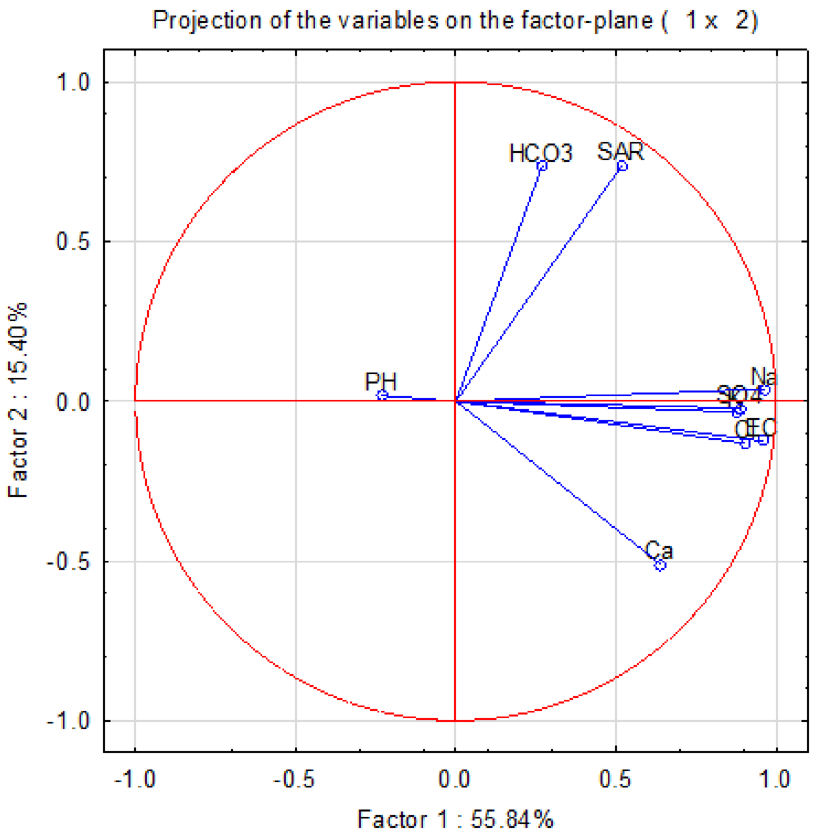


Figure 9. The PCA projection of the variables (ECw, SARw, pH, Na, K, Ca, Cl, SO4 and HCO3) on the plane (axis 1 - axis 2).

The projection of the variables on the (1x2) plane (figure 10) shows that the nine variables chosen are well correlated with excellent quality of representation (factor 1: 55.84%; factor 2: 15.40%).

Analysis of the projections of individuals linked to axes 01 and 02 revealed that the farms located on the positive side of the axe 1 are within the following perimeters: B2, B3, B4, B5, B6, B8, B9, B10, B12, B13, B15, B17, B18, B23, B28, B30, B31, B41, B42, B43, B45, B48, B49 and B61.

On the other hand, they situated the following irrigated perimeters on the negative side of the axe 1: B68, B14, B65, B66, B29, B64, B14, B59, B67, B33, B62, B63, B34, B11, B47, B51, B37, B39, B38, B1, B22, B50, B44, B20, B24, B32, B46, B36, B25, B35, B21, B7, B26, B40, B55, B57, B54, B52, B53, B27, B58, B60, B19, B56.

Compared with axis 2, we note on the positive flank of this axis the presence of the following farms: B3, B5, B6, B11, B12, B13, B14, B15, B17, B28, B29, B30, B31, B33, B34, B59, B61, B62, B63, B64, B65, B66, B67 and B68.

Whereas the farms positioned on the negative side of the axe tow are: B1, B7, B19, B20, B21, B22, B24, B25, B26, B27, B32, B35, B36, B37, B38, B39, B40, B44, B46, B47, B50, B51, B52, B53, B54, B55, B56, B57, B58 and B60.

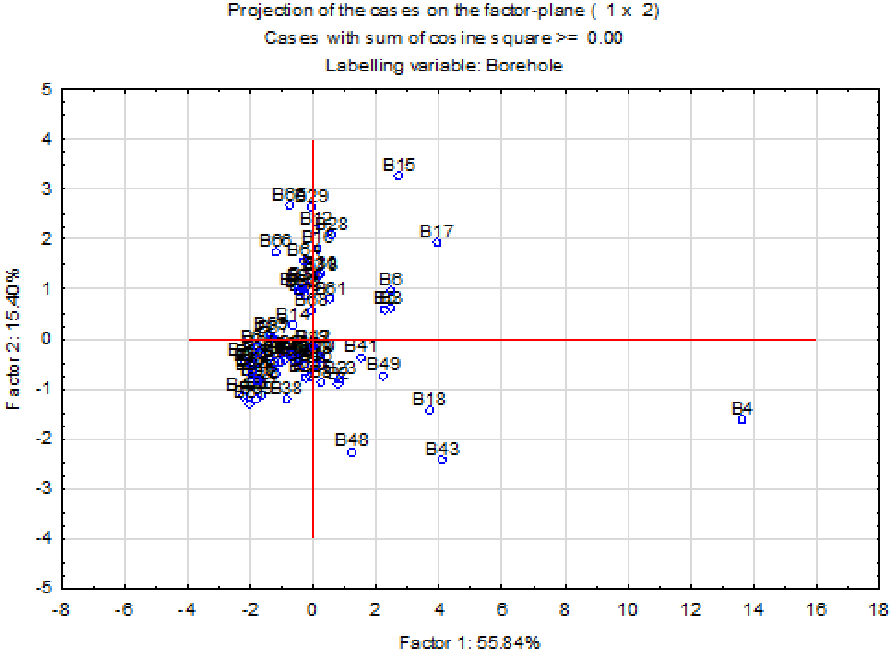


Figure 10. The projection of individuals (borehole).

Interpretation of projections

The irrigated perimeters (B3, B5, B6, B12, B13, B15, B17, B28, B30, B31 and B61) located on the positive side of the two axes are characterised by a high EC and SAR values (2.32<ECw<6.19ms/cm); (4.45<SARw<12.37 meq/l). On the positive side of Axis 1 and the negative side of Axis 2, we observed 13 irrigated perimeters (B2, B4, B8, B9, B10, B18, B23, B41, B42, B43, B45, B48 and B49) have very high values of ECw varied from: 2.64 to 24.8 ms/cm and an SARw equivalent averages between: 2.14 and 8.75 meq/l.

On the other hand, the farms were grouped together on the positive side of axis 2 and the negative side of axis 1 (B11, B14, B29, B33, B34, B59, B62, B63, B64, B65, B66, B67 and B68), with equivalent electrical conductivity of water (ECw) rates between: 1.45 and 2.51 ms/cm. The SARw index inscription rates range from: 3.47 to 7.27 meq/l.

Furthermore, the largest group is present at the level of the two negative flanks of axes 1 and 2, with 30 irrigated perimeters (B1, B7, B19, B20, B21, B22, B24, B25, B26, B27, B32, B35, B36, B37, B38, B39, B40, B44, B46, B47, B50, B51, B52, B53, B54, B55, B56, B57, B58 and B60) recording ECw values between: 0.59 and 3.23 ms/cm. Additionally, SAR index values varied between: 1.041<SARw<4.078meq/l.

Homogeneous soil farms in terms of salinity in the study area

The figure 11 shows the results of the Principal Component Analysis (PCA) of the homogeneous soil farms

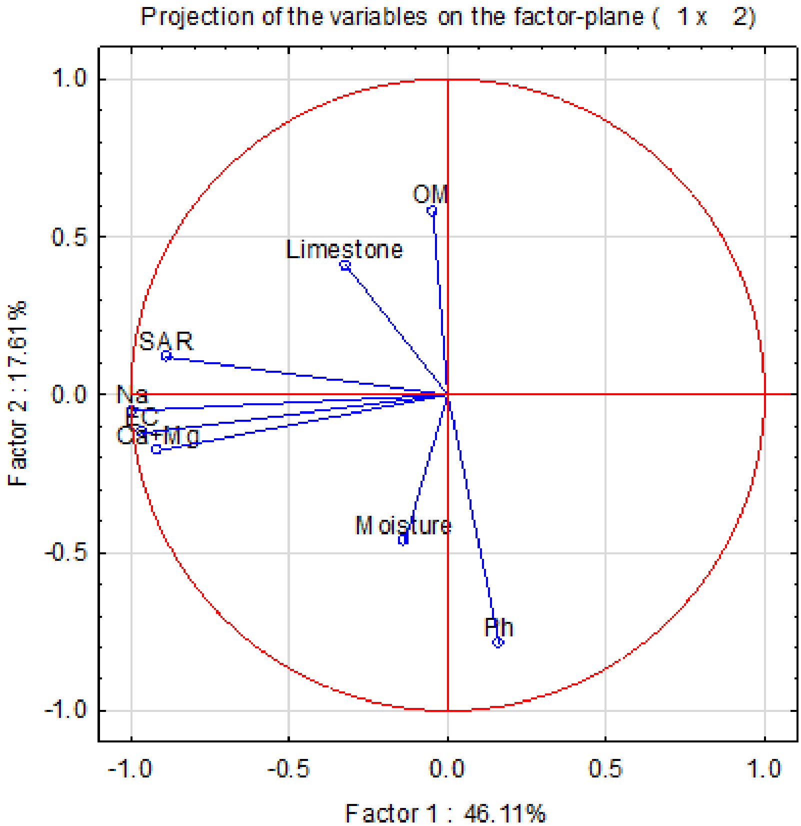


Figure 11. The PCA projection of the variables (ECs, SARs, pH, limestone, Organic Matter (OM), Moisture, Na and Ca+Mg)

The nine variables that have been selected are well correlated with excellent representation quality (factor 1: 46.11%; factor 2: 17.61%), as shown by the projection of the variables on the (1 x 2) plane (figure 11).

Interpretation of projections

We have revealed a cloud of points in the projection of individuals (figure 12), which has enabled us to distinguish 4 clearly individualised groups, as follow as:

-First group: F1, F3, F8, F24, F26, F27, F29, F35, F47, F48, F52, F60, F65, F66, F67, F69, F73 and F74,

-Second group: F4, F7, F9, F10, F11, F12, F15, F16, F17, F20, F25, F28, F30, F33, F37 and F68,

-Third group: F5, F13, F14, F18, F19, F21, F22, F32, F34, F36, F71 and F76,

-Fourth group: F2, F6, F23, F38, F39, F40, F41, F42, F43, F44, F45, F46, F49, F50, F51, F53, F54, F55, F56, F57, F58, F59, F61, F62, F63, F64, F70, F72, F76 and F77.

The first and fourth groups are on the positive side of axis 1, while the second and the third group are on the negative side of axis 1. In relation to axis 2, the first and second groups are on the positive side, and the third and fourth groups on the negative side.

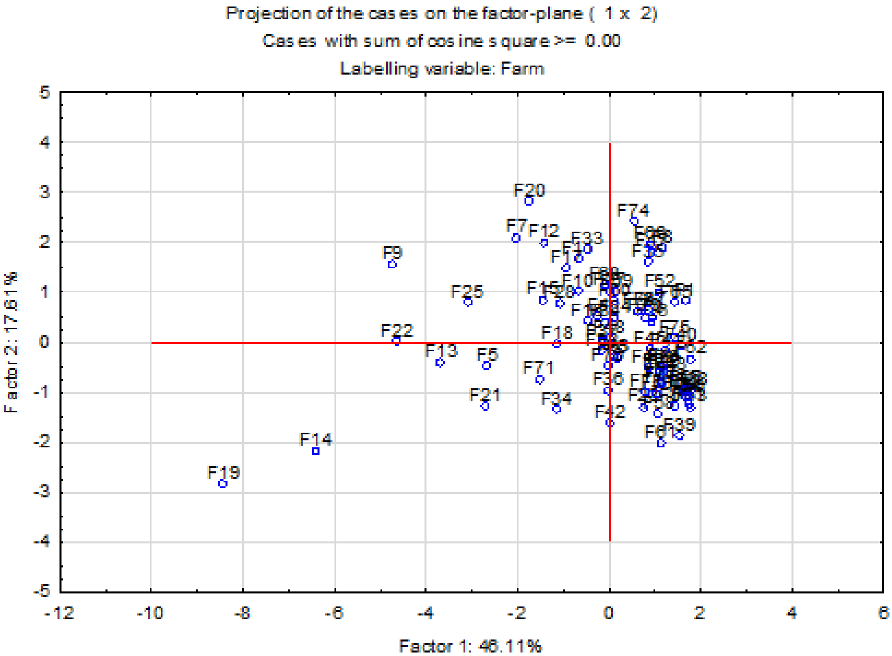


Figure 12. The projection of individuals (farms).

The ECs values in the first group vary between: 0.17 and 1.62 ms/cm. On the other hand, the SARs index has the following values: 1.64 to 6.50 meq/L. The second group comprises farms with EC averages ranging from 0.827 to 8.48 ms/cm, and SARs values ranging from: 5.74 and 12.26 meq/l. In the farms of third group, the SARs index has transcribed values of: 6.55 and 12.26 meq/l. In contrast, the average values of the ECs were recorded as 1.19 and 13.69 ms/cm. Finally, in the farms of the fourth group, the ECs recorded values between: 0.132 and 1.499 ms/cm and the SARs index transcribed values ranging from 1.46 to 6.92 meq/l.

The PCA analysis confirms the classification of the boreholes according to their EC and SAR values. The water with the highest salinity level was found in eight of the 12 boreholes (the PCA boreholes projection of individuals: B3, B5, B6, B12, B13, B15, B17) on the eastern perimeter of Messaâd, which have high EC and SAR values. The majority of boreholes with low EC and SAR values are located in the center and west of Messaâd.

Concerning soil classification, the PCA farms projection of individuals show that the farms have EC values between 0.827 and 8.48 ms/cm and SAR up to: 5.74 meq/l, are sited in the eastern of Messaâd (F4, F5, F7, F9, F10, F11, F12, F13, F14, F15, F16, F17, F18, F19, F20, F21and F22). These results prove that water salinity impacts soil salinity. In other words, using saline water for irrigation affects the soil which reduces agricultural productivity. Furthermore, high salt concentration significantly reduces the infiltration rate by clogging soil pores (particularly with sodicity), destroying soil structure, and changing the chemistry of the root zone resulting in water stress and crop failure, creating a cycle of degradation and erosion.

CONCLUSIONS

The aim of this study was to assess the quality of the irrigation water in the Messaâd arid region, determine its impact on the soil salinity. Where the identification of the water and soil salinity was based on two main parameters: the EC and the SAR index.

The found results shown that the EC values of water irrigation were varied from: 0.595 to 24.8ms/cm, and the SAR averages were ranged between one and 12.37mea/l. in contrast, the soil EC rates were various from: 0.117 and 13.69ms/cm, and the SAR index transcribed values between: 1.46 and 12.26 meq/l. the texture soil classification demonstrate that the Messaâd soil perimeters are sandy to sandy-loam and loamy-sand.

According to Piper's water classification, the borehole irrigation water in the arid Messaâd region is hyper-chloride-calcium type. Based on the EC and SAR values, the salinity level of the irrigation water in the eastern perimeters of the study area is higher than in the western perimeters and centre. Similar results were obtained for the soil in the irrigated areas of Messaâd, where the soils in the eastern farms were most affected by salinity.

On the other hand, PCA analysis of the water and soil data classified all the boreholes and farms with high EC and SAR values into the same homogeneous groups in terms of salinity, confirming the previous results.

Irrigation water in the Messaâd region impacts soil salinity, especially in the eastern areas. For this reason, irrigation techniques should be modified to avoid salt buildup for sustainable soil management and salt accumulation would be reduced by effective irrigation advised, such as drip systems. Moreover, time monitoring salinity requiring EC and SAR measurements of the soil, reserving surface cover, adding organic matter, and growing salt-tolerant crops can improve soil health and productivity.

Future studies should broaden their scope to include diverse new technologies such as remote sensing data to map and spatially estimate soil salinity. Research should also explore the effects of the Unmanned Aerial Vehicles and their role in detecting salt-affected areas with high spatial accuracy, and integrated with flieds data (EC, SAR) for precise, cost-effective assessment.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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