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Spatial Variation Analysis of Soil Salinity in an Irrigated Perimeter in Messaâd region (Djelfa, Algeria)

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Abstract: Globally, soil salinity is a major issue, especially in arid and semi-arid areas. Soil salinity has been effectively studied through the use of field measurements and remote sensing techniques. Investigating the degree of soil salinity in a desert region in North Africa is the aim of this study. This study is being done in the desert southern region of Algeria. The results of the field survey of 76 soil samples were compared with spectral image data obtained via remote sensing. Using metrics like the Electrical Conductivity (EC) and Sodium Absorption Ratio (SAR), Salinity was measured in the lab. The spectral index NDSI values of the SENTINEL 2 images were compared to the SAR and EC measurements made for soil samples in our research area. According to the lab results, 76.3% of the soil in the research region is non-salty, 13.2% is slightly saline, and just 3.9% is extremely saline. The analysis of variance revealed higher salinity levels in the eastern regions. The IDW interpolation maps of the EC and the SAR supported earlier findings. Furthermore, a strong correlation (r = 0.789) was found between the EC and SAR index. The results of the laboratory tests and the spectral index NDSI did not correlate, according to the correlation test. The spatial distribution of soil salinity in the Messaâd region was successfully interpolated and mapped in this study using geomatic techniques

Keywords: soil salinity; irrigated perimeter; electrical conductivity; Messaâd; Algeria

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1. Introduction

Before beginning any development program, a nation must have a thorough understanding of its own resources and potential. When planning various development initiatives, particularly in the areas of urbanization and agriculture, the remote sensing approach is a helpful tool that aids policymakers in making the best choice (Netzband et al., 2007; Hoalst-Pullen and Patterson, 2011;

Gumma et al., 2016; Avtar et al., 2020; Anteur et al., 2021; Saygin et al., 2023; Parvizi and Fatehi, 2024).

Salinity constitutes a major constraint to the development of agricultural production and ecological balance in the arid and semi-arid ecosystem of southwest Algeria (Nouri, 2019; Nouri et al., 2018).

The aim of policymakers in the southern Mediterranean region, which has a substantial area of semi-arid and dry regions, is to expand investment and grow the agricultural industry. In order to determine where to invest in agriculture and how to effectively utilize the limited resources, they require remote sensing. One of the southern Mediterranean nations, Algeria, has created a plan for agricultural development that will help the nation reach the Sustainable Development Goals (SDGs 2 and 15) and guarantee food security. This plan's foundation will be the expansion of investment in this field in the semi-arid and dry regions, which make up over 80% of Algeria's land area (Halitim, 1988; Benaradj, 2017; Boucherit, 2018; Mihi et al., 2019, Boucherit and Benaradj, 2024; Laoufi et al., 2025).

In the meantime, the issue of soil salinity is well-known in semi-arid and dry regions across the world, and it negatively affects the sustainability of agricultural operations (Elnaggar et al., 2017; Asfaw et al., 2018; Elhag et al., 2018; Zarai et al., 2022). Several Algerian academics (Dehni and Lounis, 2012; Douaoui and Yahiaoui, 2015; Benslama et al., 2020; Berkane et al., 2021; Boumaraf and Saadi, 2023) have conducted studies in various dry Algerian regions up to this point, but this is insufficient to have a comprehensive understanding of the situation as it stands, since it has not touched the entire region, which is quite large.

Algerian policymakers need to ascertain the extent to which this issue affects agricultural productivity in order to ensure the efficacy of agricultural investments. To assist them in this endeavor, we have attempted to suggest an approach that combines the use of remote sensing techniques, GIS, fieldwork, and laboratory work. Using spectral sensor data, the study aims to map the salinity of the soil in a dry region of Algeria and compare it with field measurements of Electrical Conductivity (EC) and Sodium Absorption Rate (SAR).

2. Materials and Methods

2.1. Study Area

The irrigated perimeter at Messaâd, located in the province of Djelfa, served as the study site. It is 400 km south of Algiers (Algeria). Its height is between 600 and 859 meters and it covers an area of 657.374134 square meters. It is located at 34°17’48.284’’ and 34°2’54.156’’North and 3°7’42.369’’ and 3°44’30.143’’East (Fig. 1).

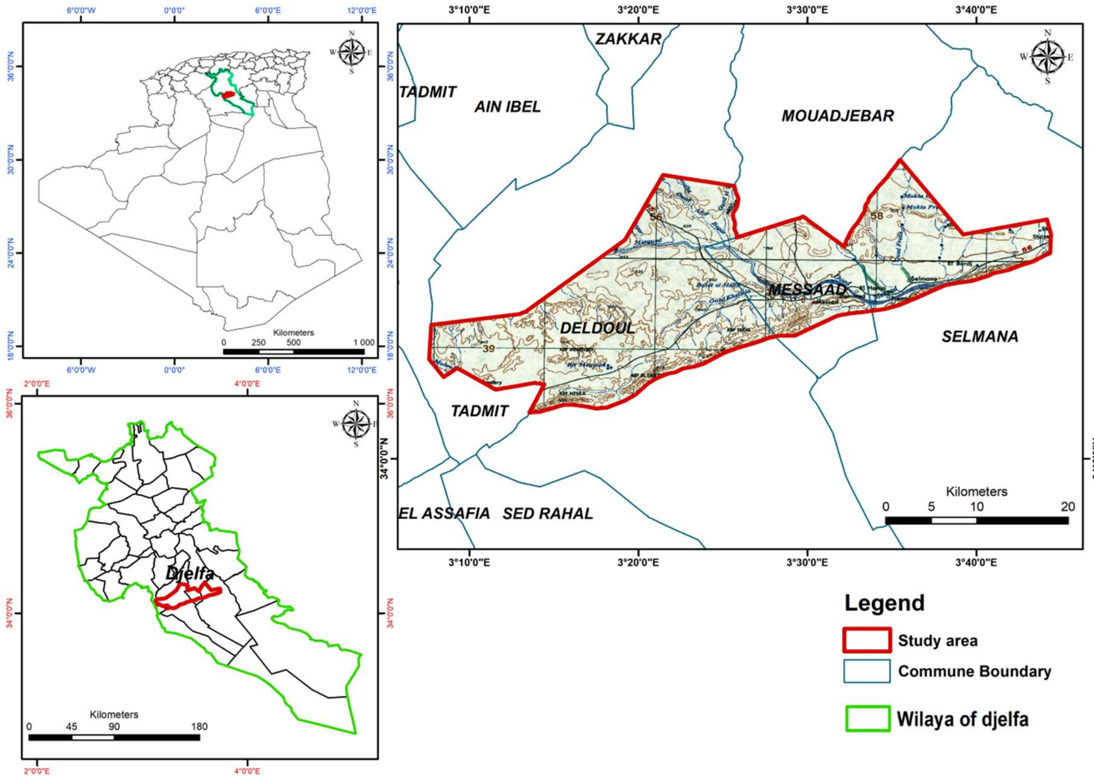

Figure 1. Geographic location of the Messaâd area in Djelfa Province, Algeria.

According to the Emberger climagram classification (1955), the Messaâd region is characterized by an arid climate, with cold winters and hot, dry summers. Precipitation is low and variable, with an annual average of less than 200mm (DPSB, 2018).

2.2. Sampling procedure

Based on the soil use and color in the study region, a subjective sample technique was used. The soil samples were drilled down to a depth of 20 cm, which is where a lot of salt builds up. With a precision of around 2 meters, the 76 sampling locations were GPS-located in latitude and longitude (Fig. 2 and Fig. 3).

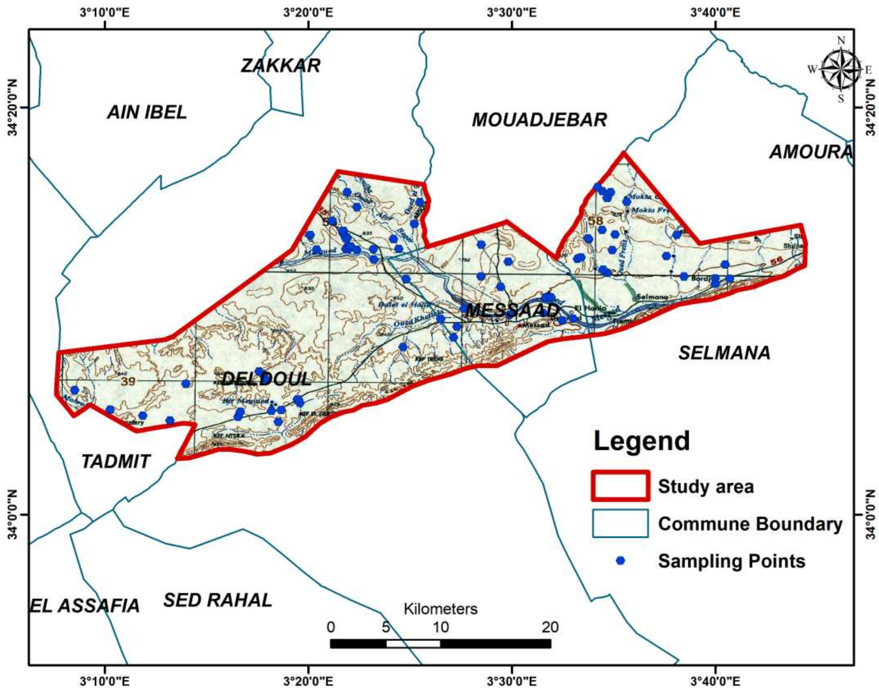

Figure 2. Localization of the soil sample sites in the irrigated perimeter in Messaâd

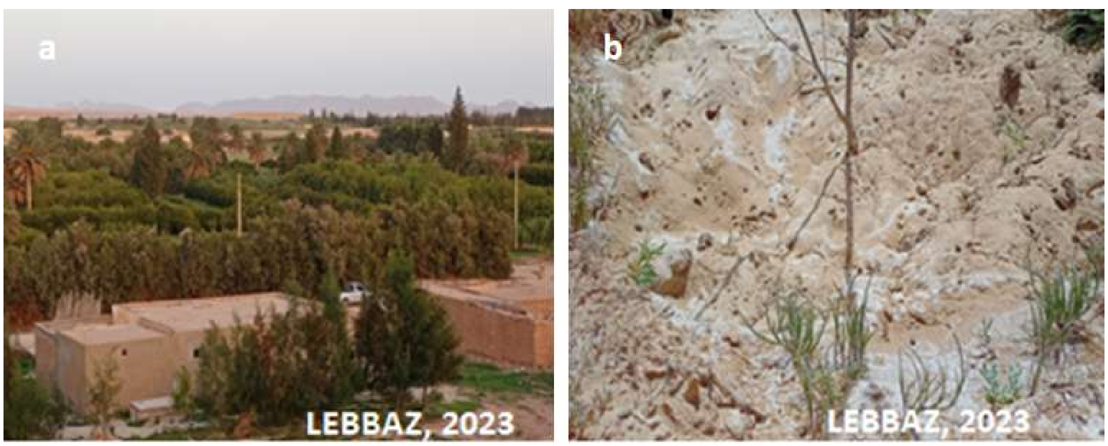

Figure 3. Photos from the study area: (a) farm in the study area; (b) Visible salts on the soil of the farm.

Following their return to the laboratory, each sample was crushed, allowed to air dry, sieved using a 2 mm sieve, and then placed in a plastic bag to await analysis. The electrical conductivity (EC), pH, calcium, magnesium, sodium, and the SAR of the soil were all measured. The SAR index was determined using the following formula:

$$\mathrm{SAR} = \frac{[\mathrm{CNa}]}{[\sqrt{(\mathrm{CCa+CMg})}}/2] \quad (\mathrm{meq}\,/\mathrm{L})$$ (Oueriemmi et al., 2025)

The EC and SAR were used to measure the soil salinity.

The detection of the soil salinity using the remote sensing data

A large-scale remote sensing using spectral data of Sentinel-2 (ETM) was used to detect and to map soil salinity in the study area. The Sentinel-2 has significantly land monitoring capabilities, particularly in the observation of agricultural zones, forest cover, urban development, and water resources. Its growing adoption in both research and operational contexts is due to its superior spatial resolution of 10 meters. This is higher than that of other medium-resolution sensors, such as Landsat (Phiri et al., 2020; Wang and Atkinson, 2018). The data of Sentinel-2 (ETM) was downloaded from USGS July, 20th 2023. The agricultural landscape was determined by the google earth images, and then it confirmed with surveys in sites. The Normalized Difference Salinity Index (NDSI) was employed to detect soil salinity, which gave the best results for assessing soil salinity in cultivated areas especially in the arid and semi-arid areas. That although there were a number of indexes with moderate to high correlation with observed EC, NDSI was an important predictor of EC differences (Allbed et al., 2014; Hernandez et al., 2014; Elhag, 2016; Aceves et al., 2019; Shrestha et al., 2021; Salcedo et al., 2022; Lekka et al., 2023).

$$NDSI = (R\text{-}NIR) / (R+NIR) \qquad \text{(Huete, 1988)}$$

The collected data after the lab work was used to realize maps of EC and SAR index, by the Inverse Distance Weighting (IDW) interpolation (Berkane et al., 2021; Benslama et al., 2020; Fazeli Sangani et al., 2019; Zhao et al., 2024). The interpolation maps of the soil salinity were designed using ArcGIS 10.8 software.

2.3. Statistical analysis

The statistical analyses were performed using the Statistica 12 software. To test if there was a difference in salinity levels, between farms of the Messaâd region, the one-way analysis of variance (ANOVA) was used. The relationship between the spectral index NDSI of salinity determined by remote sensing and the laboratory values of conductivity and SAR has been examined.

3. Results and Discussion

3.1. Chemical analyses of soil

The findings of EC, SAR and pH values are presented in Table 1.
Table 1:

Table 1. The EC, SAR and pH values measured in the laboratory

	Mini	Max	Average	SD
EC (ms.cm-1)	0.11	13.69	1.58	2.46
SAR (meq/l)	1.46	12.26	5.61	2.89
PH	7.81	9.16	8.55	0.32

In reference to the pH values, there was no variation among the irrigated perimeters, as indicated by the above table (Table 1). However, the research area's pH varied from 7.81 to 9.16. According to the pH measurements, the soil in the Messaâd region is either alkaline or very alkaline (Soltner, 2017). As for the Sodium Absorption Ratio in our study area ranged between 1.46 and 12.26 meq/l, whereas the rates of this index in the western irrigated perimeters appear inferior compare to thus recode in the other perimeters. Well, the SAR soil rates in the eastern perimeters were varied between 1.63 and 12.26 meq/l, will the values in perimeters situated in the middle that differed from 1.46 to 11.14 meq/l. The SAR and the EC are two measures used to assess the salinity of soil. A correlation between the two measurements has been noted in our study area, with rising EC values occurring concurrently with rising SAR rates. Additionally, the eastern farms outperformed the center and western farms in terms of these attributes. It has been observed that the farms in the east of Messaâd are more salinized than the ones in the middle and west.

The EC values were used to classify the fieldwork locations into salinity classes (Brown et al., 1954; Hazelton and Murphy, 2016) (Table 2).

Table 2. Agronomic classification of soil salinity based on EC in Messaâd region

Salinity Classes	EC (ms.cm-1)	Number of sites	Ratio (%)
Non-saline	0-2	58	76.3
Slightly saline	2-4	10	13.2
Saline	4-8	5	6.6
Strongly saline	8-16	3	3.9
Extremely saline	>16	0	0
Total	76	100	

According to the salinity classes given in the Table 4, we can see that 76.3% of sites aren't saline (0 < EC < 2 mS/cm), that is 58 sites. In the second class (slightly saline: 2 < EC < 4 mS/cm) 10 farms are classified-in which represent 13.2% of the total. Only five sites (6.6%) are in the third class (saline: 4 < EC < 8 mS/cm). In the fourth class, three perimeters have a soil strongly saline, which the ratio of 3.9% (Anteur, 2019; Brown et al., 1954; Hazelton and Murphy, 2016).

The EC values in the study region were varied from 0.11 ms/cm to 13.69 ms/cm. These conductivity values are very close to those transcribed in the Nile Delta region in northern Egypt, which fall between 3.85 and 16.01mS/cm (AbdElaziz et al., 2024). The EC values recoded in the Messaâd region were lower than those found in the El Ghrous soil, arid region in Algeria, which ranged from 36 mS/m to 854 mS/m (Bradai et al., 2019), and the EC values noted by (Berkane et al., 2021), in the Mina arid plain (Algeria), where the average (EC) of the soil samples ranged from 135 to 2842 mS/m.

When compared to the classification proposed by Nouri (2019), who identified five classes of soil salinity in dryland and irrigated plots—ranging from non-saline (S0) to highly saline soils (S4, ≥16 dS/m)—our results fall mainly within the S0 to S3 classes, with no areas reaching the S4 class threshold. In Nouri's study, high soil salinity was notably concentrated in the southern part of the plot, particularly under irrigation with high-salinity water (classified as C3), and was intensified by alternating dry and rainy periods that influenced salt redistribution. This dynamic may explain the moderate levels observed in our study area, where temporal and spatial patterns of irrigation and precipitation similarly affect salt accumulation. However, the absence of extreme salinity levels (S4) in the current study suggests that the hydro-pedological conditions in Messaâd may be comparatively less prone to severe salinization, possibly due to better drainage, soil texture, or water management practices. The most appropriate method is the implementation of numerous techniques of water and soil conservation, which correspond to the whole range of mechanical, biological, cultural, and agronomic practices. The cultural practices still present preserve an important agro-diversity (Boucherit et al., 2021).

3.1.1. Salinity distribution of the soil in the Messaâd region's farms

In arid regions, soil salinity is already an issue. When the soil is irrigated, it becomes even more concerning. The SAR and the EC are the two metrics that show how salinized the soil is. Using the ANOVA test, we employed these parameters in our study to determine whether the soils of the Messaâd farms differed from one another.

3.1.2. The SAR in the Messaâd soil farms

The results of the ANOVA test on the SAR values in the Messaâd farms, are represented in the Table 3.

Table 3. Results of the one-way ANOVA of the SAR in the Messaâd region

	SS	Degr. Of Freedom	MS	F	P
Intercept	2420,923	1	2420,923	429,5337	0.000000
Farm	234,489	2	117,245	20,8022	0.000000
Error	411,440	73	5,636		

The one way ANOVA test of the SAR value showed that, there is a very highly significant difference between the SAR of the soil farms of Messaâd region (p = 0).
The results of ANOVA test were confirmed by the LSD test (Table 4), which classified the study sites in three groups.

Table 4. Identification of homogenous groups of the SAR values using the LSD test (W: Western farms; M: Middle farms; E: Eastern farms)

Zone	W	M	E
SAR (meq/l)	4,0044	6,2350	8,0229
Homogenous groups	1	2	3

The first group includes the western farms soils; the second group comprises the middle farms soils and the third group gathers the eastern farms soils (Fig. 4).

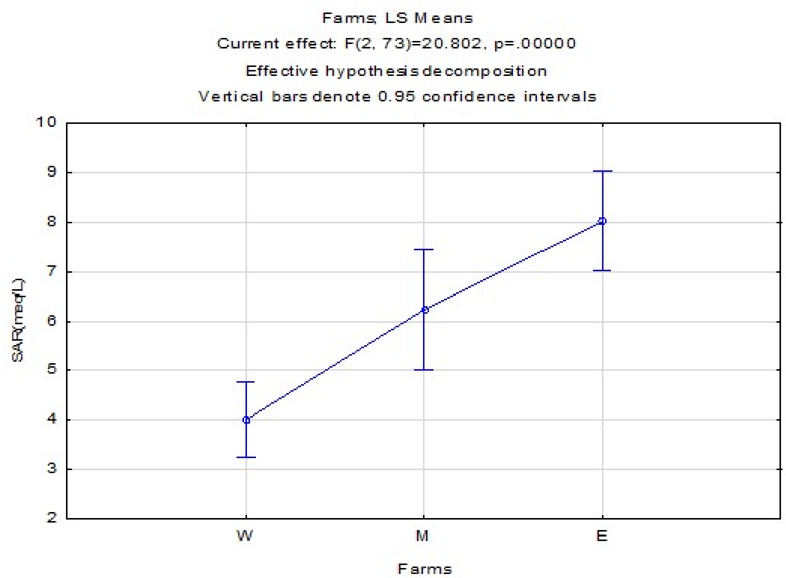

Figure 4. The ANOVA of the SAR in the soil of the Messaâd region (W: Western farms; M: Middle farms; E: Eastern farms)

Soils from farms in the Messaâd region recorded SAR values similar to those found in the arid Zelfana region (southern Algeria), in an irrigated soil farms where the SAR values ranged from 1.33 to 16.98 meq/l (Benslama et al., 2020). The high levels of the salinity in the perimeters located in the east, identified by the presence of a surface salt crust are related to the large amounts of water used to irrigate crops. This water has an EC value around of: 8.79mS/cm (Brahmi et al., 2024). The quality of this water is considered like salt water according to (Freeze and Cherry, 1979) standard which classified the water with the EC value above 2.25 ms/cm like a very salt. Additionally, the soil salinity has increased due to the excessive use of fertilisers to intensify crop production (Omuto et al., 2024).

3.1.3. The Electrical Conductivity (EC) in the Messaâd soil farms

The Table 5 represents the results of the ANOVA test for the Electrical Conductivity (EC) in the study region.

Table 5. Results of the one-way ANOVA of the EC values in the Messaâd region

	SS	Degr. Of Freedom	MS	F	P
Intercept	226,7198	1	226,7198	52,48188	0.000000
Farm	145,1114	2	72,5557	16,79545	0.000001
Error	315,3573	73	4,3200		

With a p-value of zero, the ANOVA analysis of the EC values revealed a highly significant difference between the farms' soils in the Messaâd region.
The LSD test showed that the soils in the study farms are arranged in three groups (Table 6).

Table 6. Identification of homogenous groups of the EC values using the LSD test (W: Western farms; M: Middle farms; E: Eastern farms).

Zone	W	M	E
EC (mS/cm)	0,45700	1,4657	3,6660
Homogenous groups	1	2	3

The first group includes the soils situated in the west of Messaâd. The second and the third groups hold the eastern and middle irrigated perimeters, respectively (Fig. 6).

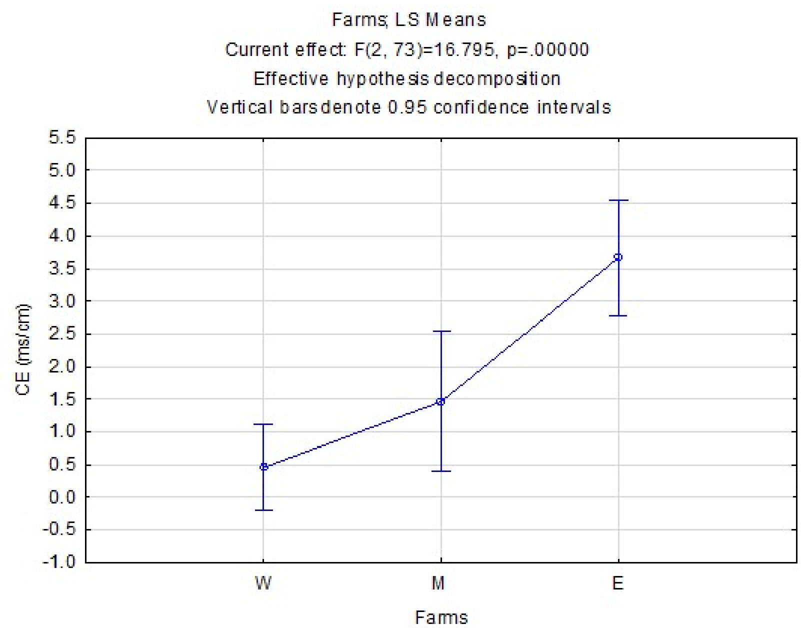

Figure 5. The ANOVA of the EC in the Messaâd farms (W: Western farms; M: Middle farms; E: Eastern farms)

3.2. Interpolation and correlation between EC and SAR index

3.2.1. The soil salinity through the remote sensing technic

The Messaâd region's EC and SAR maps were obtained by us (Fig. 6a, 6b), by the Inverse Distance Weighting (IDW) interpolation of the two parameter values using geographic data.

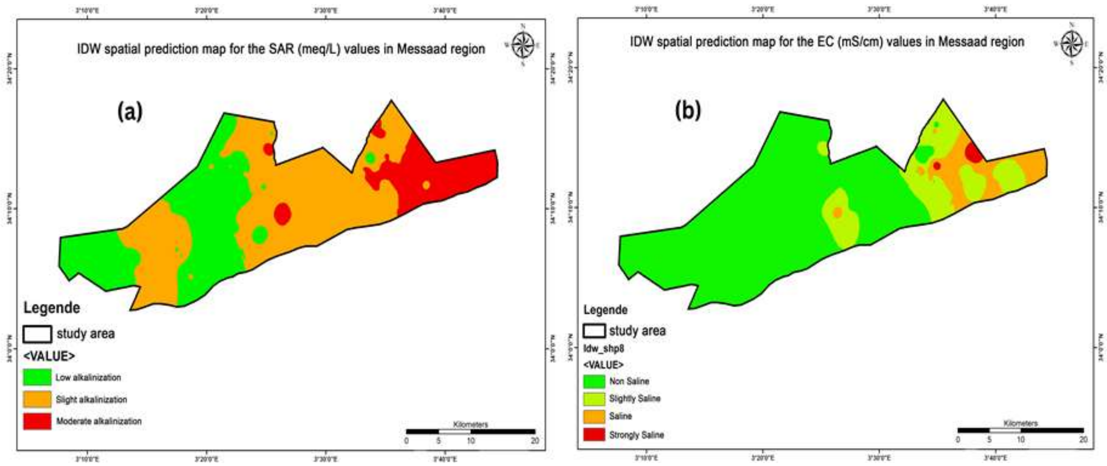

Figure 6. The IDW interpolation maps of the SAR and the EC in the study region: (a) The IDW map of the SAR in the Messaâd region; (b) The IDW map of the EC in the Messaâd region.

The highest EC and SAR values are shown in red on both maps. The excessive salt levels can be explained by this. East of the study region (Fig. 6b) is where we found the greatest EC value, which is 13.69 ms/cm. All EC values above 2.96 ms/cm are found there. On the other side, the west and center of our region have values below 2.96 ms/cm.

The SAR index map (Fig. 6a) also showed that the red color predominates in the east of the study region, which represents SAR ratios greater than 6.99meq/L, while the green color predominates in the west of the study area, which represents ratios less than 4.72meq/L

The map of the NDSI index, used to sense the soils salinity in the Messaâd region is shown in the figure below (Fig.7).

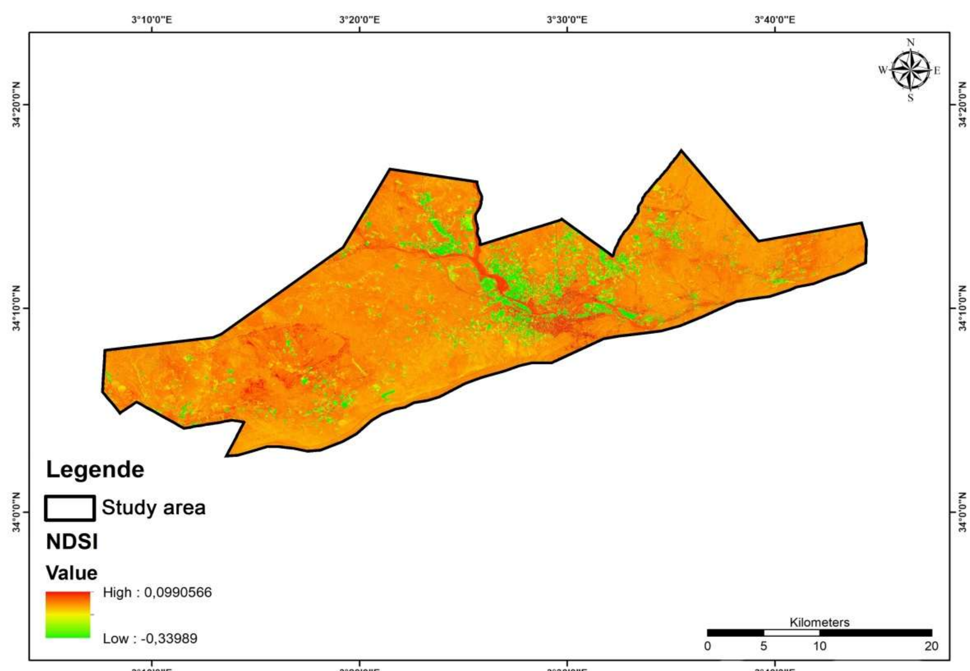

Figure 7. The soil salinity detected by the spectral Normalized Difference Salinity Index (NDSI)

As stated by the map of NDSI index above, the high levels of the soil salinity are represented in red colour. It is clear that high levels of salinity are concentrated in the hydrographic network, especially at Messaâd River (Wadi Messaâd). Conversely, medium salinity levels are evident in orange hues, which intensity in colour the further they deviate from the river (Wadi Messaâd). However, areas with low salinity levels, indicative of irrigated perimeters, appear green.

3.2.2. Correlation between the EC, the SAR and the NDSI

The results of the correlation test between the EC, the SAR and the NDSI index detected by the remote sensing, are given in the Table 7.

Table 7. The correlation matrix of the EC, the SAR and the NDSI in the study region

	EC	**SAR**	**NDSI**
EC	1,000	0,789	-0,015
SAR	0,789	1,000	-0,071
NDSI	-0,015	-0,071	1,000

There is a substantial positive association between the two indices, as evidenced by the correlation coefficient between the EC and the SAR, which came out to be 0.789. However, the NDSI index, where the correlation coefficient recorded values equal to (-0.015 and -0.071), shows no link with the two parameters (EC and SAR).

These results show that soil salinity levels increase with irrigation, which is confirmed by many studies in Algeria (Berkane et al., 2021; Abdennour et al., 2020; Abdennour et al., 2021; Benslama et al., 2020; Semar et al., 2019) and also in different countries (Gorji et al., 2015; Asfaw et al., 2018; Saad et al., 2024). Besides, the Messaâd region is an arid area, where the climate is marked by a low annual rainfall and high average temperatures (36C°), which stimulates a strong soil evaporation process leading to water loss and salt accumulation in the surface layer of the soil (Yang et al., 2024; Tashpolat and Reheman, 2025).

The fact that the soil salinity was detected via remote sensing indicates that the NDSI index and the results of the laboratory analysis did not agree. The NDSI map indicates that salinity levels are elevated in the Messaâd River (Wadi Messaâd), this is primarily due to the lack of human activities such as irrigation compare to cultivated areas, combined with the prevalence of natural environmental factors (Tashpolat and Reheman, 2025), where the Messaâd River (Wadi Messaâd) represents a tributary of other regions' minor branch valleys. In contrast, there was a considerable degree of soil salinity in the eastern farms of the Messaâd region, as indicated by the laboratory analytical results and the IDW maps of the EC and SAR. The correlation test supported the earlier findings, showing no relationship between the NDSI index and the EC and SAR index. This was connected to the predominance of non-saline and slightly saline soils in Messaâd farms, with a ratio of 89.5%, and according to (Fu et al., 2025) the NDSI identifies areas with high soil salinity. On other hand, the NDSI showed the strongest correlation with salinity in areas with sparse vegetation and bare soil (Allbed et al., 2014).

4. Conclusions

Quantifying and mapping the danger of soil salinity in the dry region of Messaâd in southern Algeria was the goal of this study. The laboratory examination revealed that the SAR index values were between 1.46 and 12.26 meq/l, and the EC was between 0.11 ms/cm and 13.69 ms/cm. Of the 76 sites, we discovered that 58 (76.3%) had non-saline soils with an EC of less than 2 ms/cm. However, the soil of 6.6% (five sites) of the farms was salty, and 13.2% of the total soils (10 farms) were slightly saline. Only three farms, or 3.9%, had highly salinized soil, though. The findings of the chemical analysis of soil samples were validated by the mapping of soil salinity. In contrast, the eastern farms in the research region had a high amount of soil salinity. The results of the laboratory investigation were consistent with the IDW interpolation maps of EC and SAR, which showed that the irrigated perimeters located in the eastern part of the Messaâd region, had higher values.

No link was found between the spectral index and either the EC or the SAR, according to the test of correlation between the NDSI index and the two parameters.
At the end of this work, we can propose a perspective to mitigate the impact of soil salinity on productivity in the eastern part of the Messaâd region:

I. The use of drip irrigation to save water and avoid the formation of a layer of salts on the surface of the soil,
II. Growing crops that are well adapted to high temperatures, are not demanding of water, and are tolerant of salinity.

Author Contributions: N.L. Conceptualizations, Methodology, Software, Formal analysis N.L., D.A., and A.B. conceived the original idea. I.H. and H.A. wrote the main manuscript text, analyzed the data, and prepared Figs. A.D. and A.B. supervised the study. A.B. proofread the manuscript text, discussed the results, and commented on the manuscript. All authors reviewed the manuscript.

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5. References

1. AbdElaziz AE, Soliman KG, Abdel Hamed EMW, Metwally MS, Abu-Hashim MSD (2024): Improving soil salinity prediction in semi-arid areas using machine learning models. Zagazig Journal of Agricultural Research 51(3), 505-517. https://doi.org/10.21608/zjar.2024.367205

2. Abdennour MA, Douaoui A, Barrena J, Pulido M, Bradaï A, Bennacer A, Piccini C, Alfonso-Torreno A (2021): Geochemical characterization of the salinity of irrigated soils in arid regions (Biskra, SE Algeria). Acta Geochimica 40(2), 234-250. https://doi.org/10.1007/s11631-020-00426-2

3. Abdennour MA, Douaoui A, Piccini C, Pulido M, Bennacer A, Bradai A, Jesus Barrena D, Yahiaoui, I (2020): Predictive mapping of soil electrical conductivity as a Proxy of soil salinity in south-east of Algeria. Environmental and Sustainability Indicators 8, 100087. https://doi.org/10.1016/j.indic.2020.100087

4. Abd El-Hamid HT, Alshehri F, El-Zeiny AM, Nour-Eldin H (2023): Remote sensing and statistical analyses for exploration and prediction of soil salinity in a vulnerable area to seawater intrusion. Marine Pollution Bulletin 187, 114555. https://doi.org/10.1016/j.marpolbul.2022.114555

5. Allbed A, Kumar L, Aldakheel YY (2014): Assessing soil salinity using soil salinity and vegetation indices derived from IKONOS high-spatial resolution imageries: Applications in a date palm dominated region. Geoderma 230, 1-8. https://doi.org/10.1016/j.geoderma.2014.03.025

6. Aceves EÁ, Guevara HJP, Enríquez AC, Gaxiola JDJC., Cervantes MDJP., Gaxiola JJC, Cervantes MJP, Barrientos JH, Herrera LE, Guevara VMP, Samuel CL (2019): Determining salinity and ion soil using satellite image processing. Polish Journal of Environmental Studies, 28(3), 1549-1560. https://doi.org/10.15244/pjoes/81693

7. Anteur, D, (2019): Intégration des données multi-sources dans un Système d'Informations Géographiques (SIG) pour le diagnostic du milieu et l'aménagement hydro-agricole de la Région steppique ouest-algérienne. Doctoral thesis in agronomic sciences on some gypsum and saline soils of the Saharan environment in Algeria. Doctoral thesis in agronomic sciences, University of Mostaganem, Algeria.

8. Anteur D, Benaradj A, Fekir Y, Baghdadi D (2021): Zakour Forest fire risk map assessment in the commune of Mamounia (Mascara, Algeria). Folia Forestalia Polonica 63(1), 21-35. https://doi.org/10.2478/ffp-2021-0003

9. Asfaw E, Suryabhagavan KV, Argaw M (2018): Soil salinity modeling and mapping using remote sensing and GIS: The case of Wonji sugar cane irrigation farm, Ethiopia. Journal of the Saudi Society of Agricultural Sciences 17(3), 250-258. https://doi.org/10.1016/j.jssas.2016.05.003

10. Avtar R, Komolafe AA, Kouser A, Singh D, Yunus AP, Dou J, Kumar P, Das Gupta R, Johnson BA, Thus Minh HV, Aggarwal AK, Kurniawan TA (2020): Assessing sustainable development prospects through remote sensing: A review. Remote sensing applications: Society and environment 20, 100402. https://doi.org/10.1016/j.rsase.2020.100402

11. Bannari A, Guedon AM, El-Harti A, Cherkaoui FZ, El-Ghmari A (2008): Characterization of Slightly and Moderately Saline and Sodic Soils in Irrigated Agricultural Land using Simulated Data of Advanced Land Imaging (EO-1) Sensor. Commun Soil Sci Plant Anal 39 2795–2811. https://doi.org/10.1080/00103620802432717 .

12. Benaradj A (2017) : Étude phyto-écologique des groupements à *Pistacia atlantica* Desf.dans le sud Oranais (Sud-Ouest algérien).Thèse de Doctorat en Foresterie, Université Abou Bekr Belkaid Tlemcen. 266p.

13. Boumaraf B, Saadi I (2023): The gypsum in the soils of Ziban, Algerian Northern Sahara. Agr. Acad. J. 6(5), 76-88. 10.32406/v6n5/2023/76-88/agrariacad

14. Benslama A, Khanchoul K, Benbrahim F, Boubehziz S, Chikhi F, Navarro-Pedreño J (2020): Monitoring the variations of soil salinity in a palm grove in Southern Algeria. Sustainability 12(15), 6117. https://doi.org/10.3390/su12156117

15. Berkane I, Boulenouar H, Bekhadda Y, Gacem F, Douaoui A, Larid M, Benabdeli K (2021): Assessment and mapping of the agro-ecological risk in the Mina plain (northwestern Algeria): Soil salinity and irrigation water quality. Ekológia (Bratislava) 40(3), 201-211. http://doi:10.2478/eko-2021-0022

16. Boucherit H (2018): Étude ethnobotanique et floristique de la steppe à *Hammada scoparia* (Pomel) dans la région de Naâma (Algérie occidentale), Thèse de Doctorat. Université Abou Bakr Belkaïd Tlemcen, 175p

17. Boucherit H, Benaradj A, Bouderbala A (2021): Conservatory Management of Natural Resources in the Naâma Region (Southwest Algeria). Water Conserv Sci Eng 6, 249–262. https://doi.org/10.1007/s41101-021-00118-9

18. Boucherit H, Benaradj A, (2024): Physico-chemical properties of steppe soils with *Hammada scoparia* (Pomel) in the Naâma region (Algeria). Ekológia (Bratislava) 43(1), 16–25. https://doi.org/10.2478/eko-2024-0002

19. Bradai A, Bennacer A, Fernandez P (2019): Application of kriging techniques for assessing the salinity of irrigated soils: the case of El Ghrous perimeter, Biskra, Algeria. SJSS, 9(2), 105-124. 10.3232/SJSS.2019.V9.N2.04

20. Brahmi S, Rahmani B., Nesrat A, Djamal C, Brahmi S. (2024): Assessment of groundwater mineralization in the arid steppe region of the Messaad plateau aquifer, Southern Algeria. Geomatics, Landmanagement and Landscape 1, 101–116. http://dx.doi.org/10.15576/GLL/2024.1.07

21. Brown JW, Hayward HE, Richards A, Bernstein L, Hatcher JT, Reeve RC, Richards L.A. (1954): Diagnosis and improvement of saline and alkali soils. United States Department of Agriculture, Agriculture handbook, (No. 60). US Government Printing Office. 160p.

22. Dehni A, Lounis M (2012): Remote sensing techniques for salt affected soil mapping: application to the Oran region of Algeria. Procedia Engineering 33, 188-198. https://doi.org/10.1016/j.proeng.2012.01.1193

23. Douaoui A, Yahiaoui I (2015): Combination of remote sensing and kriging to improve soil salinity mapping in the Hmadna plain (Algeria). Toprak Su Dergisi. Soil-Water Journal Special Issue, 1-5. https://dergipark.org.tr/en/pub/topraksu/issue/21418/229575

24. Douaoui AEK, Nicolas H, Walter C (2006): Detecting salinity hazards within a semiarid context by means of combining soil and remote-sensing data. Geoderma, 134, 217–230. https://doi.org/10.1016/j.geoderma.2005.10.009

25. DPSB (2018): Monographie de la wilaya de Djelfa. Direction de la Programmation et du Suivi Budgétaires de Djelfa, 104p.

26. Elhag M (2016): Evaluation of different soil salinity mapping using remote sensing techniques in arid ecosystems, Saudi Arabia. Journal of Sensors 1, 7596175. https://doi.org/10.1155/2016/7596175

27. Elhag AMH, Gumaa YSA, Osman EH (2018): Monitoring, Predicting and Quantifying Soil Alkalinity, Sodicity and Salinity in Blue Nile State, Sudan, Using Soil Techniques, Remote Sensing and GIS Analysis; Case Study: Blue Nile River. IRA-International Journal of Applied Sciences 11(3), 37-45. http://dx.doi.org/10.21013/jas.v11.n3.p2

28. Elnaggar A, El-Hamidi K, Mousa M, Albakry M (2017): Mapping soil salinity and evaluation of water quality in Siwa Oasis using GIS. Journal of Soil Sciences and Agricultural Engineering 8(1), 9-19. https://doi.org/10.21608/JSSAE.2017.37078

29. Fazeli Sangani M, Namdar Khojasteh D, Owens G (2019): Dataset characteristics influence the performance of different interpolation methods for soil salinity spatial mapping. Environ Monit Assess 191, 684. https://doi.org/10.1007/s10661-019-7844-y

30. Freeze RA, Cherry JA (1979): Groundwater. Prentice-Hall, Inc., Englewood Cliffs, NJ. 604 pp.

31. Fu Y, Wang P, Cao W, Fu S, Zhang J, Li X, Guo J, Huang Z, Chen X (2025): Long-Term Assessment of Soil Salinization Patterns in the Yellow River Delta Using Landsat Imagery from 2003 to 2021. Land 14(1), 24. https://doi.org/10.3390/land14010024

32. Gorji T, Tanik A, Sertel E (2015): Soil salinity prediction, monitoring and mapping using modern technologies. Procedia Earth and Planetary Science, 15, 507-512. https://doi.org/10.1016/j.proeps.2015.08.062

33. Gumma MK, Birhanu BZ, Mohammed IA, Tabo R, Whitbread AM (2016): Prioritization of watersheds across Mali using remote sensing data and GIS techniques for agricultural development planning. Water, 8(6), 260. https://doi.org/10.3390/w8060260

34. Halitim A 1988 : Sols des régions arides d'Algérie. O.P.U., Alger, 1988; 384 p.

35. Hazelton P, Murphy B (2016): Interpreting Soil Test Results. What Do All the Numbers Mean? CSIRO Publishing: Collingwood, Australia, 200p.

36. Hoalst-Pullen N, Patterson MW (2011): Applications and trends of remote sensing in professional urban planning. Geography Compass 5(5), 249-261. https://doi.org/10.1111/j.1749-8198.2011.00422.x

37. Hernández EI, Melendez-Pastor I, Navarro-Pedreño J, Gómez I (2014): Spectral indices for the detection of salinity effects in melon plants. Sci. Agric. 71(4), 324-330. https://doi.org/10.1590/0103-9016-2013-0338

38. Huete AR (1988): A soil-adjusted vegetation index (SAVI). Remote Sensing of Environment 25(3), 295-309. https://doi.org/10.1016/0034-4257(88)90106-X

39. Laoufi H, Bachir H, Hadj-Miloud S, Clark K (2025): Comparative Assessment of Three Methods for Soil Organic Matter Determination in Calcareous Soils, Eastern Algeria. Land 2025, 14, 2030. https://doi.org/10.3390/land14102030

40. Lekka C, Petropoulos GP, Triantakonstantis D, Detsikas SE, Chalkias C (2023): Exploring the spatial patterns of soil salinity and organic carbon in agricultural areas of Lesvos Island, Greece, using geoinformation technologies. Environ Monit Assess 195, 391. https://doi.org/10.1007/s10661-023-10923-5

41. Mihi A, Tarai N, Benaradj, A, Chenchouni H (2019): Spatiotemporal changes in Date palm oases of Algeria over the last century. Arabian Journal of Geosciences, 223-226. https://doi.org/10.1007/978-3-030-72896-0_49

42. Netzband M, Stefanov WL, Redman CL (2007): Remote Sensing as a Tool for Urban Planning and Sustainability. In: Netzband, M., Stefanov, W.L., Redman, C. (eds) Applied Remote Sensing for Urban Planning, Governance and Sustainability. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-540-68009-3_1

43. Nouri T, Reguieg Yssaad H, Bouyahia H, Nouar K, Ghenami N, Latigu A (2018): Effect of Salinity and Compost of Aleppo Pine *Pinus halepensis* L on the Proline and Chlorophyll Content of the Bean Vicia faba L Minor. In: Kallel, A., Ksibi, M., Ben Dhia, H., Khélifi, N. (eds) Recent Advances in Environmental Science from the Euro-Mediterranean and Surrounding Regions 559-561. https://doi.org/10.1007/978-3-319-70548-4_169

44. Nouri T (2019): Évolution de la salinité des sols irrigués de la palmeraie de Brézina (El Bayadh), étude de comportement de la fève *Vicia faba* L. Thèse de doctorat en Sciences du Sol et Environnement. Université de Mostaganem. 163p.

45. Oueriemmi H, Zoghlami RI, Le Guyader E, Mekki F, Suidi Y, Bennour A, Moussa M, Sbih M, Saidi S, Morvan X, Ouessar M. (2025): Addressing Soil Fertility Challenges in Arid Agriculture: A Two-Year Evaluation of Combined Soil Organic Amendments Under Saline Irrigation. Soil Syst. 9, 16. https://doi.org/10.3390/soilsystems901001

46. Omuto CT, Kome GK, Ramakhanna SJ, Muzira NM, Ruley JA, Jayeoba OJ, Raharimanana V, Owusu Ansah A, Khamis NA, Mathafeng KK, Elmobarak AA, Vargas RR, Koetlisi AK, Dembele D, Diawara M, Mbaikoubou M, Maria RM, Adam Boukary I, Malatji A, Amin TM, Kabore D, Mapeshoane BE, Sichinga S, Kuleile NR, Mwango SB, Wiese LD, Andich K, Isabirye M, Bgm S, Walleh ME, Nsharwasi NL, Musana SB, Kamara A, Jobe AR, Oussou Cossi TB, Nyamai M (2024): Trend of soil salinization in Africa and implications for agro-chemical use in semi-arid croplands. Science of The Total Environment, 951, 175503. https://doi.org/10.1016/j.scitotenv.2024.175503

47. Parvizi Y, Fatehi S (2024): Modeling and digital mapping of soil quality indicators in different land uses (a case study: Ravansar-Sanjabi Plain, Kermanshah). Environ Monit Assess 196, 184. https://doi.org/10.1007/s10661-024-12349-z

48. Phiri D, Simwanda M, Salekin S, Nyirenda VR, Murayama Y, Ranagalage M (2020): Sentinel-2 data for land cover/use mapping: A review. Remote sensing 12(14), 2291. https://doi.org/10.3390/rs12142291

49. Saad K, Kallel A, Castaldi F, Sahli Chahed T (2024): Soil Salinity Detection and Mapping by Multi-Temporal Landsat Data: Zaghouan Case Study (Tunisia). Remote Sens. 16, 4761. https://doi.org/10.3390/rs16244761

50. Salcedo FP, Cutillas PP, Cabañero JJA, Vivaldi AG (2022): Use of remote sensing to evaluate the effects of environmental factors on soil salinity in a semi-arid area. Science of The Total Environment, 815, 152524. https://doi.org/10.1016/j.scitotenv.2021.152524

51. Saygın F, Aksoy H, Alaboz, P, Dengizal O (2023): Different approaches to estimating soil properties for digital soil map integrated with machine learning and remote sensing techniques in a sub-humid ecosystem. Environ Monit Assess, 195(9), 1061. https://doi.org/10.1007/s10661-023-11681-0

52. Semar A, Hartani T, Bachir H (2019): Soil and water salinity evaluation in new agriculture land under arid climate, the case of the Hassi Miloud area, Algeria. Euro-Mediterranean Journal for Environmental Integration, 4(1), 40. https://doi.org/10.1007/s41207-019-0130-0

53. Tashpolat N, Reheman A (2025): Monitoring of Soil Salinity in the Weiku Oasis Based on Feature Space Models with Typical Parameters Derived from Sentinel-2 MSI Images. Land 14(2), 251. https://doi.org/10.3390/land14020251

54. Yang X, Zhang K, Chang T, Shaghaleh H, Qi Z, Zhang J, Ye H (2024): Hamoud, Y.A. Interactive Effects of Microbial Fertilizer and Soil Salinity on the Hydraulic Properties of Salt-Affected Soil. Plants 13,473. https://doi.org/10.3390/plants13040473

55. Zarai B, Walter C, Michot D, Montoroi JP, Hachicha M 2022): Integrating multiple electromagnetic data to map spatiotemporal variability of soil salinity in Kairouan region, Central Tunisia. J. Arid Land 14, 186–202. https://doi.org/10.1007/s40333-022-0052-6

56. Zhao S, Ayoubi S, Mousavi SR, Mireei SA, Shahpouri F, Wu SX, Chen CB, Zhao ZY, Tian CY (2024): Integrating proximal soil sensing data and environmental variables to enhance the prediction accuracy for soil salinity and sodicity in a region of Xinjiang Province, China. Journal of Environmental Management 364, 121311. https://doi.org/10.1016/j.jenvman.2024.121311