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RESEARCH ARTICLE

Comparison of Two Electrical Conductivity Measurement Methods for Soil Salinity Assessment in the Ouedrigh Region (Northern Sahara, Algeria)

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ABSTRACT

Soil salinity poses a significant challenge to sustainable agriculture in numerous irrigated regions of Algeria. The measurement of electrical conductivity (EC) provides a method for assessing soil salinity. Most soil laboratories in Algeria employ electrical conductivity tests of 1:2.5 and 1:5 soil-to-water suspensions (EC1/2.5 and EC1/5) to assess soil salinity due to their simplicity. The electrical conductivity of the saturated paste extract (ECe) is the primary determinant of the impact of soil salinity on plant growth. Therefore, EC1/2.5 and EC1/5 must be modified to ECe. The objective of this study was to develop regression models to predict ECe utilizing EC1/2.5 and EC1/5 data. The operation was conducted upstream of the OuedRigh region in northern Algeria, within the Blidet Amar palm grove located inside boundary 108. Fifty-one soil samples for EC1/2.5 and EC1/5 were collected and analyzed to develop the models. The results indicated significant variability in the electrical conductivity of the soil samples, with values spanning from 2.63 to 21.34 mS/cm for 1:5 soil-water extracts, 3.52 to 32.4 mS/cm for 1:2.5 extracts, and 5.92 to 142 mS/cm for saturated paste extracts. The proposed linear regression equations demonstrated robust linear correlations between ECe and EC1/2.5, as well as EC1/5. Upon validation, the equations ECe = 4.84* EC1/2.5 - 5.48 and ECe = 7.99* EC1/5 - 6.31 were selected by the study to forecast ECe based on EC1/2.5 and EC1/5, achieving an R2 of 0.95. Twelve equations derived from eight supplementary EC conversion tests were utilized to evaluate the applicability of these models. Relative to the 12 models employed in this study, ECe prediction errors were reduced by a factor of 7.42 to 4.71. This method obviates the necessity for saturated paste extraction, which is costlier and more time-intensive, hence facilitating precise assessment of soil salinity. Finally, soil salinity maps were generated with ordinary kriging. The mean error (ME) and root mean square error (RMSE) for each map were computed to evaluate the model's efficacy.

INTRODUCTION

Soil salinization poses a significant challenge to agricultural sustainability, particularly in arid and semi-arid areas (Zarai et al., 2022). Excessive salinity can result in soil impermeability and degradation, adversely impacting nutrient and water absorption, hindering root development, and inducing crop withering and stagnation, all of which significantly diminish crop yields (Machado and Serralheiro, 2017; Parihar et al., 2015). The decline in soil quality not only leads to significant soil degradation but also adversely affects local communities, agriculture, biodiversity, and food security (Machado andSerralheiro, 2017; Minhas et al., 2020; Parihar et al., 2015; Mahajan et al., 2016; Shahid et al., 2018; Zarei et al., 2021).Salt accumulation on arable land compromises food security and agricultural productivity due to increased salinity (Butcher et al., 2016; Shrivastava and Kumar, 2015). In 2021, the Food and Agriculture Organization (FAO) claimed that 833 million hectares of agricultural land worldwide, predominantly in arid and semi-arid regions, are affected by salinity, encompassing both saline and sodic soils (FAO, 2022). Saline soils constitute around 6% of the Earth's subsoil and 3% of its topsoil (FAO, 2021). By 2050, it is anticipated that fifty percent of the global arable land would be impacted by salinity (Butcher et al., 2016).

Current contributors to soil salinization include inadequate leaching efficiency (LE, the ratio of salt mass drained to that applied), heightened dependence on marginal water sources, the expansion of irrigated lands in arid and semi-arid regions, and insufficient internal soil drainage (Minhas et al., 2020). Investigations into the salinity of arid and semi-arid regions in Algeria (Yahiaoui et al., 2015; Oustani et al., 2015; Abdennour et al., 2020; Benslama et al., 2020) indicate that soil salinity is on the rise, resulting in the deterioration of the soil's chemical, biological, and physical properties. Consequently, it is imperative to create planning and soil restoration strategies to monitor and assess salinity in salt-affected soils (Mukesh Kumar et al., 2024). The total concentration of dissolved salts in soil, often shown by electrical conductivity (EC), is utilized to assess soil salinity (Kamangar and Minaei, 2023). Saturated paste extraction (SP) and soil-water extraction are now the two predominant methods for assessing soil salinity (Aboukila and Norton, 2017). Although it can be assessed at various soil-water ratios, the electrical conductivity of soil extracts (ECsw) does not accurately represent the electrical conductivity of the soil solution, thereby constraining its practical utility in the field (Aboukila and Abdelaty, 2017; Aboukila and Norton, 2017). Furthermore, the conventional method, saturated paste electrical conductivity (ECe), reflects the salinity encountered by plant roots in the soil (Bo-Seong et al., 2021).

This method is, regrettably, costly, labor-intensive, and time-consuming compared to soil/water ratio approaches, as it requires considerable time and expertise to physically create the soil paste necessary for determining the appropriate saturation point (Kargas et al., 2018; Kargas et al., 2022; Hossain et al., 2020).

Certain researchers advocate for measuring electrical conductivity (EC) in extracts at various soil-to-water mass ratios (e.g., 1:1, 1:2, 1:2.5, and 1:5) as an alternative to relying on ECe measurements to enhance procedural efficiency (Amakor et al., 2014; Mahajan et al., 2022).

In contrast to the SP extraction method, soil-water extractions are considered to be less indicative of actual soil conditions (Kargas et al., 2018). Ion concentrations and electrical conductivity in soil-water extracts are frequently inferior to those measured by the ECe method, attributable to the increased dilution of soil solutions (Kargas et al., 2018). This perspective asserts that to assess plant responses to salinity, the EC values of soil-water suspensions must be transformed into ECe (Matthees et al., 2017). Transforming soil/water ratios of 1:1, 1:2.5, and 1:5 into a saturated soil paste extract (SP) (ECe) offers considerable benefits. Utilizing these models, soil laboratories can maintain high precision and accuracy while reducing the time and costs associated with soil salinity testing (Haldar et al., 2021).

Models for the conversion of soil-water suspensions.Spiteri and Sacco (2024) assert that EC to ECe values are contingent upon certain soil types and are not universally applicable. Moreover, all equations exhibited geographical heterogeneity, underscoring the necessity for region-specific equations due to the potential for significant mistakes in ECe prediction (Corwin and Yemoto, 2017;Kargas et al., 2022). ECe values typically exceed EC values obtained from soil-water suspension methods, such as the 1:2.5 ratio, as indicated by research (Corwin and Yemoto, 2017). In soil-water extracts, ECe and EC often exhibit a linear correlation, with the strongest associations found in soils of similar textures (Mamoun A et al., 2021). Various factors, such as soil texture and the presence of gypsum and salts, influence the correlation between ECe and EC in distinct soil-water extracts (USDA, 1954; Franzen et al., 2019). Research indicates that coarse-textured soils possess a superior conversion factor compared to fine-textured soils (Kargas, 2018).Moreover, the equilibration duration and methodology are likely responsible for the observed discrepancies across different models (Li et al., 2015; Li and Kang, 2020). Moreover, ECe measurements are employed to assess soil electrical conductivity based on established criteria (US Salinity Laboratory Staff, 1954; Corwin and Yemoto, 2017). Managers would possess enhanced understanding of the transferability of these models and the reliability of ECe values derived from non-local EC conversion models (Aboukila and Norton, 2017).

The EC1/2.5 and EC1/5 methods are frequently employed in Algeria for the detection of soil salinity. There is no widely accepted formula for converting EC1/2.5 and EC1/5 readings to ECe in coarse-textured soils. The OuedRigh region was selected for this study because of its salinity, elevated water table, and ecological degradation issues (Bekkaril et al., 2017). This region is a flat trough-like expanse measuring 15 to 30 km in width and extending 150 km in a north-south direction, located between 32°49' and 34°3' N latitude and 05°10' and 06°14' E longitude. It is surrounded by several oasis adjacent to the canal (BelkacemBoumaraf et al., 2014; Sayah and Remini, 2019).

The prevalence of date palm vegetation and rural areas greatly contributes to the region's economy, underscoring the importance of date palm agriculture in Algeria. Approximately ten to fifteen percent of the area is allocated for this type of agriculture. In the northern region of OuedRigh, more than 50 palm groves were distributed among 21,772 palm trees, within an average of 23,794.5 hectares of utilized agricultural land in 2019 (Hammadi et al., 2022). This study aims to examine the relationship between ECe=f(EC1/2.5) and ECe=f(EC1/5) in soil samples obtained from the Blidet Amar palm grove in Touggourt province. Additionally, it seeks to generate salinity maps for the research area, approximately 500 kilometers from the city and upstream of the OuedRigh region in northeastern Algeria's northern Sahara (Hammadiet al., 2022; Gouasmia et al., 2016).

2- Materials and Methods

2.1 Study Area

The Blidet Amar palm grove, which was created in 1985 as a component of perimeter 108, is situated roughly 660 kilometers southeast of Algiers and 25 kilometers south of the province of Touggourt. In 2021, Algeria's most recent administrative division formally acknowledged this region.

With a maximum elevation of 84 meters, the Blidet Amar palm grove is located in the OuedRigh Valley, precisely at northern coordinates 32.94.34.87 and eastern coordinates 5.991594 (Figure 1).

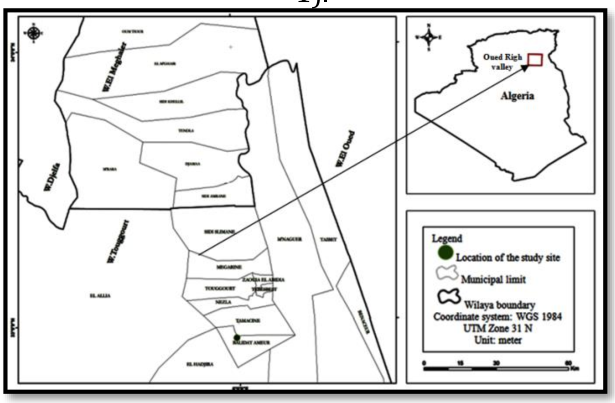


Figure 1. Geographic map of the OuedRigh region and location of the Blidet Amar study area.

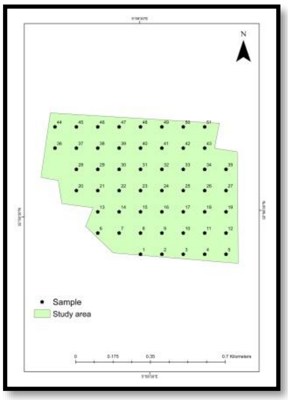


Figure 2. Soil sampling locations within the orchard.

According to local farmers, the experimental site is about 50 hectares in size and is separated into plots of about 1 hectare each, with a planting distance of 10 meters. OuedRigh has a very dry, desert environment with hot, dry summers, mild winters, and sporadic, erratic rainfall. The research area saw an average monthly high temperature of 34.82 °C, an average annual temperature of 22.59 °C, and an average annual precipitation of around 12.82 mm between 1993 and 2023 (fr.tutiempo.net, 2024).

2.2Hydrogeological and Geological Backgrounds

Tertiary and quaternary continental deposits make up the basin's center, while Mesozoic and early Cenozoic terrains dominate the region's margins. The Terminal Complex (CT) and the Continental Intercalaire (CI) are the two main post-Paleozoic hydrogeological formations found in the geological sequence (Salah, 2016).The OuedRigh basin contains two major aquifer systems (Figure 3) (Belksier M.S. et al., 2014):

The CI, or Continental Intercalaire: The main constituents of this vast, deep aquifer are sands and sandstones of Albian age.

The CT, or Terminal Complex: This multi-layered, shallower complex is separated into two parts. As the first and second aquifers of the Terminal Complex (CT1 and CT2), the first is continental and composed of sands, gravels, and Miocene-Pliocene sandstones. The second, CT3, is made up of Senonian-Eocene limestones and has a marine origin. A shallow aquifer layer of fine sands from the Quaternary to the Recent periods covers these formations (Salah, 2016).

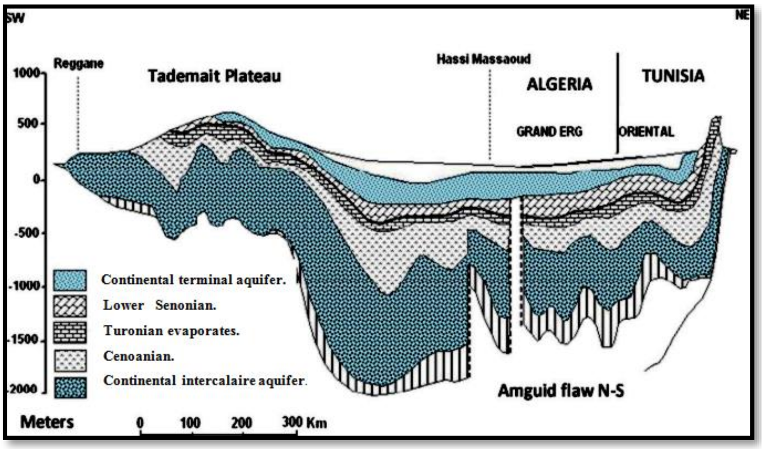


Figure 3. Synthetic hydrogeological profile of the Northern Sahara (UNESCO, 1972).

2.3 Soil Analysis and Sampling

In March 2023, soil sampling was executed according to a systematic sampling approach informed by geographical data generated by the ARC GIS Geographic Information System. This sample approach generated 51 observation points, one for each panel. We utilized the UTM Geo

Map tool to ascertain the latitude and longitude of each sampling site (Figure 2). Soil samples were collected from a depth of 20 cm utilizing an agricultural auger. The materials were crushed and passed through a 2 mm mesh screen to yield fine soil after being dried for 24 hours at 105°C in an oven. For further analysis of parameters like as pH, electrical conductivity (EC), organic matter (OM), and total lime content, the samples were preserved in plastic bags.

2.4 Methods and Metrics for Soil Extraction

2.4.1 Technique of Saturated Paste Extraction

The standard method (USDA, 1954) was employed to prepare the soil paste extracts, which entailed adding distilled water to approximately 200 g of soil and stirring until complete saturation was achieved. When the paste exhibits glitter, exhibits minor flow upon tilting, slides off a smooth spatula, forms a jar-like groove, and attains the stage of free water precipitation, it is considered fully saturated (Corwin and Yemoto, 2020). The pastes were allowed to equilibrate for an entire day. Each paste was thereafter positioned over a vacuum flask and subjected to vacuum filtration using filter paper in a Büchner funnel. The extracts were collected in 50 ml plastic bottles following filtration. The Jenway 4510 conductivity meter and Mettler Toledo pH meter were employed to measure electrical conductivity and pH at 25°C.

2.4.2 Methods for Soil-Water Extraction (1/2.5 and 1/5 Ratios)

Distilled water was added to each soil sample (X g) in a 100 ml polyethylene container, adhering to soil-to-water ratios of 1/2.5 and 1/5 (see to Table 1). Following 23 hours at ambient temperature, the samples were agitated for one hour at 132 rpm (Soil Survey Staff, 2011). The soil solutions were stirred, thereafter transferred to 50 ml polyethylene bottles, and centrifuged for five minutes at 4000 rpm. A Cond 7110 benchtop conductivity meter and a Mettler Toledo pH meter were employed to ascertain the electrical conductivity and pH at 25°C.

Table 01: Ratios for Diluted Extracts (Soil/Water)

Soil/ water	Soil (g)	water (cm^3)
1/2.5	10	25
1/5	10	50

NB :1 cm^3 = 1 ml

2.4.3 Methods for Determining Soil Characteristics

We randomly chose eight soil samples to assess their organic matter (OM), total lime concentration, and soil texture.For this purpose, Bouyoucos hydrometer method was employed (Bouyoucos, 1951).

To estimate the equivalent CaCO3 %, the Calcimeter Bernard method was utilized. This method measures the CO2 created when HCl is administered to the sample.

The organic matter content (OM) was determined using the ANNE method, which involves titrating excess potassium bichromate in a sulfuric media after carbon oxidation with potassium bichromate. It is possible to titrate the excess bichromate with a Mohr's salt solution while diphenylamine is present; this substance changes color from dark blue to green as the titration progresses.

More information regarding the ANNE method can be found at [this

link](https://docplayer.fr/20902985-10-le-carbone-organique-methode-anne-simplifiee.html).

Additional information about the Calcimeter Bernard method may be found at [La méthodeCalcimètre Bernard](https://svt.ac-

versailles.fr/IMG/archives/docpeda/banques/Limay/docs/calci.htm).

2.5 Assessing and Documenting Water Quality

The long-term productivity of date palm farms is highly dependent on the amount and quality of water used for irrigation.The soil in our research area is irrigated using water that flows from the Complexe Terminal. In March 2023, samples of drainage and irrigation water were taken for the purpose of analyzing the physical and chemical properties of the water. We kept these samples at temperatures below 4°C for storage. All analyses were conducted following the protocols laid out by Rodier (2009).

2.6 Confirming the Relationships Between the Soil-Water Extracts' ECe and EC

We computed the ECe, EC1/2.5, and EC1/5 values for the 51 soil samples after evaluating them using the traditional approach and the suitable models.

Estimates of the ECe equivalents from the EC1/2.5 and EC1/5 measurements were made using regression models. A comparison with the actual ECe readings followed.

Table 9, shows the results of our evaluation of previous models that have been used to estimate the salinity of coarse-textured soils. Table 8 shows the results of a regression analysis that compared the predicted ECe values from this study to those from other researchers' models and the actual data.

2.7.1 Statistical Analysis

The following variables were analyzed using descriptive statistics: range, variance, skewness, minimum, maximum, standard deviation, median, and standard error. With and without interceptions, regression analysis was used to examine the electrical conductivity of saturated soil paste extracts with ratios of 1/2.5 and 1/5.

To measure the strength of the regression correlations, this study employed regression slopes (r). The linear connections were subjected to validation procedures in order to determine whether the observed ECe values are consistent with the model's predictions. A total of 51 samples were used in this validation research, all taken from separate datasets. The data was handled and analyzed using Microsoft Excel.

$$\boldsymbol{RMSE} = \sqrt{\frac{\mathbf{1}}{\boldsymbol{N}}\sum_{\boldsymbol{i=1}}^{\boldsymbol{N}}(\boldsymbol{EC_1} - \boldsymbol{EC_P})^2}$$

2.8 Cartography Using Ordinary Kriging

One of the most used geostatistical methods for estimating soil salinity is ordinary kriging (KO) (Fourati et al., 2017). By predicting values at unsampled sites using available data from nearby points, this method is very useful in spatial estimation.

Ordinary Kriging uses data from nearby locations Z(xi)Z(x_i)Z(xi), where i=1,2,…,ni = 1, 2, \dots, ni=1,2,…,n, to estimate the value of a target variable Z′(x0)Z'(x_0)Z′(x0) at an unsampled site. The following is a mathematical expression for the Ordinary Kriging process:

Solving a series of equations that represents the spatial correlation between the data points yields these weights, λi\lambda_iλi. A variogram, which measures the spatial dependence of the variable under study (in this example, soil salinity), is typically used to characterize this correlation. In order to ascertain the degree to which each surrounding data point influences the prediction, the spatial structure of the data is essential to this approach.

1. Calculating the Variogram: The variogram, which shows the spatial relationships between the data points, is first calculated to ascertain the spatial dependence between the data points. The weights for every observed data point are determined by fitting the variogram to a model.

2. Weight Assignment: Each data point is given a weight via the Kriging method according to how far away it is from the target point. With the weights being modified based on the spatial structure obtained from the variogram, points nearer the goal have a greater impact on the prediction than those farther away.

3. Prediction: The Kriging approach generates an estimate of the variable at unsampled places based on the weights and observed values. Spatial maps of the distribution of soil salinity are produced as a result of this approach.

$$\mathbf{Z^*(\mathcal{X}0) = \sum_{i=1}^{n} \lambda i \, Z(\mathcal{X}_i) \ldots\ldots\ldots\ldots (2)}$$

In what context the number of experimental points used for the estimation is denoted by n. At the experimental point Xi\mathcal{X}_iXi, the weight is denoted by λ_i.

At point X0\mathcal{X}_0X0, the estimated value is *Z($\mathcal{X}_0$)**.

The weight given to observation iii is denoted by λ^k

The known value at the sampling point Ximathcal{X}_iXi is denoted by Z($\mathcal{X}_i$). According to the user-defined size of the moving window, the number of nearby sites examined for the estimation is denoted by n.

Webster and Olivier (2007) state that in order to ensure that the estimates are both unbiased and reduce the variance of the estimation, weights are allocated to each sample in a certain manner.
For more accurate forecasting:

It is expected that the normalized mean error (ME) will be around zero

As stated by Arslan (2012) and Fourati et al. (2017), it is desirable to have a minimal root mean square error (RMSE).

In order to estimate the mean error and root mean square error, we used the following formulas: These two primary indexes were computed in our research.

$$\mathbf{ME = \frac{1}{n}\sum_{i=1}^{n} Z^*(\mathcal{X}_i) - Z\,(\mathcal{X}_i) \ldots\ldots\ldots\ldots (5)}$$

$$\mathbf{RMSE = \sqrt{\sum_{i=1}^{n} \frac{1}{n}[Z^*(\mathcal{X}_i) - Z\,(\mathcal{X}_i)]^2} \ldots\ldots\ldots\ldots (6)}$$

Where:

*Z(?$_i$)** = predicted value;

Z(?$_i$) = measured value;

n = number of validation points.

For better prediction, the **normalized mean error (ME)** should be close to 0, and the **root mean square error (RMSE)** should be as low as possible (Arslan, 2012; Fourati et al., 2017).

According to Cambardella et al. (1994); Bradai et al. (2016), the nugget-to-sill ratio can be used as an indicator of spatial dependence (Table 2).

Table 2. Spatial Dependence Indicators.

Nugget-to-Sill Ratio	≤ 25%	25% - 75%	≥ 75%
Spatial Dependence	Strong	Moderate	Weak

By applying a theoretical model to the empirical variogram, one can ascertain the point weights in Ordinary Kriging (KO). The optimal model is that which produces the fewest squared errors, as stated by Boubehziz et al. (2020).

Several models, such as linear, exponential, and Gaussian, were evaluated before settling on the one that best matched KO. The model that produced the best estimates was the one with the smallest estimation error. Microsoft Excel ® was utilized for statistical analysis, whereas ArcGIS 10.2 was employed for data processing and analysis.

3. Discussion and Findings

3.1 Soil Characteristics

According to Table 3, the analyzed soil contains 79.21 ± 4.78% sand, 14.47 ± 5.83% silt, and 6.33 ± 2.05% clay. This study's soil type ranges from sandy loam to loamy sand, as shown in Figure 4 of the World Reference Base for Soil Resources (WRB, 2015).

Table 3. Characteristic statistics of the soil's chemical and physical characteristics in the Touggourt area's Blidet Amar palm grove

	Valid N	**Mean**	**Median**	**Mini**	**Max**	**Var**	**Std.Dev.**	**Coef.Var.**	**Skewness**	**Kurtosis**
Clay%	8	6.33	5.06	5.03	10.05	4.21	2.05	32.42	1.35	0.14
Silt %	8	14.47	14.43	6.86	22.40	33.93	5.83	40.26	-0.01	-1.71
Sand %	8	79.21	79.83	71.30	84.10	22.89	4.78	6.04	-0.53	-1.16
% organicmatter	8	0.53	0.55	0.25	0.78	0.03	0.18	34.31	-0.47	-0.50
% Total limestone %	**8**	4.36	3.80	3.60	6.84	1.52	1.23	28.26	1.65	1.43

The organic matter concentration of soil samples ranged from 0.25 ± 0.18% to 0.478 ± 0.18%, with an average of almost 0.53 ± 0.18%. The research region is categorized as having soils with very little organic matter, not exceeding 1%, according to Morand's scale (2001). The evaluated soils are categorized as either moderately or slightly calcareous according to Baize's (2018) evaluation criteria. The average percentage is approximately 4.36 ± 1.23%, with a range of 3.6 ± 1.23% to 6.84 ± 1.23%.

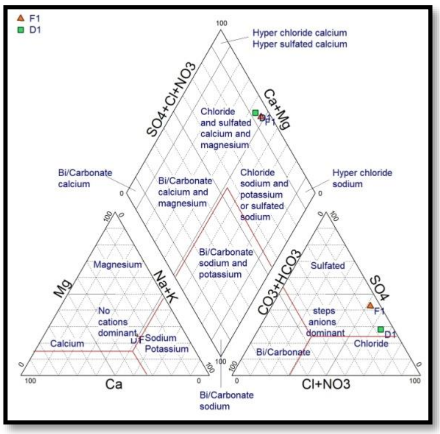


Figure 04.Textural triangle of the soil samples from the study area.

3-2-The Purity of Irrigation Water Table 4 displays the physicochemical properties of the irrigation and drainage fluids In these bodies of water, the pH is practically neutral. Drainage water has a much greater electrical conductivity (EC) value than irrigation water. The process of leaching, which involves the introduction of electrolytes into water from soil, is the one accountable for the increase.

Table 4. The chemical and physical properties of the water used for irrigation and drainage in the Touggourt area (Blidet Amar)

	pH	EC (dS/m)	Ca^{2+} (meq/L)	Mg^{2+} (meq/L)	Na^{+} (meq/L)	K^{+} (meq/L)	HCO_3^- (meq/L)	Cl^- (meq/L)	SO_4^{2-} (meq/L)	S.A.R. (meq/L)
Irrigation	7.37	5.82	214.23	123.17	434.03	13.56	165.6	926.22	1024.3	
Drainage	7.33	13.3	651.67	310.15	1020.36	31.42	471.2	2540.62	1502.66	

Using the Piper diagram, we were able to determine the chemical facies of the water. The Riverside diagram was used to assess the risk of soil salinization and sodicity (1954). In 1948, WILCOX published a method for evaluating irrigation waters based on their sodium content and electrical conductivity. Hereis the formula to determine the sodium percentage:

$$Na^+ = \frac{(Na^+ + K^+)}{(Ca^{+2} + Mg^{+2} + Na^+ + K^+)} \times 100$$

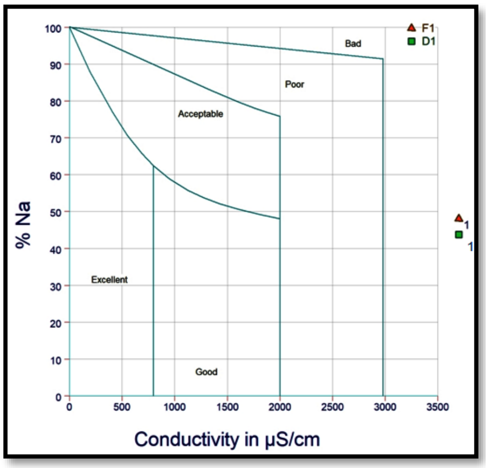


Figure 5. Evaluation of the quality of irrigation water (F1) and drainage water (D1) based on the WILCOX diagram.

The WILCOX diagram indicates that both the irrigation water (F1) and drainage water (D1) are of poor quality.

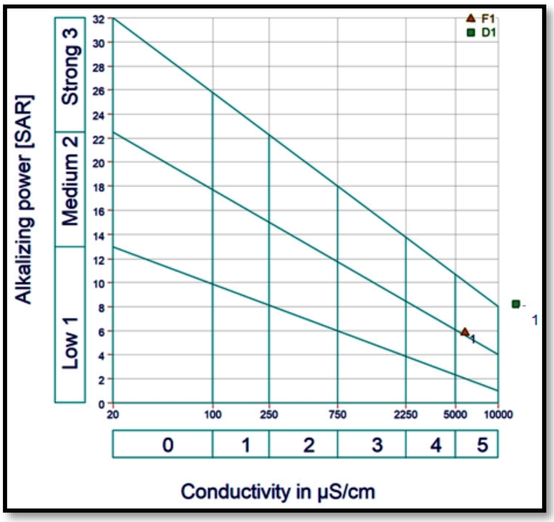


Figure 6.Riverside diagram showing the separation of irrigation water (F1) and drainage water (D1)

The Riverside diagram (Figure 6) illustrates the connection between EC and SAR. It turns out that the irrigation water samples have a C5S3 classification, which means they're very alkaline and could be very salty. Also, the drainage water samples have a C5S4 classification, which means there's a good chance the water is alkaline and a big chance it's salty. The irrigation suitability diagrams indicate that the soil and plants that rely on these fluids may be negatively affected by the mineral content. Irrigation withthese waters is hence highly discouraged.

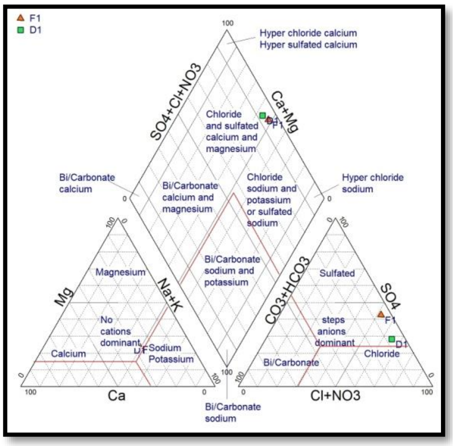


Figure 7. Piper diagram applied to irrigation water (F1) and drainage water (D1).
According to the results of the Piper diagram (Figure 7), the samples of irrigation water (F1) and drainage water (D1) have a dominant chemical facies of Chloride-Sodium and a masked chemical facies of Sulfate-Calcium.

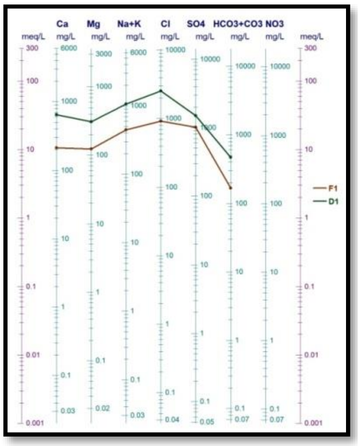


Figure 8.Schoeller-Berkaloff diagrams applied to irrigation water (F1) and drainage water (D1).

The Schoeller-Berkaloff diagram shows that chlorides are the primary anions in both irrigation and drainage waters, with sodium being the predominant cation.Thehydrochemical analysis of the waters reveals a considerable mineral load in both samples. The ionic formula of these waters is as follows:

F1: $Na^+ > Ca^{2+} > Mg^{2+} > K^+$:$Cl^- > SO_4^{2-} > HCO_3^-$.

D1: $Na^+ > Ca^{2+} > Mg^{2+} > K^+$:$Cl^- > SO_4^{2-} > HCO_3^-$.

3-3- Soil Salinity

Generally speaking, the quantity of salts in irrigation water increases together with the salinity of the soil. According to Pérez-Sirvent et al. (2003), soil electrical conductivity can range from two to six times the irrigation water's salt content. Even while every soil receives the same amount of irrigation, salinity is also influenced by environmental factors and agricultural methods.Among other things, the OuedRigh area has experienced disruptions due to wastewater and sewage stagnation brought on by inadequate drainage system management (Belkesier et al., 2018). Because of the growth of plants like reeds and the infiltration of water from the drainage into the plots, it was discovered during the field assessment that the drainage system was inadequate. Additionally, the OuedRigh valley's excessive water use (Kadri et al., 2022) has resulted in an overall surplus of water and salt in the soils, which may even cause salt crusts to grow on the soil (Figure 8). The high EC values seen in the research area may be explained by this.

Figure 8. Flat salt crust of a gray-white color on the soil surface.

The descriptive statistics pertaining to the electrical conductivity of the soil samples are presented in Table 5. The electrical conductivity of the soil extracts demonstrated variability, with measurements ranging from 5.92 to 142 mS/cm for saturated paste extracts (PS), 3.52 to 32.4 mS/cm for the 1:2.5 soil-water ratio, and 2.63 to 21.34 mS/cm for the 1:5 soil-water ratio. The findings demonstrate that various salinity levels were employed to assess the SP method relative to the EC1/2.5 and EC1/5 methods. The results are consistent with earlier studies carried out by various researchers, demonstrating that the electrical conductivity (EC) of diluted extracts is less than that of saturated paste extracts (USDA, 1954; Özcan et al., 2006; Sonmez et al., 2008; Aboukila and Norton, 2017; Kargas et al., 2018; Bakhti et al., 2024; Spiteri and Sacco, 2024). The measured average electrical conductivity (EC) of the saturated paste extracts was approximately 59.49 mS/cm. The observed value is approximately 4.43 times higher than the electrical conductivity measured in the 1/2.5 soil-water ratio extracts and 7.23 times greater than that of the 1/5 soil-water ratio extracts.The findings are in strong agreement with the observations made by Sonmez et al. (2008) and Aboukila and Abdelaty (2017), who indicated that the average electrical conductivity of the saturated paste (ECe) was roughly four times and eight times higher than the EC1/2.5 and EC1/5, respectively. The findings align with those from our research conducted in the SidiYahia palm grove (Djamâa area), located in the central section of the OuedRigh region. The ECe averages were documented at 4.71 for EC1/2.5 and 7.44 for EC1/5, respectively (Bakhti et al., 2024).

	Valid N	**Mean**	**Median**	**Mini**	**Max**	**Var**	**Std.Dev.**	**Coef.Var**	**Skewness**	**Std.Err - Kurtosis**
EC_e **(mS/cm)**	51	59.49	60.20	5.92	142	1241.35	35.23	59.23	0.29	-0.68
$EC_{1/2.5}$ **(mS/cm)**	51	13.42	12.77	3.52	32.4	48.22	6.94	51.73	0.99	1.12
$EC_{1/5}$ **(mS/cm)**	51	8.23	7.72	2.63	21.34	17.42	4.17	50.72	1.09	1.54

The examination of the electrical conductivity of the soil samples revealed a significant disparity between the conductivity of the extracts (1/2.5, 1/5) and that of the saturated paste extracts. Research conducted by the USDA (1954) and Sonmez et al. (2008) indicates that the electrical conductivity of soil extracts decreases as the soil-to-water ratio increases. The 51 soil samples were classified into three categories for the SP method and four categories for the diluted ratios: 0–2, 2–4, 4–8, 8–16, and greater than 16 mS/m. Table 6, presents the values for each class alongside their respective percentages.

Approximately 88.24% of the soil samples demonstrated an ECe greater than 16 mS/cm, 29.41% indicated an EC1/2.5 exceeding 16 mS/cm, and 3.92% recorded an EC1/5 surpassing 16. The results present a comparison of the SP method with the EC1/2.5 and EC1/5 methods across various EC values.

.Table 6. Electrical conductivity of saturated paste extracts (ECe) and two soil-to-water ratio extracts (EC1/2.5 and EC1/5) for the studied soils.

Range of EC(mS/cm)	ECe		$EC_{1/2.5}$		$EC_{1/5}$	
	No of Samples	% of Samples	No of Samples	% of Samples	No of Samples	% of Samples
2 - 4	0	0	3	5.88	10	19.61
4 - 8	3	5.88	9	17.65	17	33.33
8 - 16	3	5.88	24	47.06	22	43.14
> 16	45	88.24	15	29.41	02	3.92

3-2- Relationship Overview Between ECe and EC1/2.5, EC1/5

For each dilution pair, the regression equation and the correlation coefficient r were determined in alignment with the statistical significance threshold p (Table 7). Figure 10, 11, and 12 illustrate the graphs associated with the three data pairs. A notable correlation was observed between ECe and the EC1/2.5 and EC1/5 values ($R = 0.95$ and 0.95, $p < 0.05$), indicating that ECe in coarse-textured soils can be estimated through EC1/2.5 and EC1/5 measurements. The increase in the soil-to-water ratio from 1/2.5 to 1/5 produced a more significant slope in the regression equations of EC, suggesting that the addition of water facilitates dilution. Sonmez et al. (2008) noted that changes in the regression equations acted as a signal of dilution. The ratio of EC1/2.5 to EC1/5 (Figure 12) in the diluted extracts shows a highly significant correlation ($r = 0.97$, $p < 0.05$).

The slopes for the 1/2.5 and 1/5 extracts in our study ranged from 4.84 to 7.99, consistent with the slopes reported by Sonmez et al. (2008), which were 4.24 and 8.22, and 7.46 for the 1/5 extract as noted by Aboukila and Abdelaty (2017).

The relationship between ECe and EC1/2.5 in our study demonstrated a slope of 4.84, closely aligning with the slope of 4.15 noted in the SidiYahia area of the OuedRigh region (Bakhti et al., 2024).
Furthermore, the ratio of ECe to EC1/5 results in a slope of 7.99, indicating a significant variation when contrasted with the slopes documented by Ozcan et al. (2006), Monteleone et al. (2016), Aboukila and Norton (2017), Kargas et al. (2018), Bakhti et al. (2024), and Spiteri and Sacco (2024). The values are 5.97, 5.04, 6.53, 6.77, and 101.261.

A number of researchers have recorded variations in the regression equations. The observed differences can be attributed to several factors, including the type and clay content (Sonmez et al., 2008), the presence of various types of salts (Ismayilov et al., 2021; Isdory et al., 2021), gypsum content (USDA, 1954; Franzen et al., 2019; Kargas et al., 2018), the variability of ECe in the soil samples used for the formulation of a conversion equation (Aboukila and Norton, 2017), and soil texture (Sonmez et al., 2008; Kargas et al., 2022).

Table 7.Statistical Parameters of the Three Soil-to-Water Ratio Dilution Pairs for the Analyzed Soils with a Statistical Significance Threshold of $p < 0.05$.

	Means	**Std.Dev.**	EC_e **(mS/cm)**	$EC_{1/2.5}$ **(mS/cm)**	$EC_{1/5}$ **(mS/cm)**
EC_e **(mS/cm)**	59.49	35.23	1	0.95	0.95
$EC_{1/2.5}$ **(mS/cm)**	13.42	6.94	0.95	1	0.97
$EC_{1/5}$ **(mS/cm)**	8.23	4.17	0.95	0.97	1

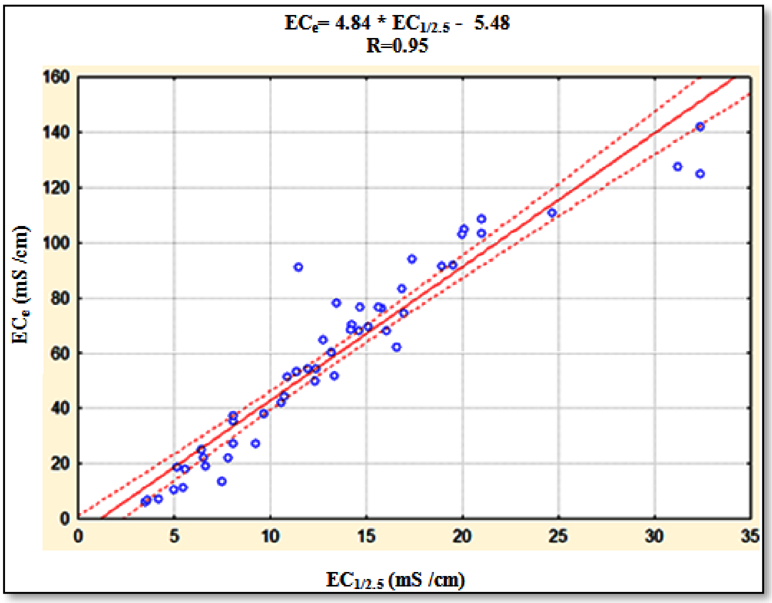


Figure 10.Correlation Between the Electrical Conductivity of the Saturated Paste and the Electrical Conductivity of the Diluted Extracts EC1/2.5

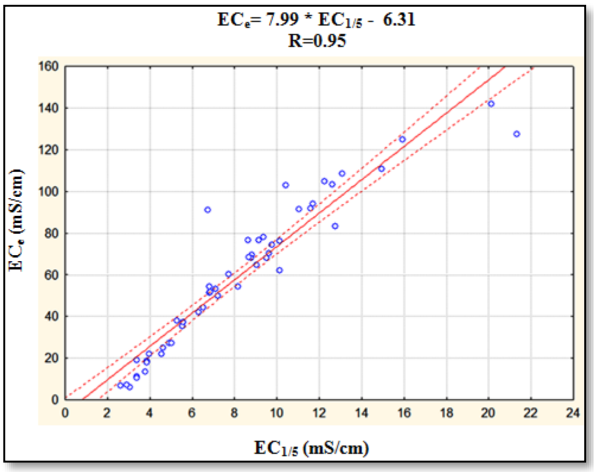


Figure 11. Correlation Between the Electrical Conductivity of the Saturated Paste and the Electrical Conductivity of the Diluted Extracts EC1/5.

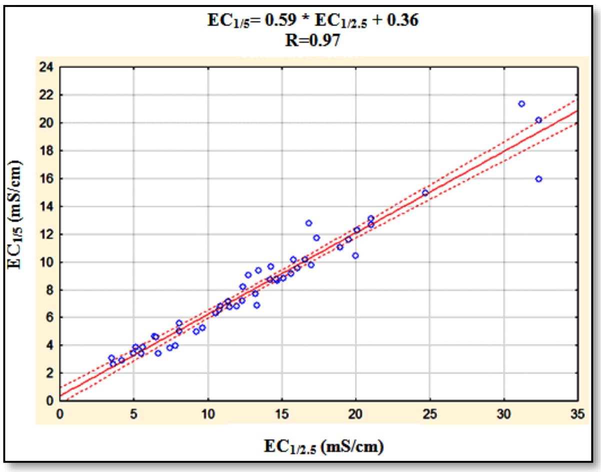


Figure 12. Correlation Between the Electrical Conductivity of the Diluted Extracts EC1/2.5 and the Electrical Conductivity of the Diluted Extracts EC1/5.

Model Validation

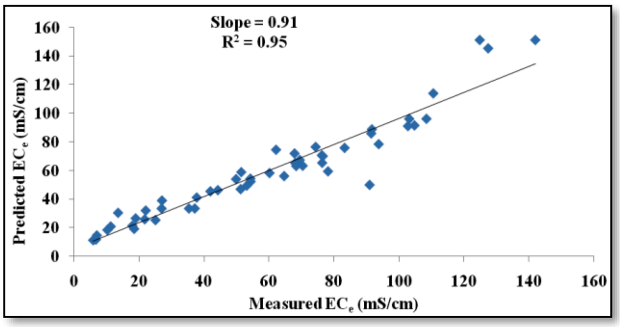
The regressions in this study employed fifty-one soil samples to confirm the relationships between ECe and the two EC1/2.5 and EC1/5. The same samples were employed to assess the models created by other researchers (Table 8).

The 1/2.5 and 1/5 models produced average ECe values of 59.49 and 59.44 mS/cm, respectively, as shown by the regression equations obtained from this study (Table 8). The 1/2.5 model showed consistent measured and predicted average values with no deviation, while the 1/5 model displayed a deviation of -0.08%.

Özcan et al. (2006) indicated that the 1/2.5 and 1/5 models forecasted average ECe values of 44.16 and 47.96 mS/cm, respectively. The values exhibited notable differences ($P<0.05$) when compared to the observed average ECe, as detailed in Table 8.The measured and predicted average values demonstrated discrepancies of -25.77% and -19.38% for the 1/2.5 and 1/5 models, respectively

Based on the regression equations developed by Sonmez et al. (2008), the 1/2.5 and 1/5 models yielded average ECe values of 58.43 and 67.32 mS/cm, indicating differences in the average values of -1.78% and 13.16%, respectively. The predicted average ECe for the 1/2.5 model was in close agreement with the observed average ECe ($P > 0.05$), while the predicted average ECe for the 1/5 model showed a significant discrepancy ($P < 0.05$) from the observed average ECe (Table 8).

The regression equations developed by Monteleone et al. (2016), Aboukila and Norton (2017), Aboukila and Abdelaty (2017), Kargas et al. (2018), Isdory et al. (2022), Bakhti et al. (2024), and Spiteriand Sacco (2024) produced calculated ECe values of 110.2, 41.35, 50.86, 67.2, and 63.17 mS/cm for the 1/2.5 soil/water ratio, and 41.85, 61.82, 53.63, 65.62, and 16.28 mS/cm for the 1/5 ratio, respectively. The calculated ECe values showed notable differences when compared to the measured average ECe (Table 8). The calculated ECe averages exhibited notable discrepancies in comparison to the actual measured ECe averages (Table 4). The measured and calculated average values demonstrated variances of 84.24%, -30.49%, -14.51%, 12.96%, 10.3%, -29.65%, 3.92%, -9.85%, 6.19%, and 43.21% for the studies conducted by Monteleone et al. (2016), Aboukila and Norton (2017), Aboukila and Abdelaty (2017), Kargas et al. (2018), Isdory et al. (2022), Bakhti et al. (2024), Spiteriand Sacco (2024), respectively.



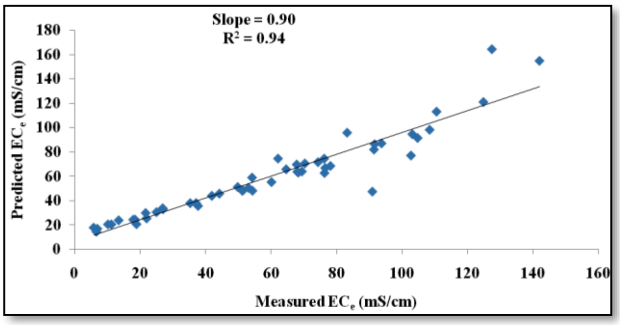


Figure 13.The Relationship Between the Measured EC (ECe) of Saturated Paste Extracts and the Predicted ECe by the Regression Equation Derived from the Soil-Water Extracts 1/2.5 and 1/5 of 51 Samples Used to Validate the Models Presented in Figures 10 and 11.

The validation RMSE values recorded were 1.05 and 1.12 mS/cm for the EC1/2.5 and EC1/5 values, respectively. The lowest RMSE values were noted in the saturated paste (ECe) conversion estimates with a soil/water ratio of 1/2.5 (Table 7). The conclusion drawn indicates that the EC1/2.5 estimates aligned more closely with the measured data compared to the EC1/5 estimates.
The newly developed equations were compared with 12 equations sourced from eight distinct studies on EC conversion (Table 8).The same validation dataset was utilized for the comparisons, as previously indicated.

The 1/2.5 and 1/5 models demonstrated the highest accuracy in predicting ECe for the studied soils, as assessed through RMSE, slope, R^2, and the predicted ECe values. The models presented by other researchers demonstrated the lowest accuracy in predicting ECe based on the EC1/2.5 and EC1/5 values, with RMSEs recorded at 7.79, 2.43, 2.14, 1.56, 1.31, 1.28 mS/cm and 5.28, 2.42, 1.81, 1.40, 1.37, 1.30, 1.17 mS/cm, respectively. Notable exceptions included Sonmez et al. (2008), which reported an RMSE of 1.11 for the EC1/2.5 value, demonstrating a closer alignment with the measured data. The prediction errors for ECe were decreased by a factor ranging from 7.42 to 4.71 in comparison to the 12 models. The variations in RMSE across the models are likely affected by differences in soil texture, types of clay, salt content, gypsum levels, equilibration techniques and durations, as well as the ECe range of the soil samples utilized for model development.The electrical conductivity values of soil in soil-water extracts are affected by changes in soil texture (Sonmez et al., 2008; Kargas et al., 2022).

The equations established in a prior study by Bakhti et al. (2024) (Table 8) for coarse-textured soils (loamy sand) in the SidiYahia oasis, located in the western part of the Djamâa district within the Méghaier province of the OuedRigh region, yielded RMSE values ranging from 1.28 to 1.30. These values are notably higher than those recorded for the equations introduced in this study, which pertain to coarse textures (sandy loam and loamy sand). Improvements in the accuracy of conversion equations can be achieved by differentiating soils according to their texture.

Table 8. A Comparative Analysis of 14 EC Conversion Equations Formulated with the EC1/2.5 and EC1/5 Equations Established in This Study.

référence	**Equation**	CE_e mesurée	CE_e prédite	**Différence %**	**slope**	R^2	**RMSE (mS/cm)**
Ozcan et al.(2006)	$ECe = 3.30\ EC_{1/2.5} - 0.20$	59.49	44.16	-25.77	0.62	0.95	2.14
Ozcan et al.(2006)	$ECe = 5.97\ EC_{1/5} - 1.17$	59.49	47.96	-19.38	0.66	0.94	1.81
Sonmez et al.(2008)	$ECe = 4.34\ EC_{1/2.5} + 0.17$ c	59.49	58.43	-1.78	0.81	0.95	1.11
Sonmez et al.(2008)	$ECe = 8.22\ EC_{1/5} - 0.33$ c	59.49	67.32	13.16	0.92	0.94	1.37
Monteleone et al. (2016)	$ECe = 9.63 EC_{1/2.5}$ b	59.49	110.2	85.24	1.81	0.95	7.79
Aboukila and Norton (2017)	$ECe = 3.05\ EC_{1/2.5} + 0.41$ f	59.49	41.35	-30.49	0.57	0.95	2.43
Aboukila and Norton (2017)	ECe =5.04 EC1/5 + 0.37 f	59.49	41.85	-29.65	0.56	0.94	2.42
Aboukila andAbdelaty (2017)	ECe =3.73 EC 1/2.5 + 0.79 c	59.49	50.86	-14.51	0.70	0.95	1.56
Aboukila and Abdelaty (2017)	$ECe = 7.46\ EC_{1/5} + 0.43$ c	59.49	61.82	3.92	0.83	0.94	1.17
Kargas et al.(2018)	ECe = 6.53* (EC1/5) - 0.108f	59.49	53.63	-9.85	0.73	0.94	1.40
Daniel Isdory et al(2022)	$ECe = 5.0143 * EC_{1/2.5} - 0.1091$ c	59.49	67.2	12.96	0.94	0.95	1.31

Dahman B et al. (2024)	$EC_e = 4.15 * EC_{1/2.5} + 9.91$ c	59.49	63.17	6.19	0.76	0.94	1.28
Dahman B et al. (2024)	$EC_e = 6.77 * EC_{1/5} + 7.46$ c	59.49	65.62	10.3	0.78	0.95	1.30
Kyle Spiteri& Anthony T. Sacco(2024)	$EC_e = 10^{1.261 * Log (EC_{1/5}) + 1.162}$ c	59.49	16,28	43.21	0.12	0.96	5.28
This study	$Ec_e = 4.84 * EC_{1/2.5} - 5.48$ c	59.49	59.49	0	0.91	0.95	1.05
This study	$Ec_e = 7.99 * EC_{1/5} - 6.31$c	59.49	59.44	-0.08	0.90	0.94	1.12

Table 09: Correlation Equations for Converting Soil-Water Extracts at Various Ratios (EC1/x) into Saturated Paste Equivalents (ECe) as Proposed by Different Researchers

Study	Regression equation			
	With intercept	R2	Without intercept	R2
Ozcan et al. (2006)	$ECe = 3.30 * EC_{1/2.5} - 0.20$	0.95	....	....
	$ECe = 5.97 * EC_{1/5} - 1.17$	0.94		
Sonmez et al. (2008)	$ECe = 4.34 * EC_{1/2.5} + 0.17$ c	0.99	$ECe = 4.41 * EC_{1/2.5}$ c	0.99
	$ECe = 8.22 * EC_{1/5} - 0.33$ c	0.98	$ECe = 7.98 * EC_{1/5}$ c	0.98
Monteleone et al. (2016)	-		$ECe = 9.63 * EC_{1/2.5}$ b	0.99
Aboukila and Norton (2017)	$ECe = 3.05 * EC_{1/2.5} + 0.41$ f	0.93	$ECe = 3.34 * EC_{1/2.5}$ f	0.92
	$ECe = 5.04 * EC_{1/5} + 0.37$ f	0.93	$ECe = 5.49 * EC_{1/5}$ f	0.92
Aboukila and Abdelaty (2017)	$ECe = 3.73 * EC_{1/2.5} + 0.79$ c	0.96	$ECe = 4.13 * EC_{1/2.5}$ c	0.94
	$ECe = 7.46 * EC_{1/5} + 0.43$ c	0.97	$ECe = 7.89 * EC_{1/5}$ c	0.96
Kargas et al. (2018)	$ECe = 6.53 * (EC_{1/5}) - 0.108$ f	0.93	....	....
Daniel Isdory et al(2022)	$\mathbf{ECe = 5.0143 * EC_{1/2.5} - 0.1091}$ **c**	0.99	$ECe = 4.926 * EC_{1/2.5}$	0.99
Dahman B et al.(2024)	$ECe = 4.15 * EC_{1/2.5} + 9.91$ c	0.93	....	....
	$EC_e = 6.77 * EC_{1/5} + 7.46$ c	0.91	....	....
Kyle Spiteri & Anthony T. Sacco(2024)	$ECe = 10^{1.261 * Log (EC1/5) + 1.162}$ c	0,91	....	....
This study	$Ec_e = 4.84 * EC_{1/2.5} - 5.48$ c	0.95	....	....
	$Ec_e = 7.99 * EC_{1/5} - 6.31$ c	0.95		

a- Units of EC are in dS m-1. b- Combined soil textures.

c- Coarse-textured soils. d- Coarse-textured soils without gypsum.

e- Coarse-textured soils containing gypsum. f- Fine-textured soils.

-4- Salinity Mapping of the Blidet Amar Palm Grove (Touggourt Area)

Table 10, shows the best theoretical models (Gaussian and Stable) fitted for soil depth (20 cm).

Table 10.Parameters of the Variogram Models for the Layer (0-20 cm)

	Modèle le mieux adapté	**Pépite (C0)**	**Seuil (C0+C)**	**Portée (m)**	**Ratio %**	**ME**	**RMSE**
Extrait diluée	Gaussain	0.12	0.58	428.46	20.68	-0.12	4.19
Pâte saturée	Stable	1.13	1.69	397.41	66.86	-0.73	3.55

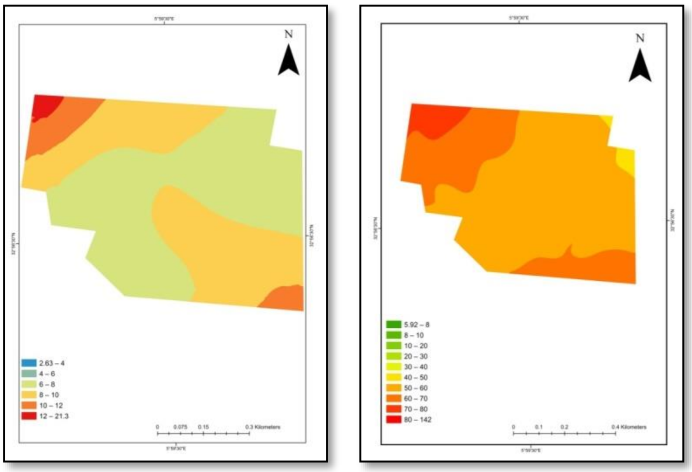


Figure 14.Prediction of Soil Electrical Conductivity Maps for Diluted Extracts (1/5) (a) and Saturated Pastes (b) Using Ordinary Kriging (OK).

Salinity distribution maps were produced through the application of Ordinary Kriging (OK) to interpolate electrical conductivity values derived from the 1/5 diluted extract.The electrical conductivity data were refined utilizing the Gaussian and Stable models, in conjunction with the fitting parameters.

The differences in electrical conductivity observed between the 1/5 diluted extracts and saturated pastes enabled the development of two thematic maps illustrating surface layer salinity (0-20 cm). The dilution effect highlights that the variation in salinity classes between the two maps offers significant insights into the salinity levels present in the study area. Figure 14, presents the distribution of four classes for the diluted extract (1/5) and four classes for the saturated paste salinity within the study area, utilizing OK. This indicates extremely saline soils based on the classification of electrical conductivity of the aqueous extract (1/5) (Durand; 1983) and the saturated paste extract (USDA, 1954), with no presence of non-saline soils.
- Salinity Distribution for the Diluted Extract at a 1/5 Ratio:

• The area characterized by extremely saline soils (6 mS/cm < CE1/5 < 8 mS/cm) encompasses 26.73 hectares, accounting for 53.46%, and is situated in the central region of the plot.
• Highly saline soils (8 mS/cm < CE1/5 < 10 mS/cm) account for 19.81 ha, or 6.2%, and are located in the northwest and southeast regions of the plot.
• An area of 3.1 ha, representing 6.2%, is characterized by extremely saline soils (10 mS/cm < CE1/5 < 12 mS/cm), situated in the northwest and the extreme southeast of the plot.
• An area of 0.36 ha, representing 0.72%, is characterized by extremely saline soils (12 mS/cm < CE1/5 < 21.3 mS/cm), situated in the extreme northwest of the plot

- Salinity Distribution for the Saturated Paste:

An area of 0.25 ha, representing 0.5%, is characterized by extremely saline soils (40 mS/cm <CEpsc< 50 mS/cm), situated in the upper section of the plot in the northeast.
• An area of 33.2 ha, representing 66.4%, is characterized by extremely saline soils (50 mS/cm <CEpsc< 60 mS/cm), situated in the central part of the plot.

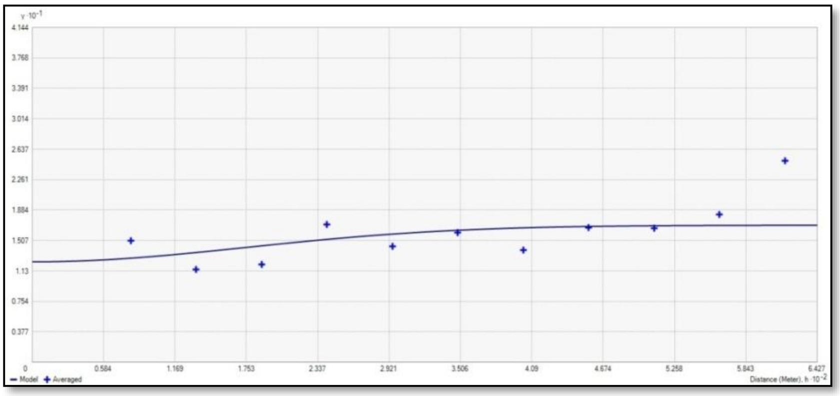
• An area of 14.25 ha, representing 28.5%, is characterized by extremely saline soils (60 mS/cm <CEpsc< 70 mS/cm), situated in the lower section of the plot in the southeast.
• An area of 2.3 ha, representing 4.6%, is characterized by extremely saline soils (80 mS/cm <CEpsc< 142 mS/cm), situated in the extreme northwest of the plot

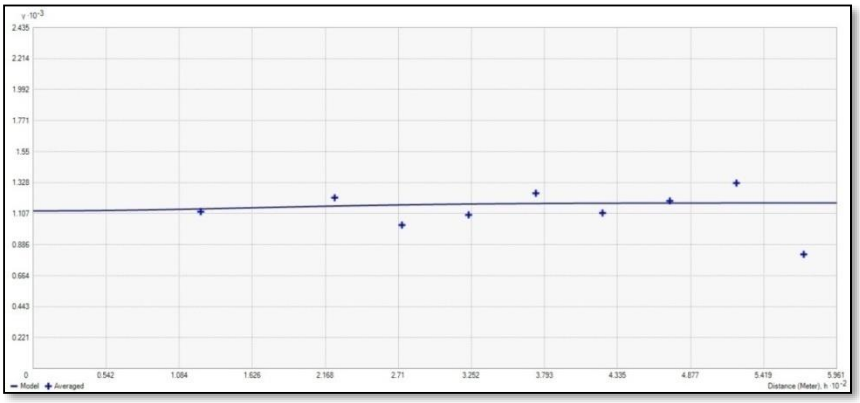
The Gaussian and Stable models, in conjunction with the fitting elements, yielded a mean squared error (RMSE) near 1 and a mean error (ME) near 0

.
Table 10, indicates that the ME values were -0.12 and -0.73, while the RMSE values were 4.19 and 3.55 for the maps depicting the electrical conductivity of the diluted extract (1/5) and the saturated paste. This indicates that the soil salinity is effectively represented by the Gaussian and

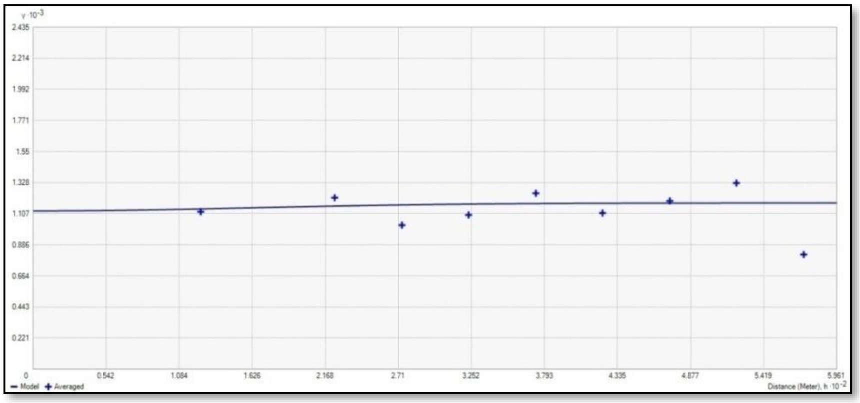
Stable models, and the thematic maps produced through Ordinary Kriging interpolation were dependable and satisfactory

The spatial dependency "range / nugget" for soil salinity fell within the classes (≤ 25% and 25%-75%) (refer to Table 02), demonstrating a strong and moderate spatial dependency, as illustrated in Table 10. Furthermore, the ranges of the chosen models are 397.41 m and 428.46 m, respectively (Figure 15).
An extensive analysis indicates that the spatial interpolation employed to forecast the horizontal distribution of soil salinity is dependable.





(a)



(b)

Figure 15. Gaussian and Stable Semi-variograms of Soil Electrical Conductivity for the Diluted Extract (1/5) and Saturated Paste from the (0-20 cm) Layer.

CONCLUSION

The ECe in coarse-textured soils can be estimated using the models developed in this study using EC (1/2.5, 1/5). According to the soil-water approach, the 1/2.5 ratio produces a more accurate estimate of ECe than the 1/5 ratio, as seen by a lower RMSE value. It should be remembered that any ratio of dirt to water in suspension can be accurate to a certain extent. Soils outside of the research area may not be suitable for use with the models, but they work well with the soils in the study area. In comparison to the 12 models that other scholars have documented, their importance has been highlighted. A thorough investigation confirms the reliability of the spatial interpolation used to predict the horizontal distribution of soil salinity.

Lastly, the equations (ECe = 4.84 * EC1/2.5 - 5.48 and ECe = 7.99 * EC1/5 - 6.31), which allow for the estimate of soil salinity in coarse-textured soils with ECe values ranging from 5.92 to 142 mS/cm, have R^2 values of 0.95.

Cleaning the drainage networks of vegetation on a regular basis is essential for the sustainable management of this palm plantation. There is a clogged drainage bed because these plants make it harder for water to flow and weaken the embankments.

Proper maintenance of the drainage networks is crucial to avoid infiltration caused by water flowing backwards into the plots.

Sand is consistently mixed in with the soil and the top layer is modified to remove the salt crust that forms on top.

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