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Experimental analysis of electrochemical treatment efficiency in enhancing the geo-chemical characteristics of Sebkha soils

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Abstract

Recent climate change has given rise to a growing environmental threat including soil salinity. Sebkha soils are classified as high saline areas usually found in arid and semi-arid regions. The characteristics of these soils make them specially challenging for agriculture, as well as for construction and land management. The Electrochemical Soil Remediation Process (ESRP) represents an eco-friendly and cost-efficient technique for the reclamation of saline soils. Applying soil ESRP is regarded as an effective technique to improve the electro-chemical and geotechnical characteristics of salt affected soils. In this study, Sebkha soil samples collected from the Great Sebkha of Oran (Algeria) were subjected to the electrochemical treatment under controlled laboratory conditions. The experiments were performed in a parallelepiped electrochemical cell under a voltage gradient of 1.5 V/cm during 7 days. Subsequently, oedometer tests were conducted to assess the soil geotechnical parameters. The results of this study show that the electrochemical treatment significantly affects the calcium carbonate content, which decreases as the processing time increases. Nevertheless, the movement of salt ions within the soil matrix induces changes in the electrical conductivity, thus affecting the electrical current flow through the soil samples. Additionally, Changes in soil pH were observed as a result of the electrolysis reactions occurring within the soil during electrochemical process. Moreover, The ESRP modifies the compressibility of the soil samples analyzed in this study through the mechanisms of electromigration and electroosmosis, indicating that ESRP can be considered as an effective technique that improves the chemical and geotechnical properties of Sebkha soil.

Keywords: Sebkha soils; electrochemical remediation; electromigration; salt ions; pH

Introduction

In recent years, droughts and floods have emerged as the principal environmental threats, primarily driven by the rise in global temperatures and increasingly erratic rainfall patterns. These climate events have significant impacts, particularly on soil quality, and result in critical challenges in various regions. One of the most notable effects is the direct influence on soil salinity, which has grown particularly problematic in arid and semi-arid regions, where water scarcity and unpredictable weather patterns already strain agricultural systems. As a result of these changing climatic conditions, the global spread of saline soils has accelerated at an alarming rate over the past few decades (Ait Lahssaine *et al.*, 2025; Bennaceur *et al.*, 2025). This phenomenon has been characterized by an annual growth rate of salt affected soils, estimated to range between 1×10^4 and 1×10^5 hectares, highlighting the urgent need to address the consequences of climate change on land productivity and sustainability (Ma and Tashpolat, 2023; Chang *et al.*, 2025; Lu *et al.*, 2025; Shi *et al.*, 2026).

Soil salinization is a critical factor that contributes significantly to the decline in crop yields and the overall degradation of soil quality. This process disrupts soil structure and nutrient availability, which in turn hampers agricultural productivity and threatens food security (Zohra-Hadjadj *et al.*, 2019; Bessaim *et al.*, 2020; Mostefa *et al.*, 2022; Maliki *et al.*, 2023). However, despite its widespread implications, the majority of research on soil salinity has predominantly focused on the agricultural impact of salinization, often overlooking some of the most saline environments, such as Sebkha areas. Sebkha soils,

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which are found in specific regions, are classified as highly saline, with salinity levels that far exceed those typically encountered in most saline lands. These soils exhibit unique characteristics, and their mechanical and geotechnical properties vary considerably depending on factors like the type of salts present and their concentrations (Hafhouf and Abbeche, 2023). This variability makes Sebkha soils particularly challenging, not only for agriculture but also for construction and land management, as their composition can lead to unpredictable behavior in terms of stability and other engineering properties.

Therefore, it is crucial to expand research into these areas to better understand the full scope of salinity issues and their broader environmental and economic impacts. Salinization phenomenon leads to soil erosion and dispersion, inducing poor load-bearing capacity of soils, making them inappropriate for construction (Abuelgasim and Ammad, 2019). Moreover, research reported that the Sebkha soils exhibit very low shear strength, excessive sensitivity to moisture variation and weakened natural strength capacity. The binding materials that connect the Sebkha grains, namely calcite and gypsum are dispersible in contact of water. As a result, Sebkha soils become vulnerable to collapse when exposed to humidity (Al-Homidy *et al*., 2017).

Researchers and engineers have attempted to improve the properties of weak Sebkha soils in view to making them more stable and suitable for construction, using various enhancement methods (Hamid and Alnuaim, 2023). Mechanical stabilization methods have been employed such as installing stone columns, preloading, dynamic compaction, and vibroflotation, in order to enhance the soil's load-bearing capacity and reduce its susceptibility to settlement (Arifuzzaman *et al.*, 2016; Dhowian, 2017). On the other hand, chemical stabilization techniques were applied incorporating Portland cement or lime, so that they modify the soil's composition, improve its strength, and reduce water-soluble salts, thereby mitigating the effects of salinity (Al-Amoudi, 2002; Mohamedzein and Al-Rawas, 2011; Al-Homidy *et al*., 2017). Besides, geotextiles were applied for Sabka soil stabilization, providing reinforcement and improving soil structure by preventing the movement of fine particles (Ghadir and Ranjbar, 2018; Abdullah *et al*., 2020; Hamid and Alnuaim, 2023; Hafhouf and Abbeche, 2023).

In recent years, the electrochemical soil remediation process (ESRP) has emerged as a highly promising alternative for improving saline soils (Zohra-Hadjadj *et al.* 2019; Ait Ahmed, 2020; Hadjadj *et al*., 2022; Abou-Shady and Yu, 2023). It is recognized as one of the most cost efficient, non-invasive and innovative technology for improving salt-affected soils. An electric field is used in this environmentally friendly technology for migration and removal of salts in soils, thus reducing salinity levels and improving soil structure. The core concept of the ESRP involves applying an electrical gradient via electrodes inserted into the salt affected soils. Electro-osmosis process (the movement of interstitial pore fluid) and electromigration mechanism (the movement of harmful salts toward oppositely charged electrodes) drive the transport of salts toward the electrodes as depicted in Figure 1 (Acar *et al*., 1993; Abou-Shady 2016; Faisal *et al*., 2018; Abou-Shady *et al*. 2023). The technique has the potential to target specific areas of salinization, making it particularly useful for localized remediation. Furthermore, ESRP can be applied in various types of soils, including those that are difficult to treat using conventional methods. Additionally, it can be implemented without disturbing the surrounding environment, making it suitable for sensitive or protected areas where traditional methods might cause further damage (Hussain *et al*., 2023; Abou-Shady and El-Araby, 2025). Previous studies have highlighted the strong influence of soil texture on the performance of electrochemical soil remediation process (ESRP). Sandy soils, owing to their low cohesion and high permeability, generally facilitate more efficient ion migration and salinity reduction. Conversely, clayey soils exhibit inherent difficulties linked to their dense structure and limited permeability. It is reported that in soils characterized by low salinity levels, the addition of electrolytes was essential to enhance the mobility of ions throughout the soil matrix (Abou-Shady, 2025). This supplementation not only facilitated more efficient ion transport but also helped to maintain the overall effectiveness of the electrokinetic remediation process over time. Furthermore, soil salinity strongly influences ESRP efficiency by affecting ion mobility, with higher salinity enhancing conductivity and key processes like electro-osmosis, electro-migration, and ion desorption, thereby improving salt removal. Nevertheless, Sebkha soils, typical of certain arid regions, have unique properties affecting salinity and contaminant transport, yet research on their electrochemical desalinization remains limited.

The present study aims to uncover how the electrochemical soil remediation process (ESRP) can be applied to extremely saline Sebkha soils, characterized by high moisture sensitivity and low shear strength. Based on samples collected from the Great Sebkha of Oran region (Algeria), the research assesses the impact of ESRP on both

Table 1: Physico-chemical properties of soil

Properties	Soil sample S1	Soil sample S2
Specific gravity (Gs)	2.336	2.503
Size fraction (%)		
• Sand (75 µm to 2 mm)	76.5	49
• Silt (2–75 µm)	12.76	26.58
• Clay (<2 µm)	10.74	24.42
Liquid limit (LL), (%)	27	32
Water content (%)	19	20
Electric conductivity (mS/cm)	10.5	12.2
Methylene blue value (mg/g)	8.4	3.2
$CaCO_3$ (%)	32.4	15.4
pH	7.62	7.74

chemical and mechanical soil properties, with the expectation that the treatment will improve soil stability and consolidation through electrochemical modification. The effects of the electrochemical processing (ESRP) on the properties of high saline soils (Sebkha) have been investigated. The electro-chemical and geotechnical characteristics of the experimental soils were measured before and after remediation process to assess the efficiency of the ESRP method in the reclamation of challenging most saline environments.

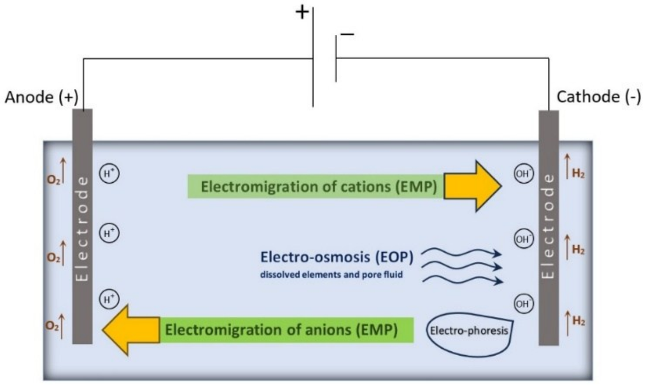


Figure 1: Electrochemical soil remediation mechanisms

Materials and Method

Field soil sampling

The collection of the soil samples was carried out in the Great Sebkha of Oran situated in northwest Algeria (Figure 2). The study area is about 298 km^2, covering a length of 40 km and a width ranging from 9 km of high saline soil. The seasonal climatic variations play a significant role in the fluctuation of soil salinity of this Sebkha. During the summer months, the high rates of evaporation lead to an increase in salt concentration in the soil. As a result, salts gradually accumulate on the surface, eventually forming a visible white saline crust. This accumulation process is particularly pronounced during the hot, dry periods, where the evaporation rate exceeds the rate at which water can infiltrate or move through the soil, exacerbating the buildup of salts.

Figure 2: Location of the study area

The soil samples were collected from two distinct locations: one on the north slope and the other on the south slope. The collection of soil specimens has been carried during the period of dry weather conditions, with no rainfall. They were carefully collected from the field, sealed in protective bags, and subsequently transported to the laboratory for further analysis. Once in the laboratory, the physicochemical properties of the soil were thoroughly assessed to obtain a comprehensive understanding of its characteristics. The results of these evaluations are presented and summarized in Table 1, providing detailed insights into the soil's composition and properties.

Laboratory electrochemical testing setup

The experiments were performed in a parallelepiped-shaped cell, with dimensions 20 cm × 10 cm × 5 cm., made from Perspex. Two copper plate electrodes, each with a cross-sectional area matching that of the cell, were installed. The electrochemical cell is divided into three distinct sections: a central soil compartment, which holds the soil sample, and two separate electrolyte chambers positioned on either side. This configuration allows for the controlled movement of salt ions between the soil and the electrolytes, promoting the electrochemical reactions necessary for the experiment. Additionally, it is crucial for maintaining the integrity of the soil sample while ensuring efficient salts migration and data collection during the testing process. The soil samples were introduced in layers, with each layer being lightly vibrated to help expel any air bubbles trapped within the soil. This step was crucial for ensuring that the soil was free from air pockets, which could otherwise affect the soil's structure and the accuracy of the experimental results. The soft vibration allowed for the particles to settle evenly, promoting a more uniform and compact arrangement, which is important for maintaining consistency throughout the testing process. The experiments were conducted at a controlled laboratory temperature (22 ± 2°C) under a voltage gradient of 1.5 V/cm during 7 days. The electrochemical setup was connected to an electronic system that facilitated the automatic monitoring of data acquisition, including current and electrical potential. The frequency of data logging was fixed to 10 minutes. Throughout the processing period, the electrical current was systematically monitored and recorded at predetermined time intervals using a calibrated digital ammeter. This procedure enabled accurate tracking of current variations, thereby ensuring the reliability and reproducibility of the experimental data. All tests were performed in duplicate under identical experimental conditions to ensure the reliability and reproducibility of the results. A schematic representation of the experimental configuration used in this study is provided in Figure 3.

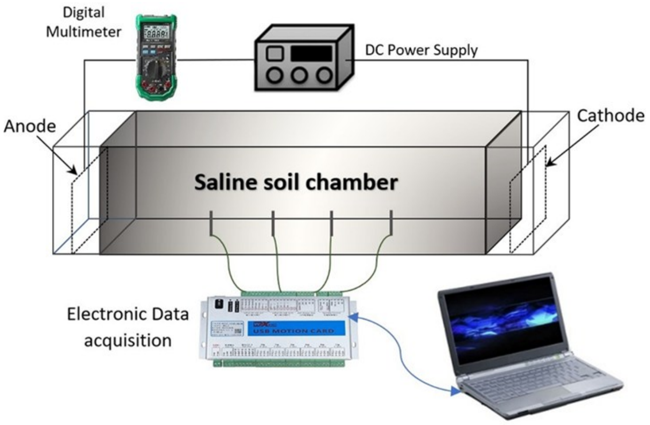


Figure 3: Schematic representation of the electrochemical soil remediation process (ESRP)

Results and Discussion

Effect of electrochemical treatment on Carbonation content of Sebkha soil

According to the volumetric method described in standard NF P 94-048, the carbonate content ($CaCO_3$) for the two soil samples S1 and S2 was measured before and at the end of the electrochemical process. In the procedure, 10 mL of 37% hydrochloric acid (HCl) was mixed by shaking with 1 g of soil samples, which had previously been sieved to a particle size of 0.2 mm. Therefore, the soil reacts with acid, and carbon dioxide (CO_2) is produced, reducing the water level within the measuring tube. As a result, the dissolution of carbonate $CaCO_3$ releases carbon dioxide gas CO_2, as indicated by the following chemical reaction:

$$CaCo_3 + 2HCl \rightarrow CaCl_2 + H_2O + CO_2 \tag{1}$$

Figure (4) represents the variation of calcium carbonate ($CaCO_3$) contents for soil specimens S1 and S2. It can be shown that the electrochemical process affects significantly the $CaCO_3$ contents. The ESRP led to lower measured contents for the two soil samples. The decrease in calcium carbonate content, recorded as a reduction from 32.4% to 22.79% in soil specimen S1 and from 15.4% to 13.35% in soil specimen S2, indicates that the electrochemical treatment effectively modifies the soil's chemical composition. Such a decrease suggests that the process may have induced the dissolution, migration, or reprecipitation of carbonate minerals, contributing to enhanced soil bonding characteristics and improved mechanical stability. Some researchers have observed that, during the initial phase of the electrochemical treatment, soil weakening occurred at the anode as a result of soil acidification, which caused the dissolution of carbonates. However, over the long term, the water content decreases and the released cations from the soil surface are replaced by cations with higher valence and increased concentration as a result of mass action (Azhar *et al.*, 2017). Accordingly, the soil particles form solid and steadier bonds, and the overall strength developing from the coagulation-crystallization process, leading to an enhancement of the soil characteristics. Subsequently, the reduction in calcium carbonate concentration is primarily associated with acid dissolution processes taking place near the anode. During electrolysis, water molecules undergo oxidation, leading to the formation of hydrogen ions (H^+), which lower the pH in the vicinity of the anode. This acidic environment facilitates the dissolution of $CaCO_3$, resulting in a measurable decrease in its content within the treated soil.

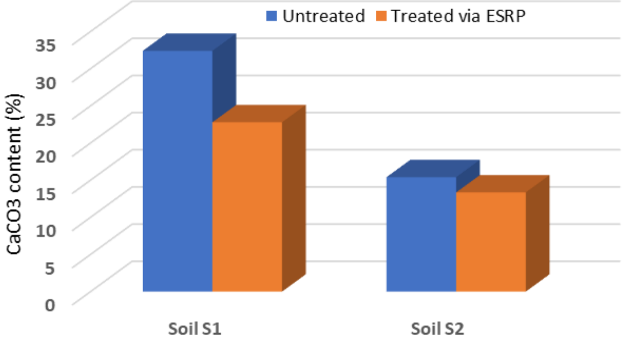


Figure 4: Variation of calcium carbonate contents (*$CaCO_3$*) for Sebkha soils before and after the electrochemical remediation

Evolution of electric current and electrical conductivity of Sebkha soil

The electrochemical process leads to various modifications within the soil matrix, one of which includes variations in electrical intensity. This occurs as the applied electric field interacts with the soil's composition, inducing changes in its physico-chemical properties throughout the ESRP. Figure (5) illustrates the evolution of the electric current amplitude over the duration of the processing time. The data displayed in the graph demonstrates that as the treatment duration progresses, a noticeable decrease in current intensity occurs. The similar trend was observed for both soil samples. This implies that over treatment time, the electrochemical process leads to a reduction in the flow of electrical current through the soil samples S1 and S2, due to changes in the soil's properties and the build-up of reaction products. Throughout the ESRP time, salt ions enclosed in soil pore matrix moved towards the electrodes via electromigration and electro-osmosis mechanisms, resulting in notable decrease in current density (Bessaim *et al.*, 2020; Keraouti *et al.*, 2024). Moreover, the removal of soluble dissolved cationic salts from the soil matrix is driven by the electroosmotic flow, which induces the movement of water and ions. As a result, the electroosmotic flow promotes the elimination of the salts from Sebkha soil, contributing to the overall effectiveness of the electrokinetic remediation process in improving soil characteristics. Additionally, it was observed that the decrease in current density is accompanied by a corresponding reduction in electrical conductivity (EC) from 10.5 to 9 dS/m in soil specimen S1 and from 12.2 to 8.7 dS/m in soil specimen S2, as depicted in figure (6). This suggests that the electrical current flowing through the soil matrix is closely connected to the electrical conductivity (EC) of Sebkha soil. During the electrochemical treatment, the movement of salt ions within the soil matrix induces changes in the EC, thereby affecting the current flow. According to (Gargano *et al.*, 2020), the depletion of mobile ions in soil results in a considerable drop in current density over time, as well as the removal of salts through leaching. This relationship highlights the role of soil composition and ion concentration in determining the soil's conductive properties during electrokinetic processes.

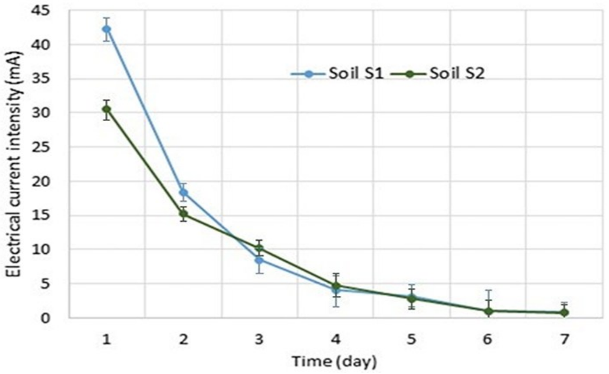


Figure 5: The variation of current intensity during the ESRP

Furthermore, the release of salt ions is fundamentally driven by the electrolysis of water, which involves an oxidation reaction at the anode and the reduction reaction at the cathode, that involved with the electrical gradient. The electrolytic reactions are as follows:

Anode: $2H_2O - 4e^- \rightarrow O_2 \uparrow + 4H^+$ (oxidation) (2)

Cathode: $2H_2O + 4e^- \rightarrow H_2 \uparrow + 2OH^-$ (reduction) (3)

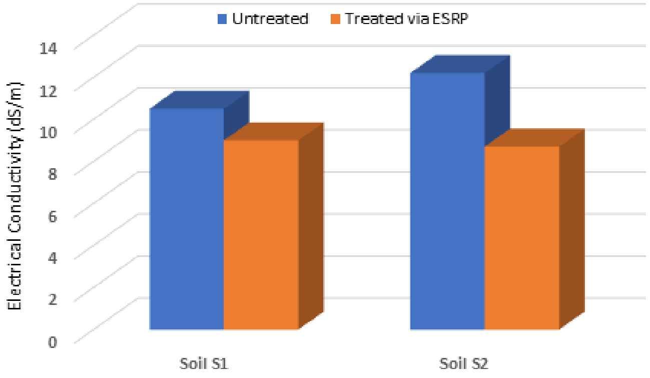


Figure 6: Variation of the electrical conductivity of Sebkha soils before and after the

The dissolution and migration of salt ions in the pore water are improved by the formation of H^+ and O^2 ions close to anode. Nevertheless, it was observed that the soil sodification and the corrosion of anode material were engendered by high number of H^+. According to (Hadjadj *et al.*, 2022), the electrolysis chemical reactions provide the development of pH gradient, producing a basic front close to cathode regions and acid front near anode regions. As a result, the acid pH promotes the solubility and migration of salt ions, thus accelerating their elimination. Accordingly, the drop in both electrical conductivity (EC) and current overtime reflects the gradual removal of easily mobile ions, notably Na^+ and Cl^-, from the soil's pore water. This phenomenon is governed by two coupled electrochemical mechanisms: electromigration, which directs ions toward their respective electrodes according to charge polarity, and electroosmosis, which induces the bulk movement of pore fluid through the soil matrix. As the concentration of these ions decreases, the overall ionic strength of the system diminishes, resulting in reduced EC and current flow.

The pH variation of soil samples S1 and S2 before and after ESRP is illustrated in Figure 7. It appears from this figure that the electrochemical process induced a change in the pH of the Sebkha soil. The pH of soil sample S1 increased from 7.62 before the ESRP treatment to 8.22 after the electrochemical process, while the pH of soil sample S2 rose from 7.74 to 8.55. These changes are the result of the electrolytic reactions that occur in the vicinity of the electrodes, as described previously in Eqs. (3) and (4). During the electrochemical process, the application of an electric field induces ion migration and chemical reactions at the electrode-soil interface. These reactions alter the local chemical environment, which in turn affects the soil pH. Moreover, the extreme salinity of the Sebkha soil leads to a significant compression of the double diffuse layer, which in turn has a significant effect on the movement of the acid front. This compression disrupts the normal flow of ions and alters the dynamics of the electrochemical processes, making it more difficult for the acid front to propagate through the soil. Moreover, under alkaline conditions, a pozzolanic reaction can take place, leading to an improvement in soil strength (Jayasekera and Hall, 2007; Malekzadeh *et al.*, 2016).

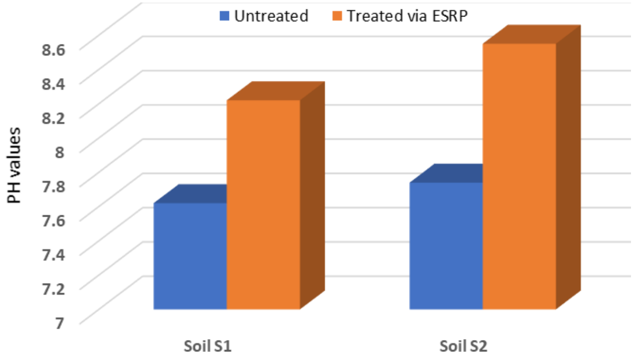


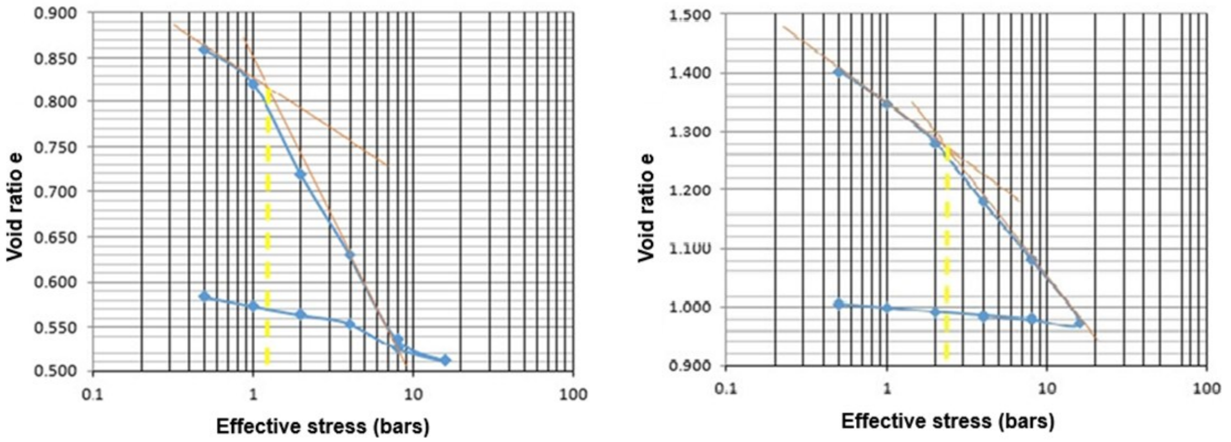
Figure 7: Variation of pH of Sebkha soils before and after the electrochemical treatment

Effect of electrochemical treatment of Sebkha soil on compressibility behavior

Consolidation tests were carried out in a standard consolidometer apparatus according to the standard (ASTM D2435, 2011). At the end of the electrochemical processes, soil samples S1 and S2 were enclosed in metal ring with the dimension of 60 mm diameter and 15 mm thick, and placed between two porous stones covered by filter papers, then placed in the consolidometer apparatus. Water was added so that the samples remained saturated. Pressures varying between 25 and 1600 kPa were applied to the soil samples. The test involves loading the samples with a provided stress increment and recording the compression through a deal gauge at steady duration. The soil samples remained under loading for 24 h for each step. The laboratory consolidation tests were carried out in order to determine soil compression expressed by the presentation of effective stress increment as a function of soil void ratio.

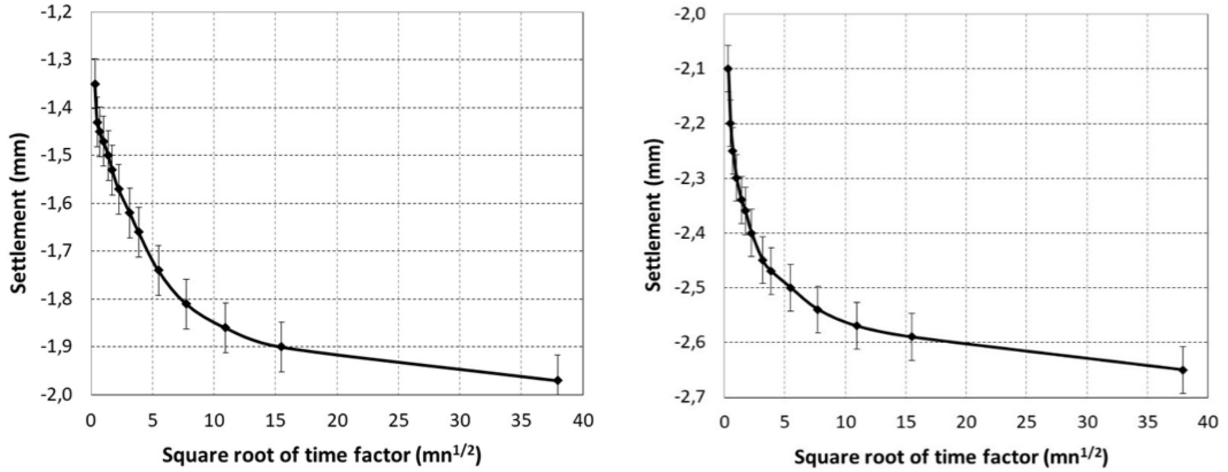
Figure 8 depicts the variation in void ratio as a function of effective stress on a logarithmic scale for applied voltage gradients of 1.5 V/cm. From this figure, it is evident that the void ratio decreases progressively with pressure, corresponding to the ESRP and the applied charges. It can be shown that compression and recompression mechanisms are induced during the consolidation process by the loading and unloading cycles. The removal of pore water and salt cations, caused by the loading action and electrochemical reactions within the soil matrix, leads to a gradual reduction in soil volume. A comparison of the oedometric curves for saline soil samples after 7 days of ESRP reveals noticeable differences in the void indices.

Logarithmic vertical pressure relationship against void ratios was used to determine the compression index Cc, that represents a key parameter defining the rate at which consolidation settlement is expected to occur. It is characterized by the slope of the linear portion of the compression curve. The obtained results classified soils S1 and S2 as low compressible soils, according to (Mitchell, 1993). This classification is derived from the specific characteristics and behavior of soils, providing crucial insight into the soil's compressibility and its behavior under applied loads. Moreover, the change in compression index values can be explained by the increase in double layer thickness, which is influenced by changes in the soil's chemical composition after electrochemical process. As the concentration of pore fluid decreases during ESRP, the attractive forces between the particles also become weaker, leading to a less compact soil structure and contributing to the observed increase in the compression index. These combined effects help to clarify the behavior observed in the soil samples.



(a) **(b)**

Figure 8: Void ratio—logarithm of pressure relationships for ESRP treated soils samples A. Soil S1 ; B. Soil S2



(a) **(b)**

Figure 9: Consolidation curves after electrochemical process A. Soil sample S1 ; B. Soil sample S2

Effect of ESRP on consolidation of Sebkha soil

In engineering approach, consolidation describes the process of the gradual reduction in soil volume over time under increased load, which leads to the expulsion of water from the pore spaces, a decrease in volume, and an increase in effective stress. Figure 9 depicts the consolidation curves for S1 and S2 soil samples after electrochemical process. It can be observed from this figure that a decrease is occurring in two stages: a rapid initial drop, followed by a more gradual decline. The primary consolidation stage is defined by the change in effective vertical stress, which reflects the soil's response to the application of load over time. At this phase, as pore water is gradually expelled, the soil undergoes compression, causing a reduction in volume and an improvement in soil stability. Afterwards, the soil begins a phase of slow consolidation, leading to a decrease of the consolidation deformation. The rate and extent of the consolidation process are influenced by factors such as soil composition, salt concentration and the magnitude of the applied load.

According to the square root of time fitting method, the consolidation rate of soil specimens upon the application of a surcharge load is calculated by the following relation (Taylor, 1948) :

$$c_v = \frac{h^2 T_v}{t_{90}} \qquad (5)$$

Where t_{90} indicates the time to complete 90% of the consolidation, t_v represents the time factor (0.848 from Terzaghi’s theory) and h is the drainage path, which may be taken as half the thickness of the sample.

The variation in the consolidation rate of the Sebkha soil specimens after the ESRP is attributed to the variation in the physicochemical parameters, namely salt concentration and consolidation pressure, that lead to modification in repulsive force between soil particles. As a result, soil particles move to a narrower gap, leading to higher consolidation rate. Furthermore, it was observed at the end of the electrochemical process that the driest region in both soil samples S1 and S2 develops near the anode, involving elevated pre-consolidation pressure. Accordingly, it can be concluded that the pre-consolidation pressure is enhanced by electroosmotic dewatering. A similar finding was reported by Jayasekera (2015 and Hadjadj *et al.*(2022). The electrochemical process (ESRP) modifies soil compressibility by driving the mechanisms of electromigration (EMP) and electroosmosis (EOP). The reduction in moisture content due to EOP leads to decreased soil compressibility. Moreover, the migration of salt ions through EMP and EOP, leads to an improvement in soil strength across three mechanisms: cation substitution, precipitation and mineralization of soil species in the pore fluid (Azhar *et al*., 2016). The electrochemical reactions induce changes in soil’s chemistry, which subsequently promote cementation between soil particles during the electrodeposition process, resulting in significant improvements in shear strength and engineering behavior of Sebkha soil.

An explicit comparison of the two soil specimens is carried out in this section, in order to highlight the contrasts in their responses under the applied experimental conditions. The discrepancies observed between their behaviors can be largely explained by their distinct initial properties, which include differences in mineralogical composition, grain size distribution, and chemical content, as reported in table 1. The higher initial salinity and mineralogical composition of S1 significantly influenced its electrochemical and geotechnical behavior. Specifically, these properties facilitated a more substantial drop in electrical current during the electrokinetic process, while also affecting its compressibility characteristics. Conversely, S2 exhibited a less pronounced current decrease and responded differently in terms of compressibility, highlighting the critical role of initial soil properties of high saline soils in governing electrochemical and mechanical responses. By comparing the two soil specimens, it becomes evident that the performance and outcomes of ESRP are inherently site-specific. The initial soil characteristics, ranging from clay fraction and texture to salinity levels and mineral content, directly influence how effectively ions are mobilized, water is transported, and soil structure responds under the applied electric field. This finding is particularly significant for field applications, as it underscores the necessity of adapting treatment protocols to the specific geochemical and physical conditions of each site to maximize remediation effectiveness.

Conclusion

This study investigated the impact of the electrochemical treatment ESRP on the characteristics of Sebkha saline soils. To this end, a laboratory electrochemical setup was developed and the electro-chemical and geotechnical tests were performed on the two soil samples collected from the study area. The following conclusions were drawn from the results.

- The electrochemical treatment has a significant effect on the calcium carbonate content. The latter decreased with increasing time processing. Additionally, it appears that over treatment time, the

ESRP leads to a reduction in the flow of electrical current through the soil, due to changes in the soil's properties and the build-up of reaction products.

- During the electrochemical process, the movement of salt ions within the soil matrix induces changes in the electrical conductivity. Moreover, the electrolysis chemical reactions that involved with the electrical gradient, provide the development of pH gradient.
- The pre-consolidation pressure is enhanced by the electroosmotic dewatering, and the rate and extent of the consolidation process are influenced by ESRP and the magnitude of the applied load.
- the migration of salt ions through Electromigration and electroosmosis, leads to an improvement in soil strength. Moreover, it has a pronounced effect on soil compressibility. Thereby, the electrochemical reactions alter the soil's chemistry, resulting in significant enhancements in the geotechnical behavior of Sebkha soil.

In conclusion, improving the electro-chemical and geotechnical characteristics of highly saline soils similar to the Great Sebkha of Oran soil using the electrochemical remediation process is efficient. Nevertheless, determining the specific season when the Sebkha experiences lower salinity levels can provide substantial benefits from multiple angles, including technical, environmental and economic perspectives. Such insights can guide more efficient management strategies. Additionally, more investigations are strongly recommended to improve ESRP using variable voltage gradient and enhancing solutions.

Statements and Declarations

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Conflict of interest statement

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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