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Microstructural Attributes for Soft Soils Affected by Salts During Soaking and Seepage

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Abstract

This study investigates the impact of salts on the microstructure of natural soft soil under water soaking and seepage conditions over specific periods, comparing results to the natural soil in dry state. The soil sample was taken from a study area in central Iraq, south of Babylon Governorate. The research utilizes scanning electron microscopy (SEM) to analyze soil structure changes. The findings reveal that soaking has a slow effect on salt dissolution, gradually altering the soil's chemical composition and reducing its cohesion. In contrast, seepage accelerates salt removal, with dissolution beginning around 7 days and nearing completion by 30 days. Seepage also has a more evident effect on soil cohesion and bearing capacity compared to soaking, suggesting that improved drainage systems are crucial to prevent rapid soil degradation. SEM results further show that soaking weakens soil structure, increases porosity, and causes general degradation. Seepage causes an irregular cohesion and gradual deformation, which significantly affects soil stability under varying loads. This study provides novel insights into the effects of salt dissolution on soil behavior under different conditions, pointing out the need for better soil management in areas with saline soils.

Keywords: EDX; SEM; TDS; Salt of Soil; Soft Soil; Seepage.

1. Introduction

Soft soil is defined as soil that can support its own overburden weight, with any extra load causing significant deformation. This group also includes soils that have not fully consolidated under their own weight [1]. Soft soil, characterized by its local existence, high water content, considerable compressibility, and low strength, is widely found in the various regions of Iraq, practically in the southern and middle Euphrates regions [2].

The investigation of soft soils affected by salts is a crucial field within soil mechanics and geotechnical engineering, particularly due to the unique challenges posed by saline environments. In Iraq, the major salts present in saline soils are sodium chloride (NaCl), calcium chloride ($CaCl_2$), magnesium chloride ($MgCl_2$), potassium chloride (KCl), gypsum ($CaSO_4.2H_2O$), sodium sulphate ($Na_2SO_4.10H_2O$), and magnesium sulphate ($MgSO_4$) [3].

Some previous studies have dealt with this topic, including Fattah et al. (2022) [4]. Investigates the leaching behavior of collapsible gypseous soils from Baher Al-Najaf in Iraq, examining samples with varying gypsum content. Using X-ray fluorescence and scanning electron microscopy (SEM), the study assesses the impact of leaching on soil properties, such as surface matrix and chemical composition. Results indicate that gypsum solubility increases with higher gypsum content and extended leaching, causing significant changes in the soil's microstructure. This includes greater voids and

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cavities, reduced structural binding, and increased collapsibility. Their study highlights the challenges of engineering on gypseous soils and provides insights into mitigating their structural issues.

Estabragh et al. (2024) [5] presented a comprehensive analysis of the effects of salt concentration on the microstructural attributes and engineering properties of clay soils. They present a clear relationship between the Atterberg, specifically the liquid limit (LL) and plasticity index (PI), and varying salt concentrations. As the salt concentration increases, the LL and PI decrease, indicating a significant alteration in the soil's plasticity and workability. Their study highlights the impact of salt concentration on the maximum dry unit weight and optimum water content of the soil. The findings reveal that the maximum dry unit weight increases with higher salt concentrations, while the optimum water content decreases, which suggests that saline conditions enhance the compaction characteristics of the soil, which is crucial for engineering applications.

Adeyemo et al. (2021) [6] investigated the intricate relationships between soil salinity, sodicity, and hydraulic conductivity, particularly in semi-arid environments. They emphasize critical knowledge gaps in the understanding of how these factors interact under varying wetting conditions. Their key insights presented in the research are the combined effects of salinity and sodicity on the saturated hydraulic conductivity of soils. These factors can lead to hysteresis in hydraulic conductivity, meaning that the soil's response to changes in moisture content is not linear and can differ based on the direction of wetting and drying cycles. This finding was significant as it suggests that conventional models of soil hydraulic behavior may not adequately predict the performance of soils under fluctuating moisture conditions, especially in regions subjected to seasonal rainfall. It was concluded that variations in solution composition affect soil hydraulic conductivity, as different salts influence soil structure and function. In addition, hydraulic pressure gradients and soil aging can further reduce hydraulic conductivity over time, particularly with specific clay mineralogy.

Xu et al. (2024) [7] investigated the permeability and microstructure of sodic-saline loessal soils under varying initial water contents (IWC) and salt contents (ISC) using constant head permeability tests and SEM analysis. Their results revealed that permeability decreases exponentially over time, with lower IWC and ISC leading to reduced maximum permeability (Kmax), while relatively stable permeability (Krs) remains less affected. Microscopic observations showed that low IWC samples experience reduced porosity, pore size, and directionality, while high IWC samples display an initial increase in these parameters followed by a decrease. Drying disrupts the microstructure of low-IWC soils, reducing aggregate stability, while higher salt content strengthens cementation but also forms rapid permeability pathways. These findings are crucial for managing soil erosion and geo-hazards in saline regions amid climate change.

Obead et al. (2023) [8] concluded that the combined salts in soil mass, particularly gypsum dissolution, significantly alter soil permeability, increasing void spaces and water infiltration. Studies have also indicated that the strength parameters of gypsiferous soils are susceptible to gypsum content and moisture conditions. In particular, soils with moderate gypsum content have demonstrated temporary improvements in cohesion after leaching, while higher gypsum concentrations result in significant strength loss due to excessive dissolution. Additionally, past research has highlighted the role of initial gypsum content in modifying internal friction angles, with lower gypsum percentages leading to reduced shear strength under dry and wet conditions. These findings align with the current study’s observations regarding permeability variations and strength parameter shifts due to gypsum dissolution and moisture exposure.

Studied the relationship between unconfined compressive strength and deformation characteristics of chlorine saline soil, highlighting how water and salt content play major roles in determining the mechanical behavior of these soils. They emphasize the necessity of conducting a series of physical and mechanical tests to fully comprehend the intricate interactions between varying salt compositions and moisture levels and propose a formula that accounts for various factors, including salt content, water content, dry density, and overlying load, to better predict the behavior of saline soils under different conditions. Their approach highlights the complexity of saline soil mechanics, suggesting that understanding is essential for effective geotechnical applications in regions affected by salinity, particularly in the context of designing foundations and other structures on soft, saline-affected soils.

Huang et al. [9] highlighted the importance of unloading stress paths in soft soil behavior, often neglected in numerical analyses. Research on Shenzhen soft soil shows that unloading ratios influence deformation, cohesion decreases, and the internal friction angle remains stable. Findings emphasize the need to incorporate unloading parameters for accurate excavation design.

Liu et al. (2022) [10] have explored the use of industrial calcium-containing waste to solidify municipal sludge for landfill liner applications. Findings indicates that such solidified sludge materials (SSM) exhibit high strength and low hydraulic conductivity, making them effective barriers against water seepage. Studies have shown that hydration reactions involving SiO_2, Al_2O_3, and CaO lead to the formation of dense C-S-H and C-A-S-H gels, enhancing mechanical properties. Optimized mixtures of sludge, desulfurized gypsum, fly ash, and slag, along with $Ca(OH)_2$ as an activator, further improve strength and permeability, demonstrating the viability of SSM as an alternative landfill liner material.

Liang et al. [11] studied the use of land subsidence in soft soil areas as a major geological issue, particularly in coastal regions. The microstructure of soft soil, such as in Guangzhou's Nansha District, reveals honeycomb, granular, and flocculent structures with limited macropore continuity. Findings strengthened that siltation affects consolidation settlement, emphasizing the need for targeted prevention strategies.

He et al. [12] examined the impact of leachate seepage on the strength properties of landfill cover materials. The study shows that solidified sewage sludge, stabilized with soda residue, slag, and quicklime, initially gains strength but weakens over time due to leachate exposure. Hydration products such as calcium silicate hydrate and ettringite contribute to strength, while pore structure changes and pollutant stabilization affect long-term performance. Results show the need to consider real landfill conditions when assessing cover material durability.

A major gap in the literature is the lack of research on the combined effects of multiple salts on soft soils under soaking and seepage. Existing studies often focus on individual salts or do not distinguish between soaking and seepage effects, which are critical in saline environments. Additionally, long-term changes in soil properties, such as microstructure and permeability, under extended vulnerability to salts are underexplored. Research also neglects the impact of soil aging and varying moisture levels on hydraulic conductivity and soil stability, limiting the applicability of present findings to saline conditions. Hence, the aim is to explore the microstructural attributes of soft soils subjected to different salts during soaking and seepage conditions, to evaluate how various salt compositions influence soil permeability and the interactions between hydraulic pressure gradients in saline environments.

2. Material and Methods

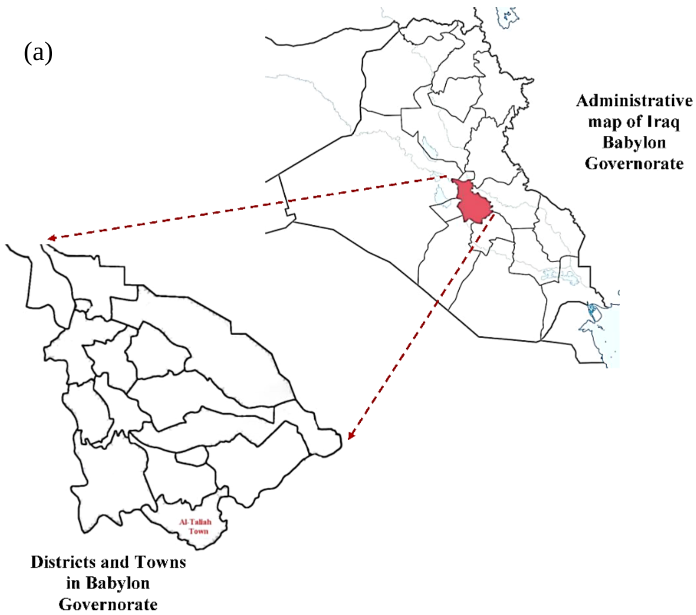
2.1. Study Area

The Babylon governorate is located in the central part of Iraq. The governorate is surrounded by the governorates of Anbar in the west, Baghdad in the north, Qadisiyah in the south, and Muthanna in the southeast. This governorate is located between latitudes 32° and 33.25° north and longitudes 44° and 45° east. The geological formation of the Mesopotamian alluvial plain and the unique climatic conditions in the region lead to the salinization of the soil in different parts of Iraq. The soil types in the governorate are mainly divided into three categories: soft soil mixed with sand deep under the earth, salty soil that faces the first level of cultivated land, and land with a mixture of salty and soft soils [13]. The soil samples were extracted from three locations in Al-Taliah town, affiliated with the Al-Hashimiya district, south of Al-Hilla city. Table 1 presents the geographic data for each site, while Figure 1 illustrates the study area map.

Table 1. Geographic data for soil samples in each site

Site No.	Depth (m)	Elevation [a] (m)	Distance (Km)	Coordinates
1	0.30	23	9.87	32°12'27.89" N 44°42'31.17" E
2	1.50	23		32°10'7.72"N 44°44'0.13"E
3	2.75	21	3.92	32°11'6.07"N 44°43'31.04"E

[a] Ground surface as per GPS data.



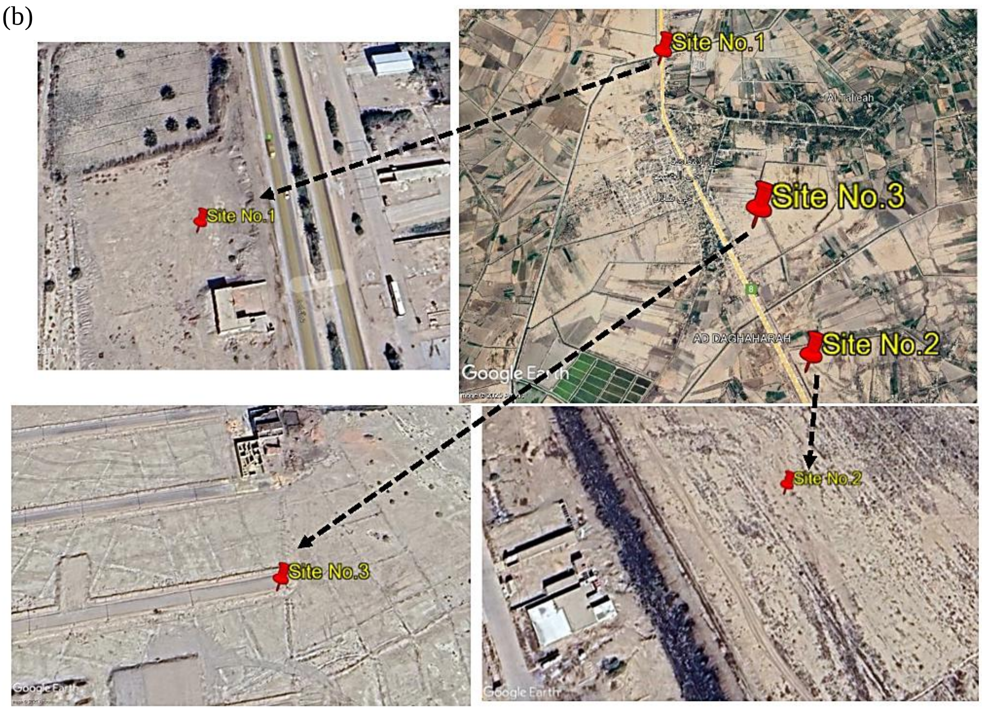


Figure 1. Map for the study area (a) general view for study area, and (b) locations for soil sampling sites

Samples were manually extracted after removing the surface soil layer (30 cm thick) to get rid of impurities and organic matter. The extracted disturbed samples were stored in heavy-duty nylon bags until experimental testing started.

2.2. Experimental Methodology

Experimental work was performed on the soft soil that was affected by salt samples. This program involves leaching under soaking and seepage conditions. The methodology proposed by the researchers [4, 8, 14] has been adopted with minor adjustments, and the modified Figure 2 provides a visual representation of this approach.

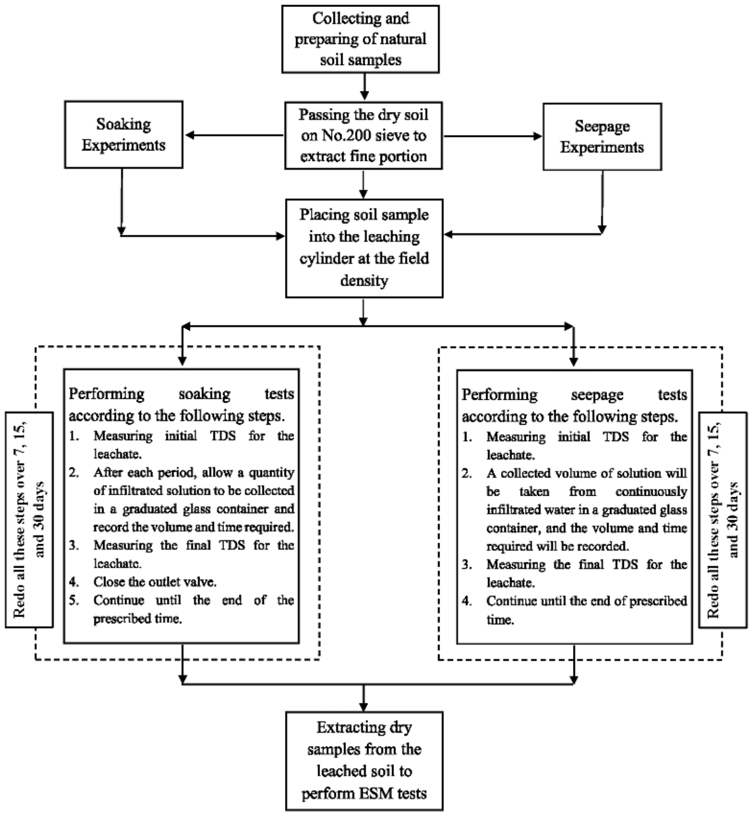


Figure 2. Leaching methodology adopted in this study

A leaching test on six soil samples was performed using a cylindrical parameter by infiltrating tap water through the sample at a hydraulic gradient of 0.5 m static water-head for the soaking condition and a hydraulic gradient of 3.34 for the seepage condition simultaneously, as shown in Figure 3. The SEM tests were conducted at multiple time intervals to observe microstructural changes over time. Specifically, analyses were performed at the final stage of soaking and seepage at 7, 15, and 30 days. This approach allowed for a comparative evaluation of how soil microstructure changed under both conditions, providing understanding into the progressive effects of continued water contact.

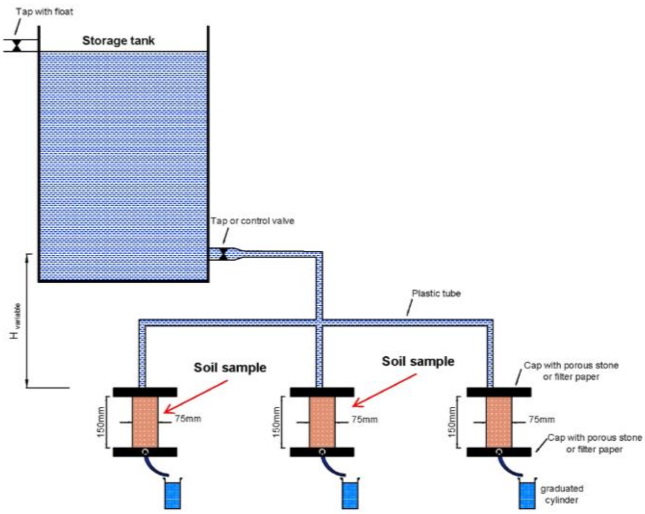


Figure 3. Device for the soil sample under soaking and seepage conditions

3. Results and Discussion

3.1. Physical and Chemical Properties of the Soil

Table 2 gives the basic geotechnical properties of the soil samples. The particle size distributions were conducted per specification ASTM D422 (sieve analysis and hydrometer analysis). The unified soil classification system (USCS) made soil classifications.

Table 2. Parameters for the soil particle size distribution

% Gravel	% Sand	% Fine	D_{50} mm	LL[a]	PL[b]	USCS
0	46.77	53.23	0.103	25.32	21.23	ML[*]

[a] Liquid limit, [b] Plastic limit, [*] Low-plasticity silt.

Figure 4 shows the soil particle distribution for a soft soil sample after randomly extracting it from samples taken from the selected locations in the study area.

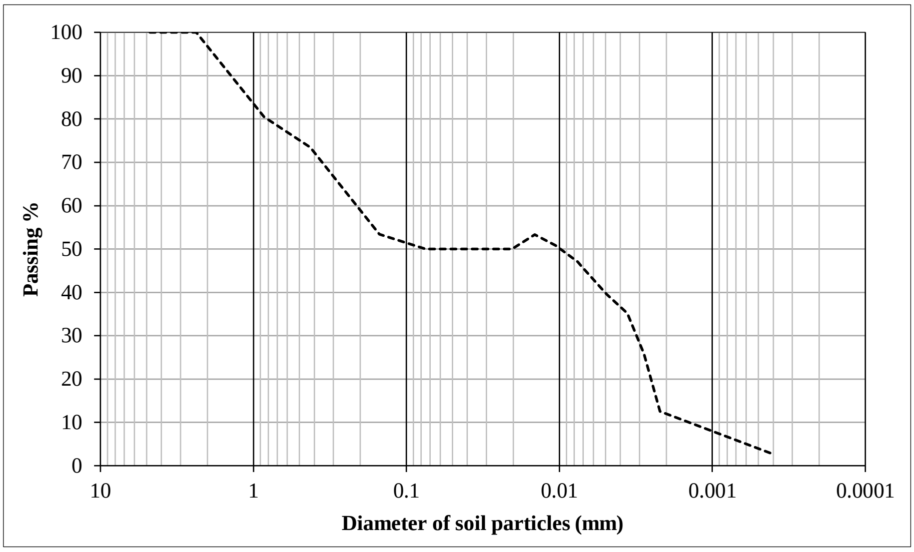


Figure 4. Distribution of soil particles sizes

3.2. Results of Energy Dispersive X-Ray Spectroscopy (EDX)

Figure 5 shows the Energy Dispersive X-ray Spectroscopy (EDX) results for the natural dry soil.

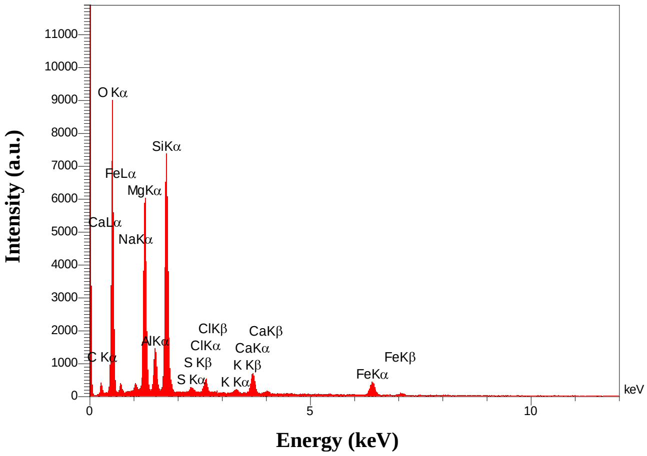


Figure 5. EDX-spectrum analysis for sample of dry soil

The analysis of major peaks corresponded to the higher concentration of elements. In Figure 5, there are clear peaks for elements such as calcium (Ca), sodium (Na), and sulfur (S), indicating that the sample contains concentrations of salts such as significant calcium sulfate ($CaSO_4$) and sodium chloride (NaCl). While the small peaks represent other elements present in lower concentrations, such as magnesium (Mg), potassium (K), and silicon (Si). The presence of silicon reflects the mineral components present in the soil.

The presence of peaks for sulfur and sodium indicates salt contamination or accumulation due to saltwater intrusion or high groundwater levels. (Ca) with (S) may indicate the presence of gypsum as a component. Peaks for (Mg) and (K) are probably associated with the presence of extra mineral compounds such as carnallite or dolomite. The EDX-spectrum tests were performed for 7, 15, and 30-day soaking periods, as shown in Figures 6 to 8, to investigate the changes due to water soaking on the microstructural composition of samples of soft soils affected by salts.

From Figure 6, the higher peaks appear for elements such as (Ca), (S), (Na), (Mg), and (Si). These concentrations indicate the presence of salts (sulfates and chlorides) and minerals (silicates) in the soil. Results of Figure 7 show that there was a slight decrease in the intensity of the major peaks (especially Ca and S). This indicates the start of dissolution of water-soluble salts and was reflected in a reduction in the concentration of elements associated with the dissolved salts. From Figure 8, the peaks of Ca, S, and Na elements decreased significantly, while there was a slight development of some new peaks. This is attributed to the continued dissolution of salts in water, which reduces their concentrations and increases the relative concentration of some insoluble minerals such as silicon (Si), indicating a redistribution of minerals. Overall comparison refers to the soluble elements (Na, S, Ca) decreasing gradually with increasing soaking duration, while insoluble elements (such as Si) became more evident due to the dissolution of salts. The soil lost large amounts of dissolved salts over time, affecting its stability, and thus the soil became less cohesive after soaking due to the loss of salts. Accordingly, the water soaking contributes significantly to modifying the chemical composition of the soil.

On the other hand, Figures 9 to 11 display the results of EDX-spectrum tests for 7, 15, and 30-day seepage periods under a constant hydraulic gradient of 3.34.

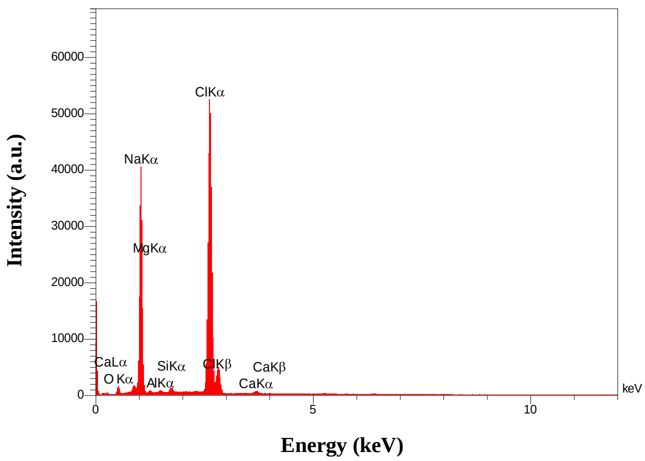


Figure 6. EDX-spectrum analysis for 7-days soaking period

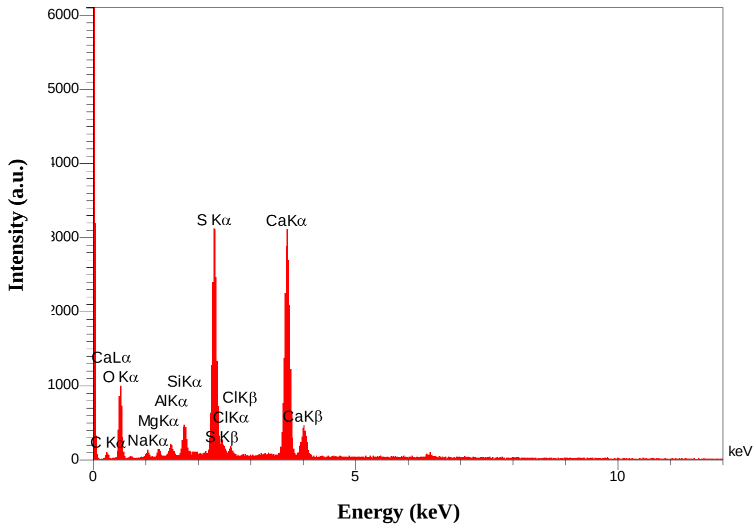


Figure 7. EDX-spectrum analysis for 15-days soaking period

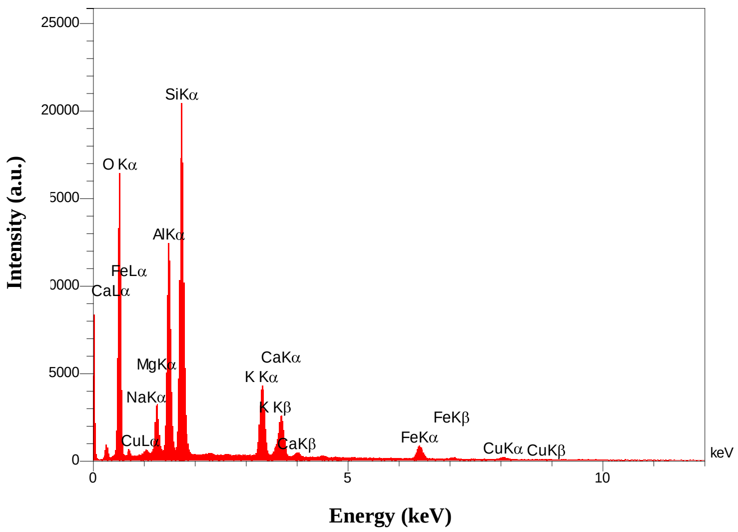


Figure 8. EDX-spectrum analysis for 30-days soaking period

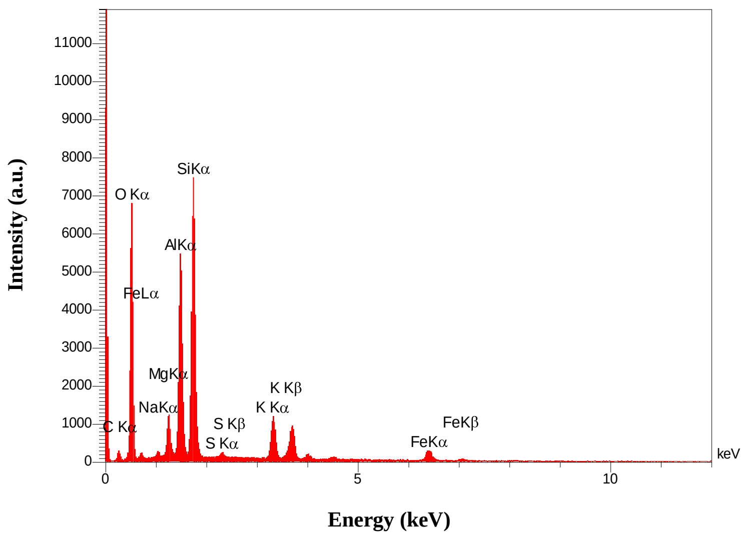


Figure 9. EDX-spectrum analysis for 7-days seepage period

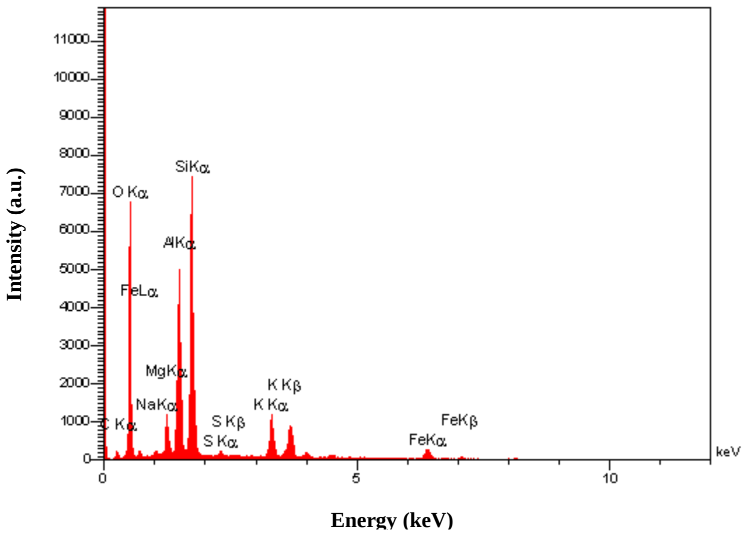


Figure 10. EDX-spectrum analysis for 15-days seepage period

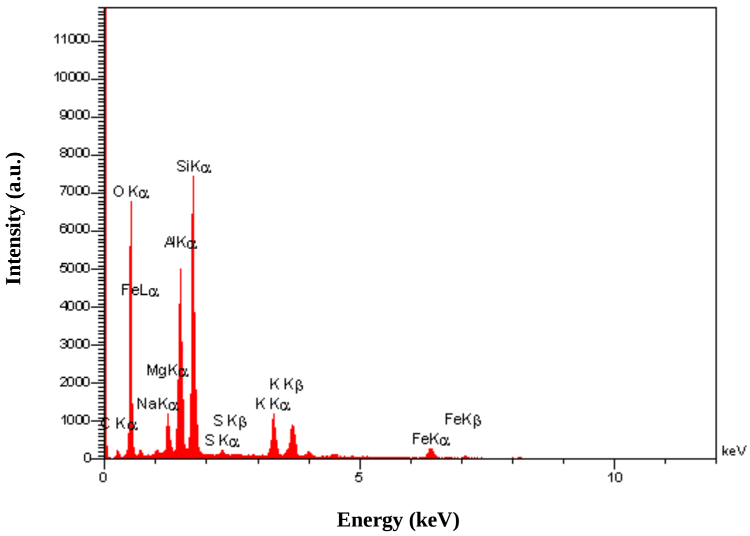


Figure 11. EDX-spectrum analysis for 30-days seepage period

Figure 9 reveals that the major peaks of elements such as sodium, calcium, and sulfur are high, while minor peaks, such as silicon, are starting to arise. This was explained by the fact that the hydraulic gradient gradually dissolves the water-soluble salts, and no significant changes in the stable minerals are observed due to the short time. From the results of Figure 10, a significant decrease in the intensity of the peaks of Na and Ca with a slight increase in minor peaks such as Si. This was due to the effect of seeping water becoming more obvious, as it led to the dissolution and transport of part of the soluble salts. While the insoluble minerals became relatively more concentrated because of the decrease in soluble salts. Figure 11 shows the major peaks, such as Na, Ca, and S, decreased to their lowest levels, while the minor peaks, such as Si, became dominant. This was attributed to the fact that the prolonged seepage period and hydraulic gradient removed most of the soluble salts, and the concentration of fixed (insoluble) minerals became more certain.

As an overall inference for the seepage effect, the results show that the effect of water infiltration under a hydraulic gradient of (3.34) leads to a gradual decrease in the concentration of soluble elements (Na), (Ca), and (S) over time, with a relative increase in the concentration of insoluble minerals (Si). After 7 days, salt dissolution begins to be noticeable, and by 15 days, salt concentrations decrease further, indicating a transitional phase showing a clear dissolution of soluble salts. Over 30 days, salts are almost completely drained, with stable minerals remaining dominant. These changes significantly affect the geotechnical properties of the soil, as a decrease in salt concentration leads to a decrease in cohesive strength and a decrease in the bearing capacity of the soil. In addition, the concentration of insoluble minerals indicates that the soil may retain some of its basic properties despite the loss of salts. These results highlight the importance of designing appropriate drainage systems to minimize the effect of salts on engineering sites and avoid soil degradation over time.

From the Quantitative and Automatic Identification results of EDX-spectrum tests for dry and soaked soil samples, Figure 12 presents the comparison between Weight Percentage (W%) for dry and soaked soil during different periods.

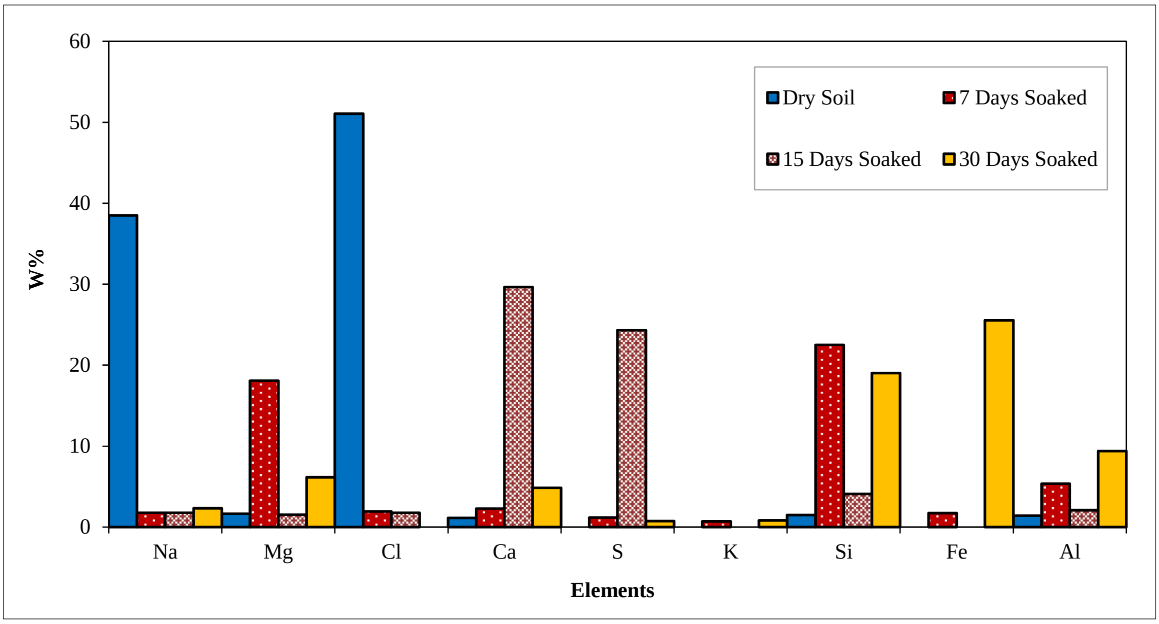


Figure 12. Relationship of W% versus dry and soaked conditions

The percentage change (ΔW%) can be calculated from Equation 1:

$$\Delta W\% = \left(\frac{W_{Dry} - W_{Soaked}}{W_{Dry}}\right) \times 100 \tag{1}$$

where; W_{Dry} is the weight percentage for sample from dry soil, and W_{Soaked} is the weight percentage for sample from soaked soil. Table 3 gives the percentage changes for all soaked samples of soil under consideration corresponding to each element.

Table 3. Results of the weight percentage changes for elements at different soaking periods

Element	Soaked Soil		
	ΔW% for 7 days	ΔW% for 15 days	ΔW% for 30 days
Na	95.4	95.5	94
Mg	53.1	96	84
Cl	95	95.4	100
Ca	94.1	22.9	87.5
S	96.9	36.9	98
K	98.1	100	97.9
Si	41.5	89.3	50.6
Fe	95.5	100	33.7
Al	86	94.5	75.6

The results of Table 3 are evidence that water-soluble elements (such as Na, Cl, and K) were effectively dissolved by soaking, with Cl and K showing very high dissolution rates of up to 100%. Fixed elements (such as Fe and Al) showed relative stability with a gradual decline, reflecting their slow release from the soil. Mg and Ca showed complex interactions due to the dissolution of the metals and their interaction with water, resulting in variations in concentrations over time. The results indicate the efficiency of soaking in removing soluble salts with limited effect on more fixed metals. Figure 13 shows a relationship between W% for dry and seepage during various periods.

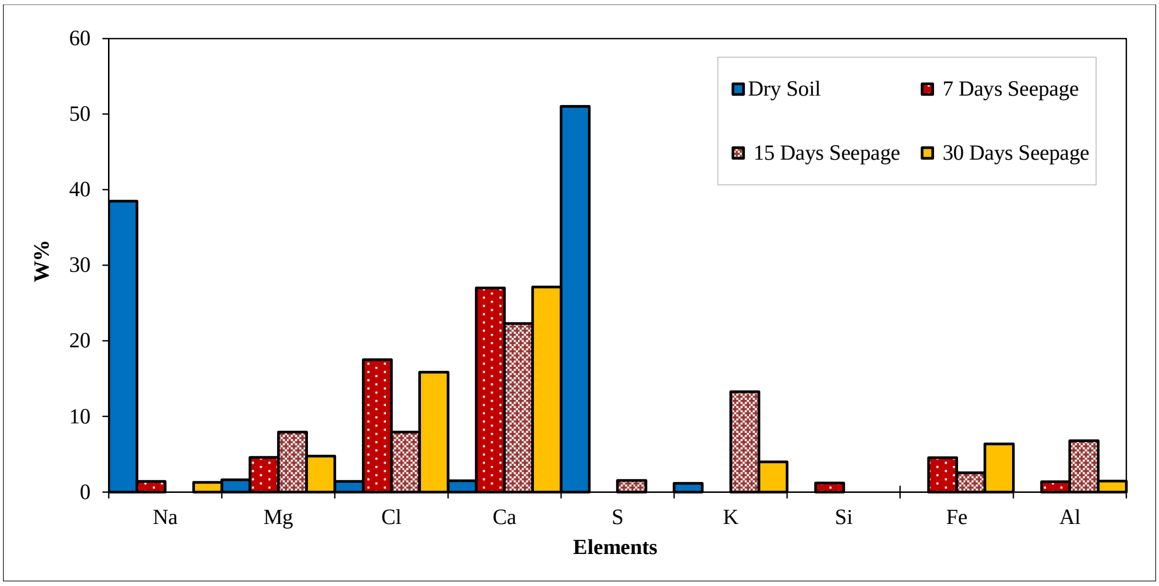


Figure 13. Relationship of W% versus dry and seepage conditions

According to Figure 13, the changes in (W%) of elements indicate the effect of seepage conditions on the soft soil elements was obvious. In the dry soil, the highest percentages are for elements chlorine (Cl) and sodium (Na), reflecting the saline nature of the soil. Under 7-day seepage conditions, a significant increase in the percentages of silicon (Si) and aluminum (Al) was observed, indicating the dissolution of salts and the precipitation of silicates. After 15 days, the percentages of magnesium (Mg) and calcium (Ca) increase, indicating the redistribution of dissolved minerals. After 30 days, silicon returned to dominance, with elements such as potassium (K) and calcium (Ca) remaining in relatively constant percentages, indicating that the soil was partially stabilized because of continuous seepage. These changes reflect the chemical reactions and mineral changes caused by prolonged exposure to water. The percentage changes (DW%) for samples under seepage are given in Table 4.

Table 4. Results of the weight percentage changes for elements at different seepage periods

Element	Under Seepage Soil		
	ΔW% for 7 days	ΔW% for 15 days	ΔW% for 30 days
Na	96.3	100	96.7
Mg	88	79.4	87.6
Al	54.5	79.4	58.8
Si	29.9	42	29.5
Cl	100	96	100
Ca	100	65.5	89.6
S	96.9	100	100
K	88.2	93.4	83.5
Fe	96.4	82.3	96.2

The results in Table 3 show clear changes in the weight percentage of elements under the seepage condition for 7, 15, and 30 days compared to their dry state. Water-soluble elements such as Na and Cl show relative stability over time due to the saturation of the medium, while Mg and K show initial dissolution followed by an equilibrium between dissolution and precipitation. On the other hand, elements such as Al and Si gradually decrease due to chemical reactions related to pH and salt quality. As for Ca and Fe, they were significantly affected by dissolution and precipitation processes, which leads to fluctuations in their weight percentage. These results highlight the important role of the properties of each element in determining its behavior under different seepage conditions.

Based on the results of the present study, regarding the natural soil, Liang et al. [11] identified intrinsic vulnerabilities-salt dissolution and silting-that degrade stability, whereas the engineered solutions [12, 10, 15] mitigate these risks through chemical stabilization (hydration products like C-S-H gels) but face challenges from prolonged environmental experience (e.g., leachate corrosion). These studies align with these findings, bridging natural degradation mechanisms (e.g., elemental dissolution, silting) and engineered solutions (e.g., additive stabilization). However, microstructural analysis (EDX) is critical for detecting failure modes (salt loss, pore blockage) and validating stabilization ability.

Finally, the comparison between the results of the soaking EDX and the seepage EDX tests showed that soaking causes rapid and efficient dissolution of soluble salts, weakening the bonds between soil particles and increasing the compressibility of soft soils and rapid loss of geotechnical stability. Seepage causes gradual changes in the balance between dissolution and precipitation, reducing the immediate impact on geotechnical properties, but may lead to long-term changes in soil stability and structure due to slow chemical reactions.

3.3. Results of Electronic Scanning Microscope (ESM)

Figure 14 displays the ESM photo of a dry soil sample of the soft soil type affected by salts.

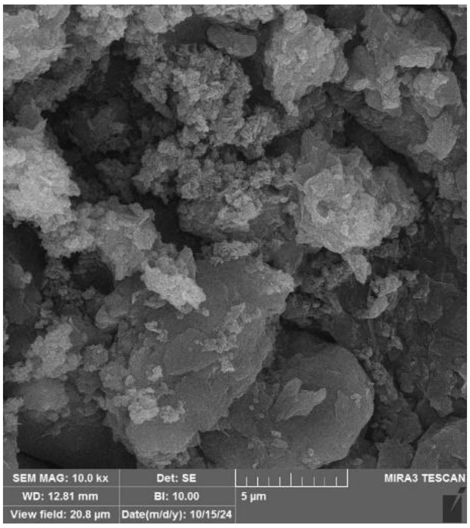
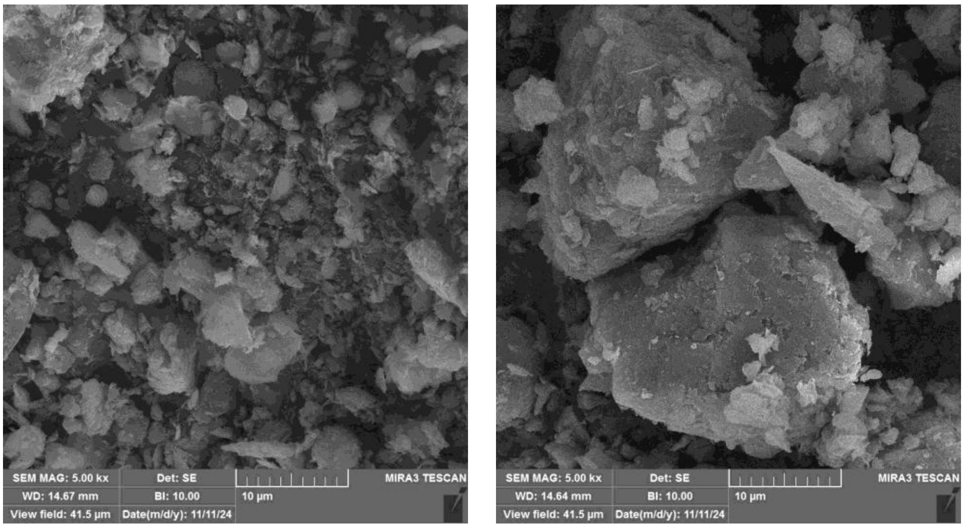


Figure 14. SEM photo for dry soil sample

As revealed in Figure 14, the engineering characteristics include irregularly shaped grains and low porosity due to the accumulation and deposition of salts between the grains, which leads to a reduction in permeability and an increase in hardness. Also, the effect of salts on the adhesion of the grains and the formation of sharp-edged crystals, with the presence of erosion of the edges in some grains, affects the general structure of the soil and makes it mechanically weak and susceptible to high compression.

In order to investigate the effect of the leaching process, whether by soaking or seepage, electron scanning microscope (SEM) photos were taken of soil samples at specific intervals, as shown in Figures 14 to 16, respectively.

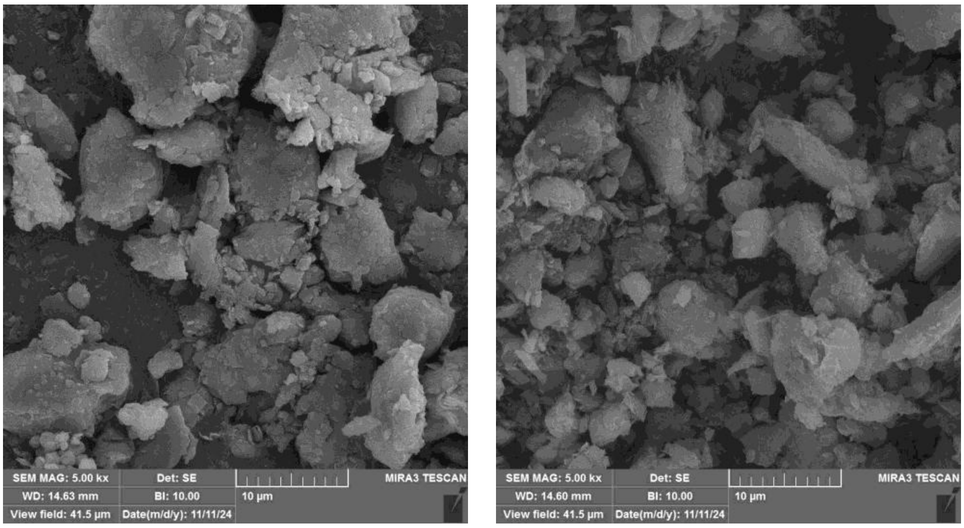
Figure 15 shows obvious effects on the engineering properties of the soft soil after soaking and seepage for 7 days. From Figure 15-a, water produces the disintegration of the general structure of the soil and increased porosity due to the dissolution of the bonds between the particles and the dissolution of salts, which led to a decrease in mechanical stiffness and an increase in the probability of collapse under loads. The disintegration of the particles also reflects the weakness of the overall structure of the soil. From Figure 15-b, a different effect appeared as the gradual seepage contributed to the accumulation and concentration of salts around the large particles, which led to increased cohesion in some areas but weakened the overall cohesion between the small particles. The edges also showed more obvious signs of erosion, with gradual structural distortion due to the uneven distribution of salts.



(a) under soaking for 7-days (b) under seepage for 7-days

Figure 15. ESMs for leached soil sample under soaking and seepage for 7-days

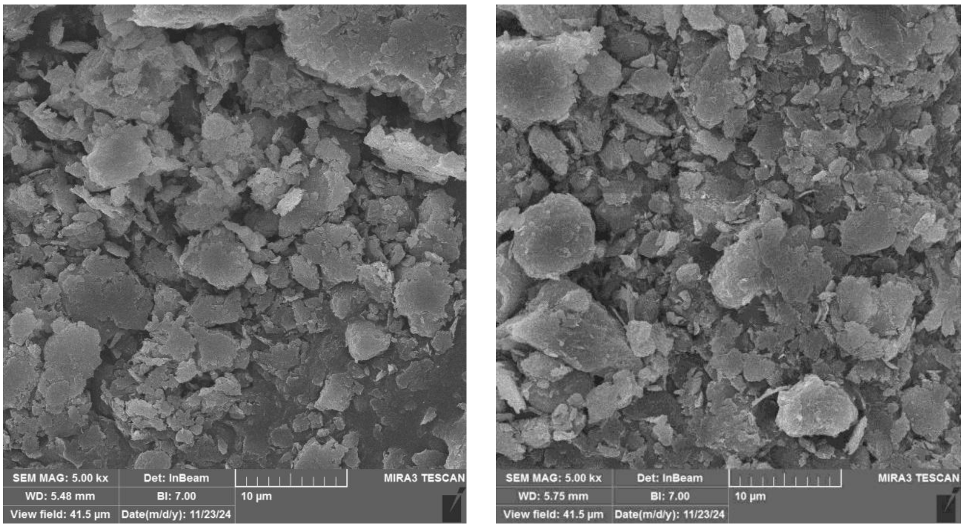
From Figure 16-a, evident developments can be observed after 15 days of soaking; greater disintegration of the grains was observed with a noticeable increase in porosity and clear erosion of the edges, reflecting the continued process of disintegration of the bonds between the grains by water and the dissolution of salts more widely. This leads to severe mechanical weakness and a decrease in the stability of the soil in general, making it more susceptible to collapse under any additional load. For Figure 16-b, a higher concentration of salts was observed around the larger grains with the appearance of sharper salt crystals, which increases the cohesion of some grains but also leads to larger deformation of the overall soil structure. Erosion and uneven deformation continue due to the distribution of salts, which increases the possibility of gradual deformation or partial collapse of the soil under stress. Overall, the deformations vary across soil samples due to differences in salt content and structure, showing no consistent pattern but a general trend of gradual weakening and uneven settlement.



(a) under soaking for 15-days (b) under seepage for 15-days

Figure 16. ESMs for leached soil sample under soaking and seepage for 15-days

After 30 days of soaking and seepage, there were obvious differences in the engineering properties of the soil, as shown in Figures 17-a and 17-b. In the case of soaking, prolonged exposure to water resulted in almost complete disintegration of the grains and a significant increase in porosity, resulting in severe mechanical weakness and overall collapse of the structure. While seepage resulted in significant salt accumulation around the large grains, which increased local cohesion but caused irregular structural deformations, with the edges remaining eroded and the small grains weakened.



(a) under soaking for 30-days (b) under seepage for 30-days

Figure 17. ESMs for leached soil sample under soaking and seepage for 30-days

4. Conclusions

- The study highlights how soaking and seepage play distinct roles in affecting soil stability. Soaking is a slow process that gradually dissolves salts, altering the soil's chemical makeup over time. This leads to a steady decrease in soil cohesion, which eventually extends to structural weak points. On the other hand, seepage-especially under a hydraulic gradient infiltrate up salt dissolution. The effects become evident within a week, with nearly all salts removed in about 30 days. Because seepage involves constant water movement, it weakens the soil more quickly than soaking.
- Seepage has an immediate impact on soil cohesion and its ability to resist weight compared to soaking. As water continuously flows through the soil, it accelerates salt removal and drainage, rapidly degrading the soil's structure. This emphasizes the importance of effective drainage systems in areas subjected to seepage to prevent fast decline. Temporarily, in regions where prolonged soaking occurs, chemical treatments may be necessary to stabilize the soil composition and maintain its strength.
- Scanning Electron Microscope (SEM) test results show that soaking leads to increased porosity, weakening the overall structure of the soil. In contrast, seepage causes uneven cohesion and gradual distortion, which can equalize the soil's stability under different loads. These changes make construction on affected soil more difficult, reveals the need for effective soil stabilization techniques to preserve structural integrity.
- Over time, continued soaking can cause complete soil collapse, while seepage leads to uneven settlement and gradual deformation, with smaller soil particles being the most vulnerable. These findings underline the need for engineering solutions based on the specific type of soil degradation. For instance, chemical stabilization is more suitable for soils weakened by soaking, whereas well-designed drainage systems are essential for areas affected by seepage. Addressing these issues is key to maintaining soil stability in construction and geotechnical applications.

5. Declarations

5.1. Author Contributions

Conceptualization, S.S.H. and Z.H.M.; methodology, S.S.H.; software, S.S.H.; validation, S.S.H., Z.H.M., and I.H.O.; formal analysis, S.S.H.; investigation, S.S.H.; resources, S.S.H.; data curation, S.S.H.; writing—original draft preparation, S.S.H.; writing—review and editing, S.S.H.; visualization S.S.H.; supervision, S.S.H.; project administration, S.S.H.; funding acquisition, S.S.H. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available in the article.

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5.5. Conflicts of Interest

The authors declare no conflict of interest.

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