Journal Home Page: https://sjes.univsul.edu.iq/

Research Article:

Geotechnical and Index Properties of Soils Contaminated by Landfill Leachates from Erbil and Shaqlawa

Zainab Dler Saeed [1,a,*]
Yousif Ismael Mawlood [2,a]
[a] College of Engineering, University of Salahaddin, Erbil, Kurdistan Region, Iraq

Article Information

Article History:
Received: May 21, 2026
Accepted :August 14, 2026
Available online: August , 2026

Keywords:
Permeability; Landfill Leachate; Contaminated Soil; Geotechnical properties.

About the Authors:
Corresponding author:
Zainab Dler Saeed
E-mail: zainabbarik2000@gmail.com
Researcher Involved:
Prof.Dr. Yousif Ismael Mawlood
E-mail: yousif.mawlood@su.edu.krd

DOI https://doi.org/10.17656/sjes.10228

Abstract

Leachate from waste disposal can significantly alter the geotechnical properties of adjacent soils. Although urban expansion in the Kurdistan region has been rapid, research on local leachate chemistry and its effects on the geotechnical characteristics of regional soils remains limited. This paper examines the impact of landfill leachates from Erbil and Shaqlawa on the geotechnical properties (permeability, Atterberg limits, and compressibility) of clayey soils sourced locally from Kani Qirzhala, Erbil, Iraq. The experimental results reveal that leachate exposure increases the soil's liquid and plastic limits and decreases permeability, compressibility, and swelling potential. The Shaqlawa leachate showed more pronounced changes than the Erbil leachate, implying that the former leachate has a more pronounced chemical composition. Based on these results, landfill leachate has the potential to considerably alter soil characteristics, and its presence should be accounted for in landfill design, settlement measurement, and environmental safety analysis.

1. Introduction

Soil leachate is a complex, often highly contaminated liquid produced by the long-term decomposition of urban and industrial West and percolation of water through solid waste [1]. Due to high concentration of organic matter, dissolve the salt, and other potentially hazards substance, imperial contamination rendered this project highly toxic [2]. Landfill bottom line liner and covering often use glycerol as a natural or manufactured barrier because of this height absorption capacity and limited permeability. What design recruitment is that hydraulic conductivity must be 10-7 cm/s for Lord in order to effectively prevent the leachate migration [3]. Conversely clay's physical chemical and microstructural property may change with extent exposure to landfill leachate, which 10 compromise the long-term efficacy of the contaminated system [4]. This change may be due to the chemical constituents of the highly polluted liquid. Among others, high levels of total dissolved solids (TDS), heavy metals, dissolved organic matter (DOM), and complex chemical ions are very decisive factors in changing the soil structure [5]. Long term exposure to landfill leachate can alter clay soil's physical, chemical, and microstructural property potentially reducing the effectiveness of contaminated system [6]. laboratory and field investigation indicated that the hydraulic conductivity of clay soil contaminated with natural or manufactured leachate may increase or decrease depending on leachate composition, concentration, exposure duration soil fabric [7]. Leachates containing high amounts of salts and multivalent cations may lower permeability and, in rare cases, induce self-sealing behavior due to flocculation, pore clogging, and reduced total pore volume [5]. Conversely, in the long run, exposure to hostile chemical or organic species may improve hydraulic conductivity by a ratio of 2-4, decrease clay mineral content, increase the volume of bigger holes, and coarsen pores [8]. The Nineth Research on sandy clayey and granitic sandy clayey soils that have been exposed to leachates has shown that, depending on the concentration, these types of soils may display complicated behavior, including increasing porosity, even at low to moderate contamination levels. The stability of slopes and foundations close to landfills might be jeopardized, and flow pathways can be altered as a result [10]. On the other hand, the effect of landfill leachate on the plasticity and compressibility of clay soil varies across studies conducted over the years. The reason for the variability lies in the different soil types and their interactions with the leachate chemicals. Regarding plasticity properties, [11] showed that leachate, by expanding the diffuse double layer (DDL) around clay particles, generally increases Atterberg limits. On the other hand, [12] and [13] showed that the liquid and plastic limits decreased, indicating that certain chemical contaminants reduce the structural affinity of water molecules to clay surfaces and inhibit plastic behavior. In the case of soil consolidation, [11] indicated that contamination disrupts soil structure, resulting in a higher initial void ratio, compression index Cc, swelling index, and collapse potential. On the other hand, [14] showed that compressibility parameters for contaminated samples were lower than those for uncontaminated control samples. A comprehensive study of the chemistry of leachate, the quantity of contamination [15], and the effects of clay type on hydraulic conductivity [16] is necessary since there are inconsistencies in the literature on whether permeability increases or decreases when exposed to leachate. Very little is known about the effects of long-term exposure to leachate on different types of clay soils, how these effects vary from short- to medium-term testing, or how they relate to the development of microstructure and the processes of contaminant transport. Specific local materials have been the primary focus of most investigations [17]. In this controlled laboratory setting, we will use varying concentrations and durations of landfill leachate to measure the impact on the hydraulic conductivity (permeability) of clay soil. Therefore, the aim of the present research is to determine the impact of leachates from the Erbil and Shaqlawa landfills on the Atterberg limits, consolidation properties, and hydraulic conductivity of low-plasticity clayey soil in a laboratory setting. In addition, the paper aims to investigate the difference in effect between the two leachates and analyze the potential consequences for geotechnical and environmental engineering issues associated with landfills.

2. Experimental work

2.1 Study Area and Soil Sampling

Approximately 2 m^3 of disturbed soil samples were collected from the Erbil Municipal Landfill (Kani Qirzhala), Kurdistan Region, Iraq (Coordinates: 398863.1E, 4006831.2N), the main site for disposing of the city's solid waste. Samples were collected at depths of 6 to 9 meters; the soil parameters are presented in Table1. The samples were sealed in plastic bags and transported to the soil laboratory at Salahaddin University (Fig. 1). Upon arrival, they were placed in a large container for subsequent analysis. According to the Unified Soil Classification System (USCS), the collected soil was classified as low plasticity clay (CL), and soil samples were generated to reflect different levels of contamination for each type of leachate.

2.2 Leachate Source & Properties

In the Kurdistan Region of Iraq, two municipal landfill sites in Erbil and Shaqlawa have been selected for this research. The two landfills are simple dumps that lack basic environmental protection measures, including composite liners, leachate collection and treatment systems, landfill gas recovery systems, and environmental monitoring. As a result, these landfill sites produce leachate that may contaminate surrounding soil and groundwater, making them ideal for studying the effects of municipal landfill leachate on soil geotechnical properties.

The Erbil landfill (Kani Qirzhala) began operations in 2003 and will reach the end of its 23-year lifespan in 2026. It is located about 12 km west of Erbil City and serves as the primary disposal site for municipal solid waste generated in Erbil. The landfill covers about 800,000 m^2 (80 ha). According to official data from the Kurdistan Region Ministry of Municipalities and Tourism (2026), the landfill receives about 2,000 tons of municipal solid waste per day, totaling roughly 730,000 tons per year. The landfill receives mixed municipal solid waste, including food waste, plastics, paper, textiles, garden waste, glass, metals, and other household refuse.

The landfill in Shaqlawa has been operating since 2014 and is located within the Harir administrative boundary. In addition to serving Shaqlawa District, the landfill serves as the regional disposal site for the surrounding areas, including Kore, Harir, Basrma, Hiran, and Balisan. Municipal solid waste from these areas is regularly transported to the landfill. According to official documents obtained directly from the Kurdistan Region Ministry of Municipalities and Tourism (2026), the Shaqlawa landfill receives 43.92 tons of municipal solid waste daily and accepts mixed municipal solid waste, including household refuse, organic waste, plastics, paper, glass, metals, textiles, construction debris, and other municipal wastes. Like the Erbil landfill, the Shaqlawa disposal site is an open dump without engineered liner systems or leachate collection facilities. To date, no official engineering study or publication has reported the exact surface area of the Shaqlawa landfill.

Raw leachates were taken from leachate lakes naturally formed from the wastes at the Erbil and Shaqlawa landfill sites (Fig. 2). To keep the samples source and avoid any changes in their biochemical characteristics, the containers filled with leachate were preserved in a cooler at approximately 4°C. The original physicochemical characteristics of the raw leachate, including its detailed chemical composition, are shown in Table 2.

2.3 Sample Preparation

Collected soil samples were first oven-dried for 24 hours to the complete removal of moisture content and then cooling to room temperature under normal conditions of laboratory. The soil was mixed with the landfill leachate using a mixing machine to carry out a simulation of contamination. Leachate was added to the soil at two different concentrations—15% and 22.5%—in terms of the dry weight of the soil sample (Fig. 3 a, b), which is the case for all leachate types. After the contamination, the soil samples were double sealed in containers and kept in a laboratory environment with controlled conditions for 60 days. This period was enough time for chemical reaction and stabilization between the soil particles and the leachate before further sampling and testing. There have been contamination doses of 5% to 20% in most previous studies [18]. After curing, 6 samples for each leachate type and 6 control samples, for a total of 18, were remolded to field dry density and prepared for testing. Below is the experimental methodology flowchart

Soil Sampling (6-9m Depth)
↓
Soil Classification and Initial Tests
↓
Leachate Collection
↓
Mixing Leachate with Soil
↓
60-Day Curing Period
↓
Sample Remolding (Same as Field Dry Density
↓
Performing Laboratory Tests
↓
Results And Data Analysis

2.4 Laboratory Tests

2.4.1 Permeability

Falling-head permeability method was used to measure the hydraulic conductivity of the contaminated soil according to ASTM D5084. After 60 days of curing, both contaminated and clean soils were remolded to the identical field dry density and compacted into the permeameter mold in three equal layers for uniform preparation of the specimens. Prior to testing, specimens were saturated.

This method was chosen because the falling-head method is most suitable for fine-grained soils having relatively low hydraulic conductivity. The hydraulic conductivity coefficient (k) was computed using Darcy's law based on the recorded decrease of hydraulic head with time during the test.

To this effect, the test was carried out to evaluate changes in permeability features due to soil-leachate interaction and to find out the impact of different leachate types and levels of contamination on the hydraulic behavior of the clay soil under investigation.

2.4.2 Atterberg Limits

The Atterberg limits testing was performed as per ASTM D4318 guidelines to determine how the landfill leachate contaminant might change the soil's consistency properties. After the 60-day curing time, both the contaminated and uncontaminated soil samples were defrosted, mixed well, and tested.

The Casagrande cup apparatus was used to find out the liquid limit (LL) by correlating the moisture level with the groove closing that is made in a standard manner and of the length of 12.7 mm in 25 blows. As for the plastic limit, soil rolls were smashed on a glass plate repeatedly until their diameter reached about 3.2 mm and at that point, the threads started to break into pieces. The difference between the liquid limit and plastic limit was termed as the plasticity index (PI). The laboratory data were utilized to examine the influence of soil-leachate interaction on soil plasticity.

2.4.3 Consolidation

The one-dimensional consolidation experiments were executed as per ASTM D2435 standard so as to study the impact of the landfill leachate pollution on the soil compressibility properties. Initially, after the 60-day curing period, soil specimens both contaminated and uncontaminated were remolded at the same field dry density and put into the consolidation ring.

Before running the tests, the specimens were saturated and vertical loads were applied in increments with the help of an oedometer apparatus. Due to the low-plasticity nature of the clay under study and its field compaction position, the load sequence started with an initial stress of 2.5 kPa, and then load increments were applied in a doubling sequence. To understand the soil consolidation, vertical deformation was measured during each loading phase.

Based on the test results, the compression index (Cc) and swelling index (Cs) were determined and the effect of leachate type and degree of contamination on the soil compressibility and volume-change behavior was evaluated. Using the same dry density for all the specimens allowed the differences observed to be mostly attributable to soil-leachate interaction rather than density changes.

3. Results & Discussion

Results from Atterberg limits, consolidation, and hydraulic conductivity tests were used to assess how landfill leachate contamination affects the geotechnical properties of clay soil. The investigation compared uncontaminated soil with soil contaminated by leachates from the Erbil and Shaqlawa landfills at various concentrations. Because all soil samples after 60 days of curing were remolded to the same field-dry density, any changes would be primarily due to the physicochemical interactions between the leachate components and the soil particles. The following sections will discuss how contamination affects soil consistency, compressibility, swelling, and permeability.

3.1 Permeability

A reduction in hydraulic conductivity was observed in both Erbil and Shaqlawa soil samples, as shown in Table 3, at 15% leachate contamination. This was compared to the uncontaminated soil. The permeability of the samples decreased from 5.22×10^{-7} cm/s (uncontaminated soil) to 2.20×10^{-7} cm/s for contaminated soil with Erbil and 1.88×10^{-7} cm/s for Shaqlawa leachate. That is a drop of about 58% and 64%, respectively, which shows that even a moderate amount of leachate drastically modifies the soil's conductivity. This decrease in properties can be explained by the fact that at this stage, soil particles and chemical species in leachate interact closely, leading to changes in soil surface properties and microstructure. Electrolytes in leachate cause the clay particles to come together (flocculate) by compressing the diffuse double layer. This not only changes the clay fabric but also reduces pore space, thereby limiting water movement. Based on the permeability results, this can be attributed to the more intense chemical reaction of Shaqlawa leachate with the soil. This may be due either to a high concentration of ionic species or to the presence of other, more active chemical species within the leachate of "Shaqlawa". It should be noted that all samples underwent a two-month curing period and were then remolded at the same field dry density. Therefore, the observed differences cannot be attributed to variations in the compaction process but rather to chemical influences affecting soil structure.

When contamination reached 22.5%, the decrease in permeability was much more noticeable for both types of leachates. The hydraulic conductivity decreased further to and 6.99×10^{-8} cm/s for Erbil and 5.17×10^{-8} cm/s for Shaqlawa. This is approximately 86% and 90% lower than that of clean soil, respectively, indicating a significant change in the soil's hydraulic properties. At this contaminant level, the dominant processes are further enhanced. Double-layer compression increases moderately. The reason is that as the concentration of dissolved ions increases, the molecules become more clumped together. In addition to these mechanisms, the higher concentration of dissolved solids increases the possibility for soil matrix precipitation, which contributes to partial pore blockage. Migration of fine particles may also contribute to the blockage of smaller pores, thereby lowering permeability. Once again, the Shaqlawa leachate samples show relatively lower permeability than the Erbil samples at the same contamination level. This fact supports the conclusion that leachate from Shaqlawa has a stronger effect on soil structure than that leaching from Erbil. As the concentration increases, the contrast between the behavior of two soils becomes more significant, indicating that the chemical nature of the leachate as a key factor affecting hydraulic conductivity under contaminated conditions. The study's findings confirm previous research on soils contaminated with landfill leachate, particularly regarding the decrease in permeability as the level of contamination goes up. Several research papers investigating landfill leachate-contaminated clays have reported a decrease in hydraulic conductivity. This is attributed to physicochemical interactions, such as ion exchange and pore clogging, occurring within the soil matrix [19-23]. Likewise, soils polluted by oily wastewater have exhibited changes of this nature. Here, the reduction of void ratio owing to the presence of hydrocarbons and other chemicals inside the pores results in a drastic decrease in fluid flow capacity [20]. In addition, microstructural analysis shows that contaminants at higher levels cause a redistribution of pore size, mostly a shrinkage of large pores and a growth of finer pores. Naturally, this reduces permeability [22]. The results of this study align with the above points as hydraulic conductivity was very much down at contamination levels 15% and 22.5% as compared to the uncontaminated condition for both Erbil and Shaqlawa leachates. This circumstance could be owing to a number of mechanisms working at the same time, for example, double layer compression as a result of the high ionic strength of the leachate, flocculation of clay particles, and clogging of pores due to precipitates and migration of fine particles. These multifarious effects not only lead to a reduction in pore connectivity but also hamper fluid movement through soil. Therefore, one may reasonably infer that permeability reduction is a prominent feature of the soil response to contamination with fine particles, that is, the contaminating fluid could be either landfill leachate or oily wastewater.

3.2 Atterberg Limits

The Atterberg limits for the contaminated soils are shown in Table 4 and reveal a steady progression in both the liquid limit (LL) and plastic limit (PL) with the addition of the leachates for the soil sample. The liquid limit of the unpolluted soil, which was 37.6%, went up to 39.0% and 39.3% at 22.5% contamination by the Erbil and Shaqlawa leachates, respectively. The PL value of the natural soil sample, which was 21.7%, also increased to 22.7% and 23.0% at the same contamination level. As a result, the plasticity index increased only slightly, from 15.9% to 16.3%.

Increased consistency limits are most likely due to the physicochemical interactions between clay particles and components of landfill leachate. Leachates contain dissolved salts, organic compounds, and suspended particles that together alter soil structure, thereby increasing the water adsorption by surrounding clay particles. During the 60-day curing period, these interactions gradually altered the diffuse double layer and improved the soil's water-holding capacity, hence increasing the liquid and plastic limits.

The Shaqlawa leachate was stronger in this regard since it, on average, yielded values of LL and PL which were somewhat higher than those of Erbil, and this is very much in keeping with the chemical composition of Shaqlawa leachate, i.e., higher electrical conductivity, higher total dissolved solids, and higher suspended solids, which all led to intensified soil-leachate interactions and alteration of the clay structure.

This aligns well with the study's findings, which showed that consistency limits can increase because of physicochemical interactions between contaminants and clay minerals [11]. [24] also made similar observations that leachate contamination enhanced the plastic behavior of fine-grained soils, whereas [25] stated that changes in the diffuse double layer due to contaminants can affect the consistency of clay soils.

3.2 Consolidation

The results of the consolidation test, given in Table 5, showed that the compression index (Cc) and the swelling index (Cs) decreased as the contamination level increased due to both landfill leachates. The compression index decreased from 0.147 for uncontaminated soil to 0.117 and 0.101 at the 22.5% contamination level for Erbil and Shaqlawa leachates, respectively. Likewise, the swelling index decreased from 0.0072 for uncontaminated soil to 0.0065 and 0.0063.

The decrease in both Cc and Cs indicates that the contaminated soils become stiffer and less prone to swelling as the leachate concentration increases. Because all samples had the same 60-day curing time and were remolded to the same field-dry density, the observed differences cannot be attributed to changes in density. Rather, they illustrate changes in soil texture resulting from the physicochemical interactions between the leachate constituents and clay particles.

The leachate, which contains dissolved chemical species and salts, can compromise the diffuse double layer of clay particles by reducing repulsive forces, thereby favoring their flocculation and aggregation. As a result, the soil fabric becomes more resilient and less prone to volume change under load. Additionally, contaminant adsorption and partial pore clogging could have reduced the soil skeleton's capacity for extensive rearrangement during consolidation.

The greater decrease in samples contaminated with Shaqlawa leachate indicates that the higher ionic strength and dissolved solids content led to more pronounced particle aggregation and structural stabilization than in samples contaminated with Erbil leachate. This hypothesis is consistent with the lower hydraulic conductivity values recorded in the permeability tests, which indicate that the same mechanisms responsible for permeability reduction were also involved in reducing compressibility.

These results are more in line with the ideas of [26], who noted that electrolyte-rich pore fluids can compress the diffuse double layer and induce flocculated structures that are less compressible. Reductions similar to those in the compression index have also been reported by [14] and [25], who attributed the decline in compressibility to particle aggregation, double-layer collapse, and tighter particle packing caused by exposure to highly concentrated contaminant solutions.

4. Conclusion

The aim of this research was to examine the extent to which landfill leachate alters the geotechnical characteristics of a fine-grained soil sample. Here are some main conclusions of the study based on the tests carried out:

- Landfill liquid significantly altered the index, consolidation, and hydraulic properties of the tested clay soil.
- The liquid limit, plastic limit, and plasticity index increased with higher leachate concentration for both Erbil and Shaqlawa leachates, indicating that soil–leachate interaction was more intense and that the soil could retain more water.
- The soil's compressibility and swelling potential were reduced due to changes at the physicochemical level, as evidenced by the results of the compression index (Cc) and swelling index (Cs), which decreased with each level of contamination.
- The particle contamination was at such a level that the percentage of pore space in the soil available for water flow was reduced, as shown by the decrease in hydraulic conductivity when the leachate concentration was increased.
- In general, the changes in Atterberg limits, consolidation parameters, and hydraulic conductivity caused by Shaqlawa leachate were greater than those caused by Erbil leachate. This indicates that the chemical composition of the Shaqlawa leachate has a greater influence on soil

behavior.

- The observed changes can result from processes such as diffuse double-layer compression, particle flocculation, aggregation, and partial pore clogging caused by prolonged soil–leachate interaction.

From a civil engineering perspective, reduced permeability is expected to enhance the barrier performance of landfill liner systems. However, variations in soil consistency and consolidation properties may affect settlement behavior and long-term geotechnical performance. Thus, both leachate type and contamination level must be considered when designing landfills, conducting environmental risk assessments, and evaluating soils exposed to landfill leachate.

References

[1] Abdel-Shafy HI, Ibrahim AM, Al-Sulaiman AM, Okasha RA. *Landfill leachate: Sources, nature, organic composition, and treatment: An environmental overview*. Ain Shams Engineering Journal. 2024 Jan 1;15(1):102293.

[2] Dagwar PP, Dutta D. *Landfill leachate a potential challenge towards sustainable environmental management.* Science of The Total Environment. 2024 May 20;926:171668.

[3] Kabir MS, Wang H, Luster-Teasley S, Zhang L, Zhao R. *Microplastics in landfill leachate: Sources, detection, occurrence, and removal.* Environmental science and ecotechnology. 2023 Oct 1;16:100256.

[4] Sabba F, Kassar C, Zeng T, Mallick SP, Downing L, McNamara P. *PFAS in landfill leachate: Practical considerations for treatment and characterization*. Journal of Hazardous Materials. 2025 Jan 5;481:136685.

[5] Özçoban MŞ, Acarer S, Tüfekci N. *Effect of solid waste landfill leachate contaminants on hydraulic conductivity of landfill liners.* Water Science and Technology. 2022 Mar 1;85(5):1581-99.

[6] Norouzi A, Uygar E, Nalbantoglu Z. A *review on the effects of landfill leachate on the physical and mechanical properties of compacted clay liners for municipality landfills.* Arabian Journal of Geosciences. 2022 Jun;15(12):1174.

[7] Al-Soudany K, Fattah M, Rahil F. *Clay barriers performance in landfills: A review.* Engineering and Technology Journal. 2024;42(11):1327-42.

[8] Lima AN, Silva TF, Silva DL, Silvani C, Monteiro VE, Melo MC. *Soil-contaminant interaction in silty sand-bentonite liners percolated by landfill leachate.* International Journal of Environmental Science and Technology. 2026 Jan;23(1):77.

[9] Nikbakht M, Sarand FB, Dabiri R, Hajialilue Bonab M. *Investigation of the leachate effect on permeability and geotechnical characteristics of fine-grained soil modified using nanoclay–nanofiber composites*. Water. 2023 Jan 11;15(2):294.

[10] Chaudhary E, Swami D, Joshi N, Reddy KR. *Sustainable landfill liner using local soils and wastes amended with bentonite: hydraulic conductivity and stochastic leachate transport modeling*. Journal of Geotechnical and Geoenvironmental Engineering. 2024 Jan 1;150(1):04023126.

[11] Karkush, M.O., Zaboon, A.T. and Hussien, H.M. *Studying the effects of contamination on the geotechnical properties of clayey soil*. In: Coupled Phenomena in Environmental Geotechnics. London: Taylor & Francis Group, 2013 pp.599–606. https://doi.org/10.1201/b15004-80.

[12] Harun, S.N., Rahman, Z.A. and Damanhuri, N.A., *Impact of landfill leachate contamination on the geotechnical behavior of granitic sandy-clayey soil*. International Journal of Environmental Science and Technology,2025 https://doi.org/10.1007/s13762-025-06622-y

[13] Ebadi, T., Nabavi, E. and Dezvareh, G.A., *Effect of existing pollutants in leachate on geotechnical parameters of soil emphasizing organic pollution*. Journal of Advanced Environmental Research and Technology, 2023, 1(3), pp.1–14.

[14] Okeke, I. E., Okagu, T. T., Okonkwo V.O., Ezeagu, A. C., *Effect of municipal solid waste leachate on the Geotechnical properties of soil.* International Journal of Engineering Science Invention (IJESI), 2019, 8(7), 40 -52.

[15] Falamaki A, Salimi M, Vakili AH, Homaee M, Aryanpour M, Sabokbari M, Dehghani R, Masihzadeh K, Karimi AH. *Experimental investigation of the effect of landfill leachate on the mechanical and cracking behavior of polypropylene fiber-reinforced compacted clay liner*. Environmental Science and Pollution Research. 2023 Jul;30(31):77517-34.

[16] Wang S, Lu B, Zhu W. *Effect of minerals on the threshold of compacted clay material liners and service life of barriers in municipal solid waste*

landfills. Acta Geotechnica. 2023 Feb;18(2):1025-37.
[17] Kumar R, Kumari S. *Geotechnical properties of* materials *used in landfill clay liner: A critical review*. Sādhanā. 2023 Apr 11;48(2):64.
[18] Al-Fares, Rana A. *"Effects of Leachate-Soil Interaction on Shear Strength, Permeability,* Compaction*, and Chemical Characteristics."* Journal of Environmental Systems 2011, 33(11):1–18.
[19] Shariatmadari N, Askari Lasaki B, Eshghinezhad H, Alidoust P. *Effects of landfill leachate on mechanical behaviour of* adjacent *soil: a case study of Saravan landfill, Rasht, Iran*. Int J Civ Eng. 2018;16(11):1523–1535.
[20] Medhat FKA, Mawlood YI. *Study of in-situ and laboratory hydraulic conductivity of contaminated soil with oily wastewater*. J Univ Duhok. 2020;32(2):745–753.
[21] Francisca FM, Glatstein DA. *Long term* hydraulic *conductivity of compacted soils permeated with landfill leachate*. Appl Clay Sci. 2010;49(3):187–193.
[22] Zhao Y, Soltani A, Taheri A, Karakus M, Deng A. *Application of slag-cement and fly ash for strength development and permeability reduction of contaminated clay*. Appl Clay Sci. 2014;99:1–10.
[23] VanGulck JF, Rowe RK, Rittmann BE. Biological *clogging of granular media in wastewater applications*. J Environ Eng. 2003;129(9):849–856.
[24] Sunil, B.M., Shrihari, S. and Nayak, S., *Shear* strength *characteristics and chemical characteristics of leachate-contaminated lateritic soil*. Engineering Geology, 2009, 106(1–2),pp.20–25. https://doi.org/10.1016/j.enggeo.2008.12.011
[25] Khodary, S.M., Elwakil, A.Z., Fujii, M. and Tawfik, A., 'Effect of hazardous industrial solid waste landfill leachate on the geotechnical properties of clay', Arabian Journal of Geosciences, 2020, 13, 543. https://doi.org/10.1007/s12517-020-05699-8
[26] MITCHELL JK, SOGA K., *Fundamentals of Soil* Behavior. *3rd ed*. 2005.

الخصائص الجيوتقنية والنسيجية للتربة الملوثة برشاحة مكبّي النفايات في أربيل وشقلاوة

المستخلص

تُحدث الرشاحة المتسربة من مكبّات النفايات تغييراتٍ جوهرية في الخصائص الجيوتقنية للتربة المحيطة بها. ورغم التوسع العمراني السريع في إقليم كردستان، لا تزال الدراسات حول خصائص الرشاحة المحلية وتأثيرها على السلوك الجيوتقني للتربة المحلية محدودة. تهدف هذه الدراسة إلى تقييم تأثير رشاحة مكبّي النفايات في أربيل وشقلاوة على الخصائص الجيوتقنية للتربة الطينية. وقد جُمعت عينات مياه من منطقة كاني قرجلة في أربيل، العراق، وشملت قياسات النفاذية، وحدود أتربيرغ، والانضغاطية. أظهرت النتائج التجريبية أن تعريض التربة للرشاحة يزيد من حد السيولة وحد اللدونة، بينما يقلل من النفاذية والانضغاطية وقدرة الانتفاخ. أظهرت النتائج أيضاً أن عصارة مكب نفايات شقلاوة كانت ذات تأثير أكبر نسبياً مقارنةً بعصارة مكب نفايات أربيل، مما يشير إلى الدور المهم للتركيب الكيميائي للعصارة في التحكم بسلوك التربة. وتشير هذه النتائج إلى أن عصارة مكبات النفايات يمكن أن تؤثر بشكل كبير على الخصائص الهندسية للتربة، مما يستلزم مراعاة تأثيراتها في تصميم أنظمة مدافن النفايات الصحية، وتقييمات الهبوط، ودراسات السلامة البيئية.

الكلمات المفتاحية:

النفاذية؛ عصارة مدافن النفايات؛ التربة الملوثة؛ خصائص الجيوتكنيكية.

Table 1. Physical and Index Properties of the Investigated Soil

Parameters	Value
Soil Type (USCS)	CL
Sand%	4.5
Silt and Clay%	95.5
Wet Unit Weight of Field (kN/m^3)	15.6
Dry Unit Weight of Field (kN/m^3)	14
Specific Gravity	2.612
Liquid Limit (%)	37.59
Plasticity Index (%)	15.94

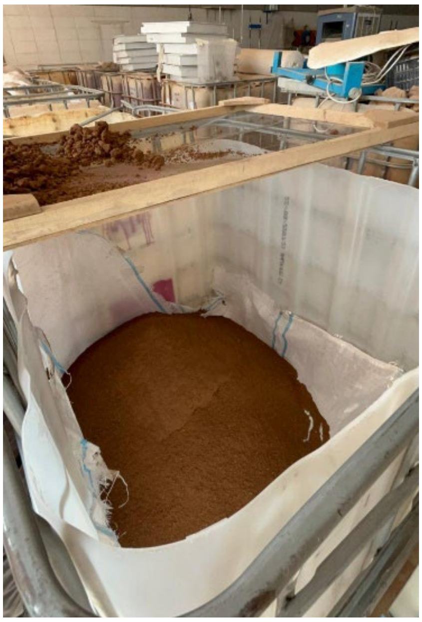


Fig. 1. Collection of soil samples from the study area and transportation of samples to the laboratory

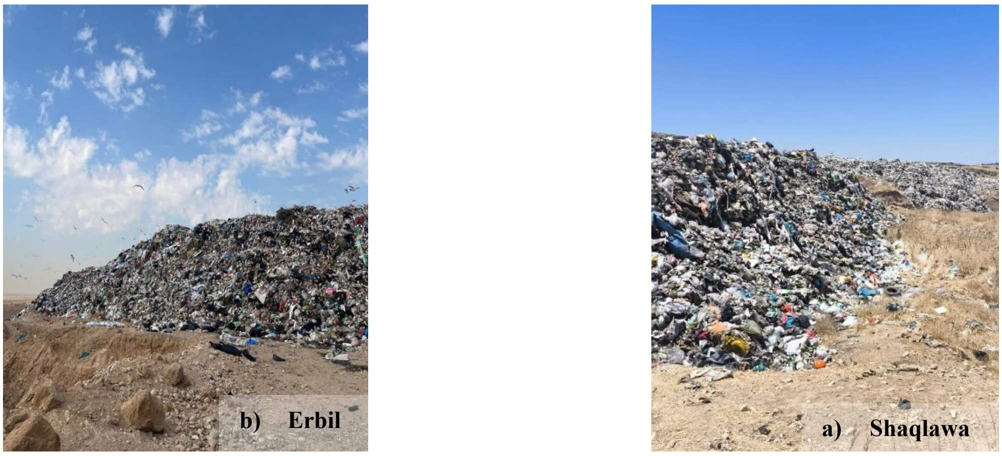
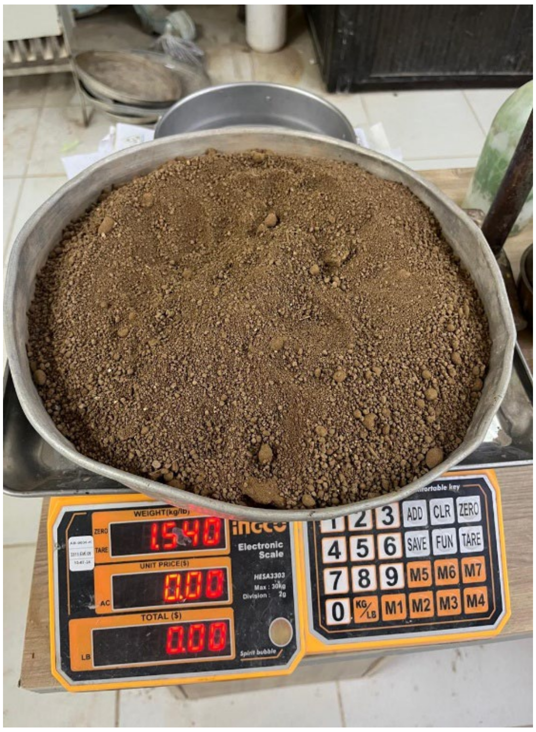


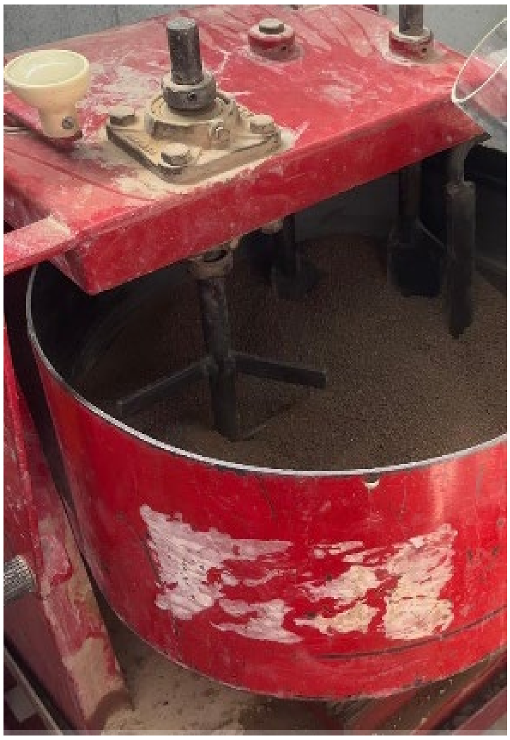
Fig. 2. Collection of Landfill, Erbil and Shaqlawa Leachates

Table 2. Physicochemical Characteristics of Leachates Collected from the Erbil and Shaqlawa Landfills

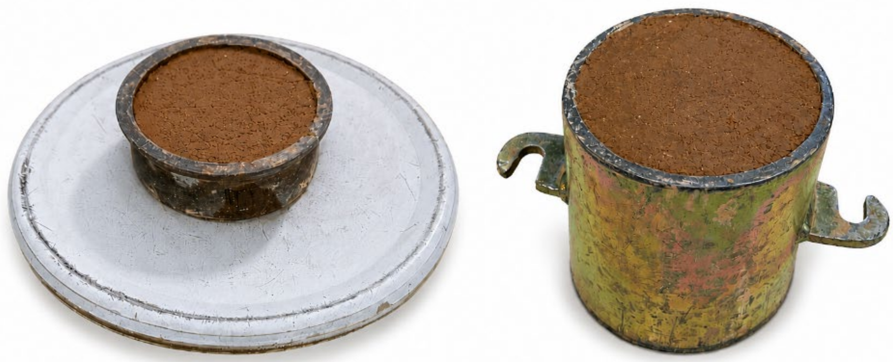
Parameter	Unit	Erbil	Shaqlawa
Temperature	Celsius	14	14
pH	-	5.4	5.2
Total Suspended Solids (TSS)	mg/L	2750	2850
Chemical Oxygen Demand (COD)	mg/L	28400	24580
Electrical Conductivity (EC)	μS/cm	30000	35984
Total Dissolved Solids (TDS)	mg/L	15000	25188.8
Turbidity	NTU	424	1250
Total Hardness as $CaCO_3$	mg/L	11937.5	4240.311
Calcium	mg/L	38.6	956.16
Magnesium	mg/L	18.4	450.1
Total Alkalinity as $CaCO_3$	mg/L	14561	10200
Sodium	mg/L	6300	4890
Potassium	mg/L	60	2400
Chloride	mg/L	4052.4	3868.1
Sulphate	mg/L	2980	3200
NO_3-N	mg/L	1750	1020
Phosphate	mg/L	280	27.3
Ammonia	mg/L	74	384.6



a) Weighing and preparation of oven-dried soil prior to contamination

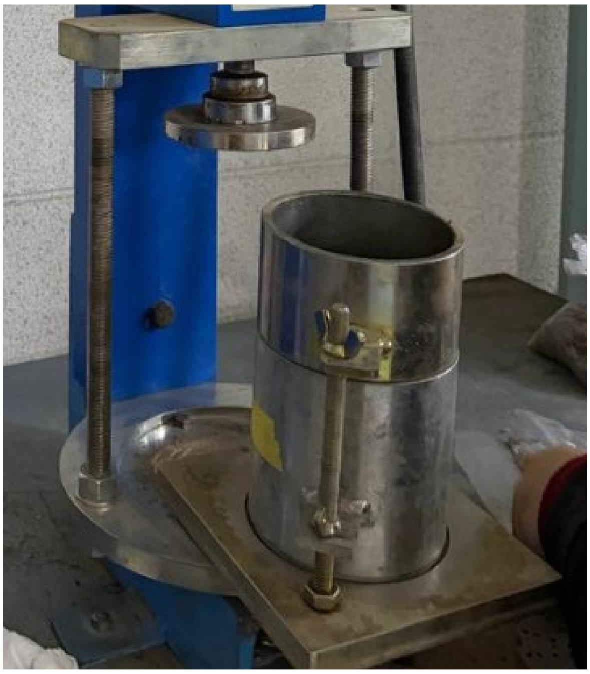


b) Mechanical mixing of soil and landfill leachate to obtain a homogeneous contaminated sample.

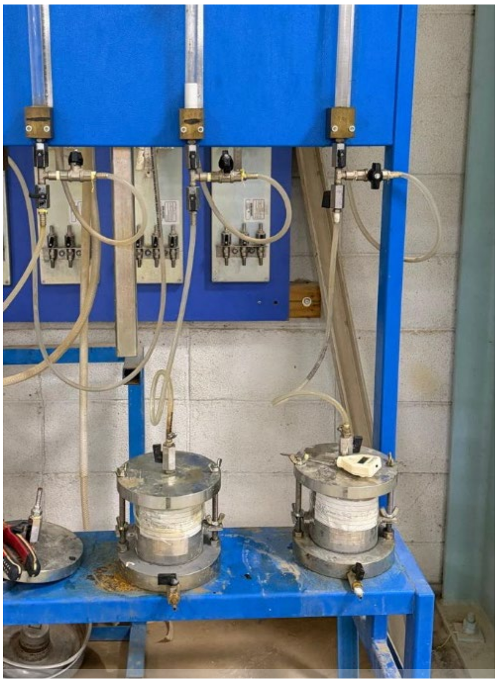


c) Remolded Samples of Consolidation and Permeability

Fig. 3. Soil sample preparation. (a) Soil preparation; (b) Mixing process; (c) Remolded consolidation and permeability samples.



a) preparation and compaction of the remolded soil specimen in the permeameter mold



b) Falling-head permeability apparatus used for determination of hydraulic conductivity as per ASTM D5084.,

Table 3. Hydraulic conductivity of uncontaminated and leachate-contaminated soil specimens

Contamination Level (%)	Leachate Source	Hydraulic Conductivity cm/s
Control	Tap Water	5.22×10^{-7}
15	Erbil	2.20×10^{-7}
15	Shaqlawa	1.88×10^{-7}
22.5	Erbil	6.99×10^{-8}
22.5	Shaqlawa	5.17×10^{-8}

Table 4. Atterberg Limits of uncontaminated and leachate-contaminated soil specimens

Contamination Level (%)	Leachate Source	LL (%)	PL (%)	PI (%)
Control	Pure Water	37.6	21.7	15.9
15	Erbil	38.4	22.3	16.1
15	Shaqlawa	38.7	22.6	16.1
22.5	Erbil	39	22.7	16.3
22.5	Shaqlawa	39.3	23	16.3

Table 5. Consolidation parameters of uncontaminated and leachate-contaminated soil specimens

Contamination Level (%)	Leachate Source	Cc	Cs
15 Control	Tap Water	0.147	0.0072
15	Erbil	0.140	0.0070
15	Shaqlawa	0.139	0.0066
22.5 Control	Tap Water	0.163	0.0073
22.5	Erbil	0.117	0.0065
22.5	Shaqlawa	0.101	0.0063