Effect of existing pollutants in leachate on geotechnical parameters of soil emphasizing organic pollution

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Journal of Advanced Environmental Research and Technology

Vol. 1, No.3
page 1-14 ,summer 2023
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Received 05 September 2023
Accepted 21 November 2023

Abstract

Changes in pore fluid can significantly impact the geotechnical behavior of soil, especially clayey soil. One source of soil contamination is leachate, which can infiltrate nearby soil during the collection, transportation, and deposition stages of the residential waste disposal process, exerting geotechnical influences on the soil in the surrounding area. To assess these effects, four leachate samples were collected from different sites. The specimen comprises fine soil, created from a mixture of sand, bentonite, and kaolinite. Experimental results reveal a decreasing trend in the liquid limit, compaction parameters, and cohesion values of the soil with an increase in contamination level. However, the internal friction angle exhibits an increasing trend with higher leachate concentration, resembling the behavior of sandy soil, as opposed to the typical behavior of clay.

key words

Fine soils

Shear strength

Soil elasticity

Leachate

Electric conductivity

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[DOI: 10.22034/jaert.1.3.1]

1. Introduction

Soil is one of the important and valuable resources of nature. Soils are considered as nature's purifiers. In addition to providing food, they also have purifying properties. As a result of various human activities, the soil becomes polluted [1].

Leachate can enter environmental resources, including underground water and soil, in various ways, both in the steps before entering the landfill, including collection and transfer, and during the time that municipal waste is in the landfill [2].

The primary constituents of leachate encompass organic hazardous substances, including aromatic and chlorinated aliphatic compounds, phenols, phthalates, and pesticides. As previously noted, the concentration of leachate depends on various factors, including the composition of the waste and other environmental conditions [3–7]. Pollutants, all of which pollutants have accumulative, threatening, and detrimental effects on the survival of aquatic life forms, ecology, and food chains that lead to public health crises including carcinogenic effects, acute toxicity, and genotoxicity [8–11].

In the past, landfills and the land around them were considered only for green space, due to the significant development of structural and building measures in the creation of airports, underground tunnels, the construction of huge docks, highways, the construction of dams and their related structures, and huge networks. With the growing demands for infrastructure such as irrigation and drainage, the need for building materials has surged significantly. Concurrently, as the number of construction projects rises and the demand for suitable land intensifies, the concept of utilizing even contaminated land has become ingrained in the mindset of engineers and governing bodies. This is while the infiltration of leachate into the soil can not only have harmful environmental effects on it but also cause changes in some of its geotechnical parameters, including compressive and shear strength, amount of soil settlement, degree of permeability, etc [12,13].

to improve the conditions, there are different ways to clean the soil. Cleaning the environment, especially the soil, is a very expensive process. Therefore, it is more logical, that instead of carrying out expensive soil purification processes, new geotechnical properties and behaviors are investigated, and new calculations are made concerning contaminated soil to build structures on it.

Substantial research efforts have been dedicated to gaining a deeper understanding of the impacts of different contaminants on the soil profile [14–17]. In this regard, many researchers have studied the impacts of hazardous waste leachate on the engineering behavior of soils, especially in clays used as barriers in landfill liners and covers [18–23]. Roque & Didier [24] proposed linear expressions for precise soil selection as cover and liner of landfills, due to possible changes that can occur in the geotechnical properties of soils in contact with landfill leachate (with a focus on hydraulic conductivity changes). A study by Francisca & Glatstein [25] on the long-term permeability of compacted clay affected by leachate proved that permeability was reduced in compacted clays due to the microorganism clog of effective pores.

Most of the research has been specifically on the natural soils present in the site and the leachate of the landfills. In this research, an attempt has been made to measure the parameters of shear, compaction, permeability, settlement, etc. with the presence of pollution with variable concentration.

In this research, laboratory investigations have been carried out to measure the behavioral changes of fine-grained soil in the presence of pollution. The difference in this research compared to the works done is the types of leachates, which were collected from different sites in Iran.

2. Materials and methods

2.1. General Information

The soil employed in this study is a composite comprising sand, bentonite, and kaolinite, blended in proportions of 60%, 30%, and 10%, respectively. The physical and chemical properties of bentonite and kaolinite soils are detailed in Tables 1 and 2, respectively. A granulation test for sand, conducted in accordance with the ASTM D 422 standard, yielded results presented in Figure 1. The outcome of this experiment indicates that the sand possesses a uniform grain size, classified as SP type according to the unified classification system.D_{50} for this sand is about 0.24 mm. C_c and C_u for this sand are 0.88 and 1.9, respectively. To perform the tests, we first wash the soil and then dry it. For this purpose, we put some soil in a container and mix it with water, and stir it so that the particles float lighter than water. The mixture is allowed to settle for 3 days, then the suspended particles are collected. The soil dries in it. In order to determine the specific mass, the ASTM D 854-02 standard test was used, and finally G_s of

[DOI: 10.22034/jaert.1.3.1]

Table 1. Chemical and physical analysis of bentonite

Chemical Analysis	2-4%	Na_2O
	2-4%	MgO
	8-15.1%	Al_2O_3
	1.5-4%	CaO
	50-55.2%	SiO_2
Physical Analysis	Minimum 600%	Water absorption
	Maximum 6%	Moisture
	W.t Maximum 20%	The residue on the sieve (45µ)

Table 2. Chemical and physical analyses of kaolinite soil

Chemistry Analysis %	L.O.I	9±1
	SiO_2	63±1
	Al_2O_3	24±1
	Fe_2O_3	0.55±0.1
	TiO_2	0.04±0.01
	CaO	1.2±0.2
	MgO	0.55±0.06
	Na_2O	0.4±0.1
	K_2O	0.3±0.1
	SO_4	-
Mineralogical Analysis %	Kaolinite	64±2
	Quartz	27±2
	Calcite	2.1±0.5
	Total Feldspar	-
	Others	6±1
Particle size distribution %	> 150 µ	0
	> 40 µ	0-0.5
	< 20 µ	99
	< 2 µ	47±3
Technical properties	M.O.R (Kgf/cm^2)	30±0.5
	Peff.Plasticity	31±1
	Brightness (1180°C)	92±2
	% Drying Contraction (110°C)	5±0.5
	% Firing Contraction (1180°C)	3.5±0.5
	Physical Form	Micronized
	% moisture	< 1
	Packaging	Big Bag

[DOI: 10.22034/jaert.1.3.1]

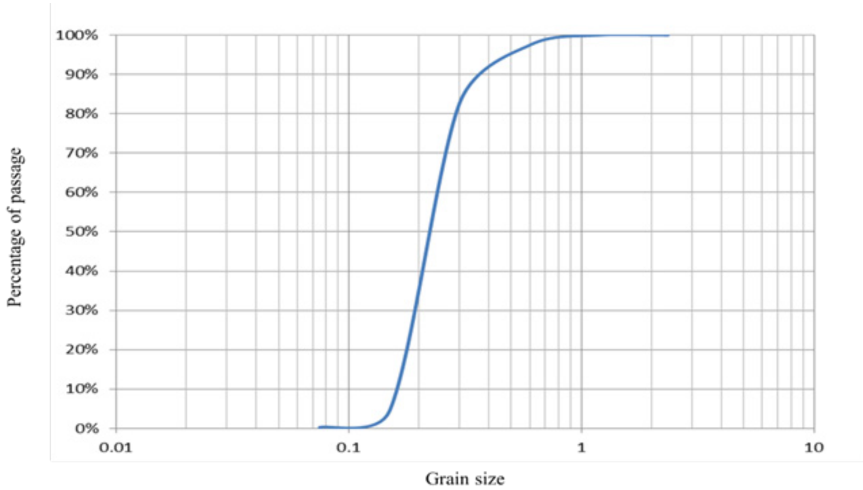

Figure 1. Grain size curve of tested sand

the soil was obtained as 2.65. Pycnometry method or specific gravity (ASTM-D854-92) was used to determine the specific gravity of bentonite, and thinner was used instead of water in this test, and a desiccator was used to fill the space between the clay particles. Several direct shear tests were conducted to determine the alterations in shear parameters of contaminated soil. Then, the specimens had chemical reactions over different periods of time and after that, the next phase of direct shear tests was developed. The other parameter that has been checked is to study soil plasticity with different amounts of contamination. To evaluate it atterberg limits tests were conducted. Additionally, a series of compaction tests for all samples with distinct amount of contamination are performed. The other tests that have been conducted include the Gr and Dr measuring to evaluate the physical specifications of soil and the COD test has been done to measure the organic loading rate.

2.2. Leachate Characteristics

The leachates employed in the soil contamination experiments were sourced from four distinct sites, each characterized by unique features. The organic load of the samples was quantified using the laboratory spectrophotometer, measuring Chemical Oxygen Demand (COD) in milligrams per liter (mg/lit). The COD values for the leachate samples were as follows: Leachate 1 = 6352, Leachate 2 = 9466, Leachate 3 = 67000, and Leachate 4 = 102700.Leachate 1 was sampled from an agricultural soil site polluted by local wastes, leachate 2 was collected from food-packing industry wastes dumped near the factory. The third was collected from the Halghe Dare landfill in Karaj and the last sample was collected from the Aradkouh in Tehran landfill site.

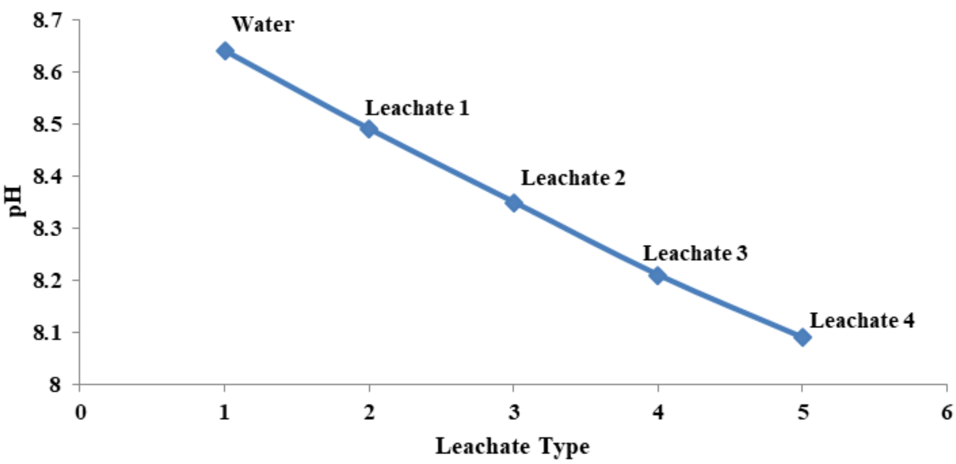

Figure 2. The curve of contamination rate-pH of the sample with 18% moisture percentage

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3. Results and discussion

3.1. pH Effects

The pH values of soil samples with varying degrees of pollution were measured. As illustrated in Figure 2, the pH values of the samples exhibit minimal variation with changes in the contamination percentage. However, it is observed that the pH value slightly decreases with an increase in the organic load of the leachate in the soils. This slight acidic shift in the pH is attributed to the presence of a combination of organic substances in the artificial leachate.

3.2. Effects of EC and TDS

According to Figures 3 and 4, with the increase of organic load in the soil, the amount of electrical conductivity of the soil and consequently the

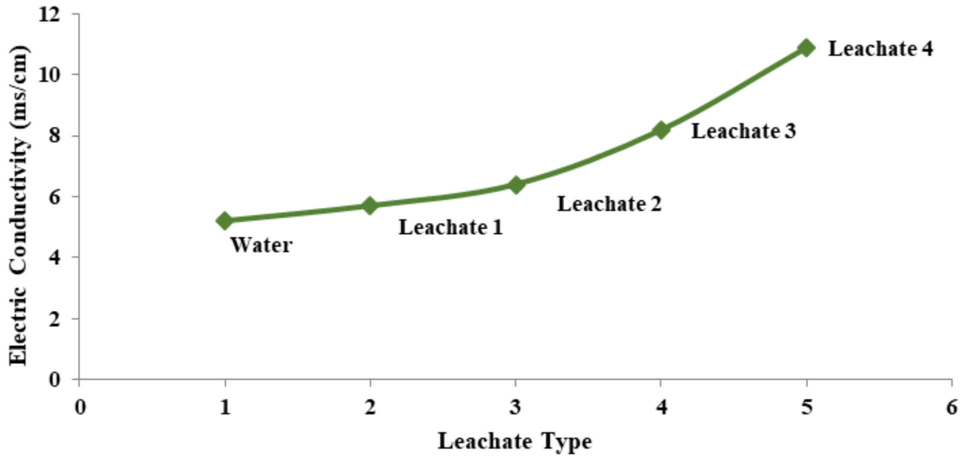

Figure 3. The curve of contamination rate-EC of the sample with 18% moisture percentage

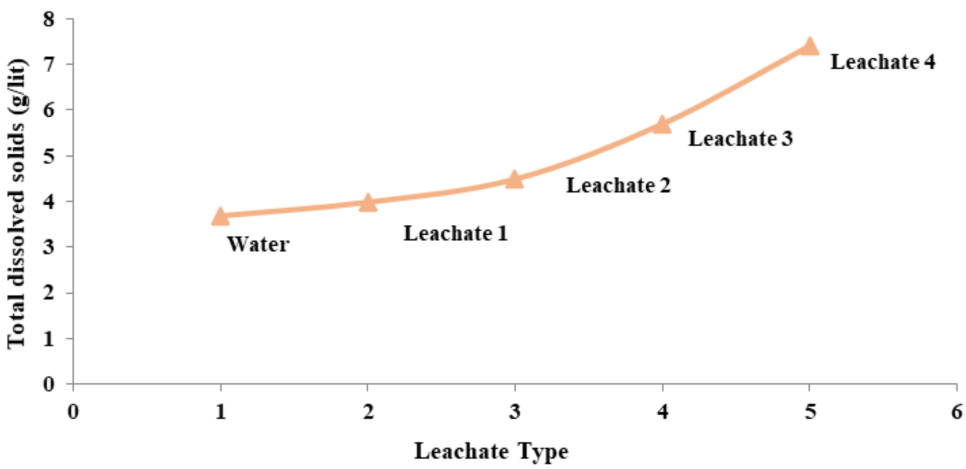

Figure 4. The curve of contamination rate-TDS of the sample with 18% moisture percentage

Table 3. EC and TDS values of pollutants

Type of Pollutant	EC (ms/cm)	TDS (gr/lit)
Leachate 1	7.36	5.1
Leachate 2	12.73	8.9
Leachate 3	36.3	25.1
Leachate 4	54.2	38

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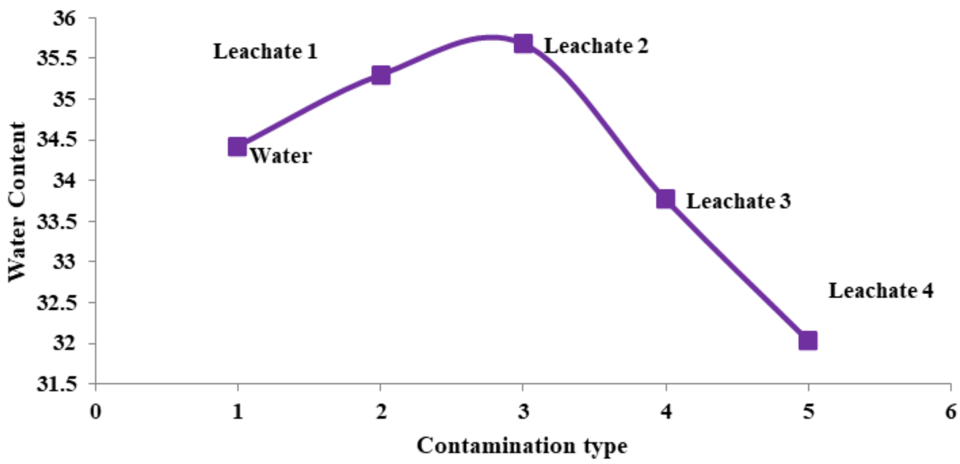

Figure 5. Changes in Atterberg limits with changes in pollution level (life of samples: 1 day)

amount of TDS of the soil has increased [26–28]. This increase can be considered due to the increase of positive and negative ions due to the increase in the concentration of pollution in the soil, which increases the ability to carry electrons in the soil. In addition to the measurements made about soil EC and TDS, similarly, the amount of electrical conductivity and TDS in the leachates used are measured and shown in Table 3.

3.3. Atterberg limits

The results of the liquid limit test on uncontaminated and contaminated soil with different amounts of synthetic leachate with different COD values are given in Figure 5.

As the pollution level increases up to a COD of 9466 mg/lit (leachate 2), the liquid limit experiences an increase. However, with a further increase in pollution up to a COD of approximately 102700 mg/lit (leachate 4), the liquid limit undergoes a complete decrease. This behavior can be attributed to the chemical composition of clays, where the surface of clay particles carries a negative charge. The negative charge on the clay particles leads to the absorption of positive ions present in the water within the soil pores onto the surface of the clay particles. This process forms a dispersed layer of positive ions in the proximity of the clay particles, collectively known as a diffuse double layer (DDL).

In the DDL, water molecules are attracted to the clay particles in three ways: a) Positively charged water particles, due to their bipolarity, are attracted by the negatively charged clay surface. b) Water particles, due to their negative charge, are attracted to cations, and cations, in turn, are attracted to charged clay particles. c) Hydrogen atoms in water molecules are absorbed due to hydrogen bonding by oxygen atoms on the surface of clay particles. When the clay soil is contaminated, the leachate with a low organic charge only establishes hydrogen bonds with dipolar water molecules, and as a result, the splashing phenomenon is created due to the presence of negative charges on the surface of the colloidal clay particles. In addition, due to the balance of water molecules with polar molecules, clay leachate has a greater tendency and capacity to take water and form a double layer. Therefore, we see an increase in the psychological limit of the soil. Meanwhile, the leachate with a lower dielectric constant compared to water and an organic charge of more than 10000 mg/lit starts to destroy the double layer after forming ionic bonds with all dipolar water molecules and replaces its positive ions with water H^+ ions. and this causes the van der Waals force of attraction between clay particles and causes the phenomenon of clay coagulation. When the clay particles are lumped and become granular, the clay soil acts like sandy soil and therefore the liquid limit is reduced. This trend is similarly observed for soil PI value. One of the characteristics of fine-grained soils is the pasty characteristic of these soils, and with this reduction, it can be said that the soil acts exactly like sandy and coarse-grained soils and loses its pasty properties.

3.4. Consolidation Test

According to what can be seen in the diagram of Figure 6, with the increase in pollution, the percentage of optimal humidity decreases from 16.32 to 14.02. The dry specific gravity has not undergone any significant changes and the presence of soil pollution can be considered to not affect the maximum dry specific gravity.

The diagram of changes in the percentage of op-

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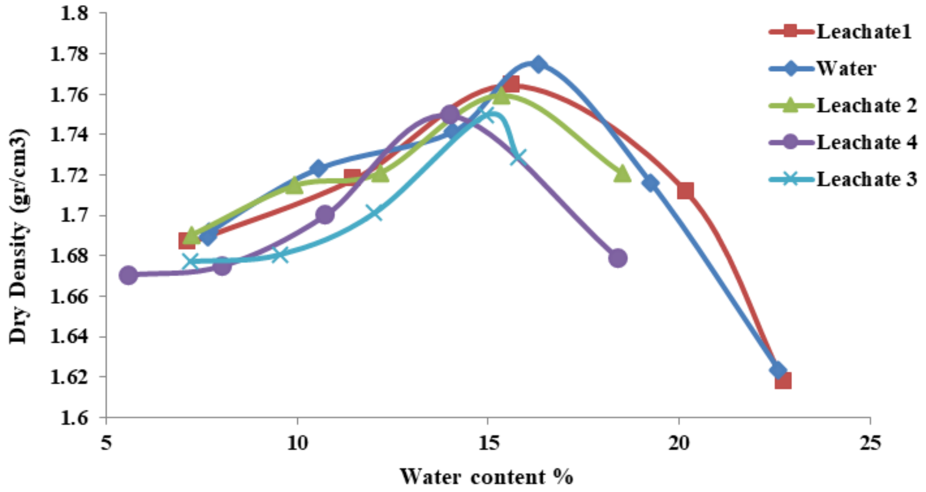

Figure 6. Consolidation curves for contaminated samples with different organic load

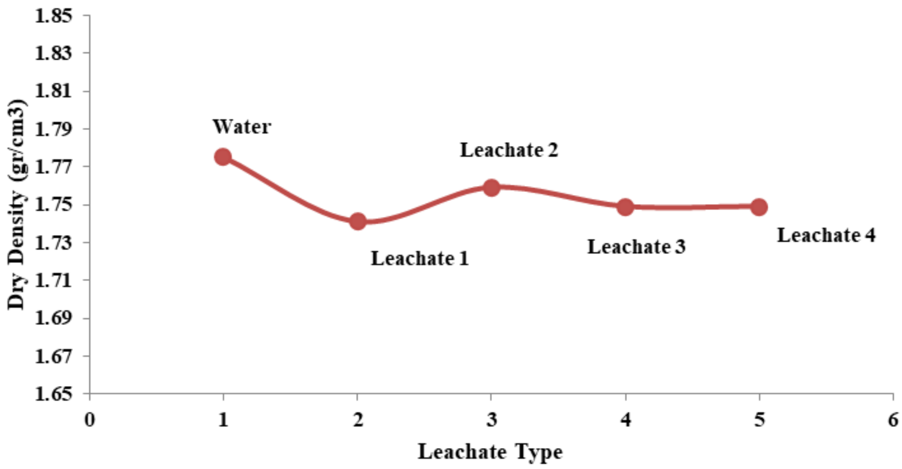

Figure 7. The amount of contamination - the maximum specific gravity

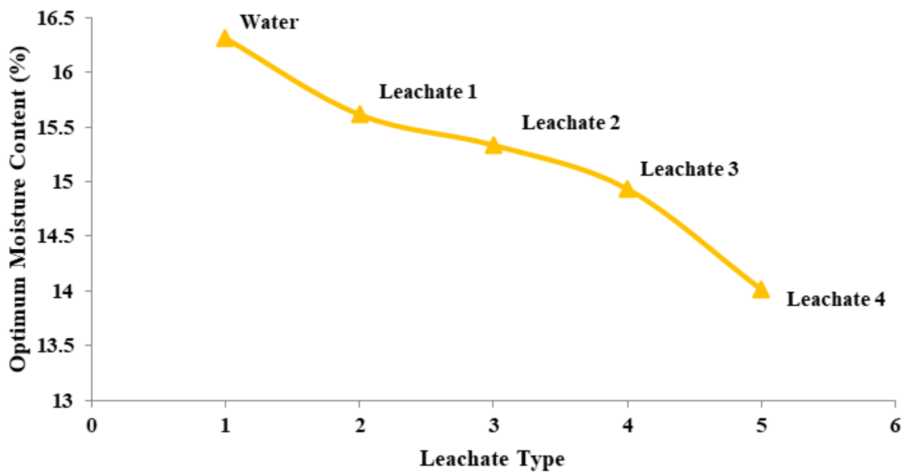

Figure 8. The amount of pollution - optimal humidity

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timum moisture and maximum dry weight with the change in pollution level is shown in Figures 7 and 8. Regarding the reduction of the optimum soil moisture, it can be said that due to the presence of soil contamination, the soil becomes grainy and loses its desire for water, and this reduction in the pasty property of the soil causes the optimum moisture of the contaminated samples. The optimal soil moisture percentage is directly related to its PI value.

3.5. Direct Shear Test

3.5.1. Effects of leachate pollution

Figures 9 to 11 depict the variations in soil cohesion with an increasing organic load of leachate over a single day, considering moisture percentages of 8%, 13%, and 18%. The direct shear test results reveal that changes in cohesion at 8% and 13% moisture percentages follow a similar trend, while at 18% moisture, the graph exhibits a slightly different pattern. Upon closer examination, it becomes apparent that the graph for the 18% moisture percentage encompasses the trends observed in the previous two graphs. After the organic load reaches 67000, the graph for 18% moisture displays a more comprehensive trend, reflecting a larger leachate volume in the soil. Consequently, a heightened reaction occurs between clay particles and pollution, illustrating an additional step in the geotechnical soil transformation process. In summary, the cohesion between soil particles increases up to a value of 67,000 and then begins to decrease. This is noteworthy, as at a high moisture percentage, the cohesion value stabilizes, reaching a constant value.

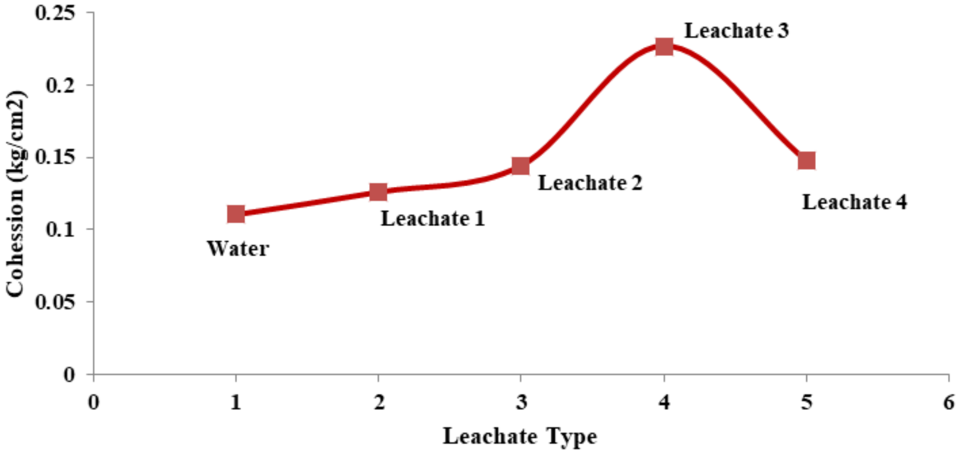

Figure 9. The amount of contamination-adhesion for the sample with 8% humidity

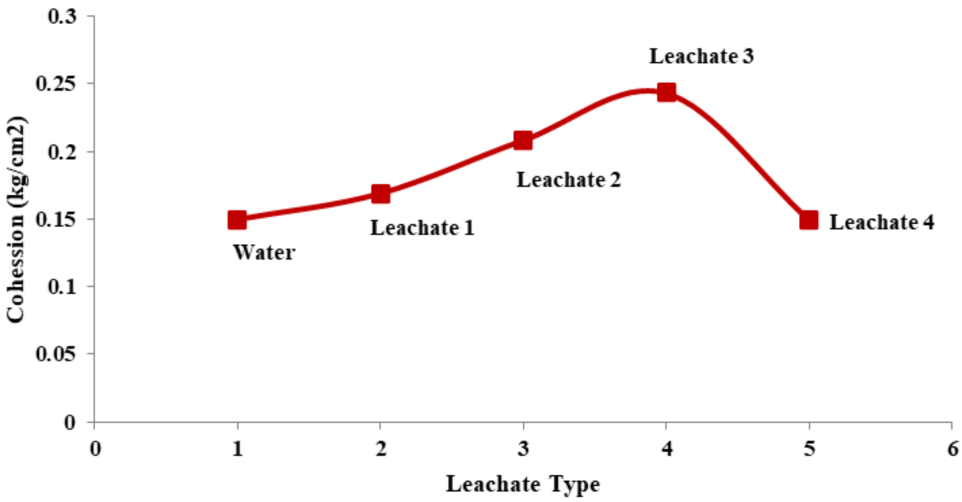

Figure 10. The amount of contamination-adhesion for the sample with 13% humidity

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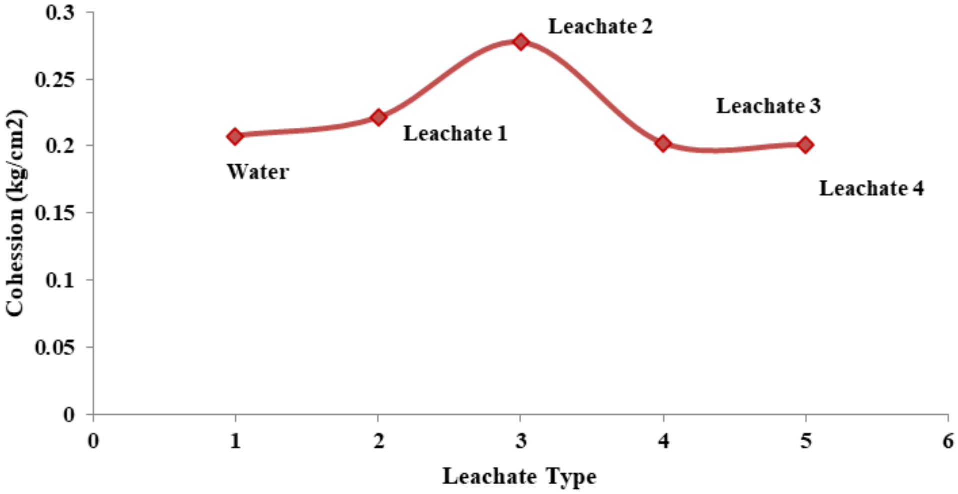

Figure 11. The amount of contamination-adhesion for the sample with 18% humidityT=25°C, 140 min).

At first, pollution with less organic charge starts to react with dipolar water molecules. This causes the water molecules of the diffusion double layer, which formed a bond with the anions around the clay colloidal particles, to gradually begin to form a bond with the contaminant ions. Consequently, the reduction in the thickness of the double layer results in a heightened negative charge on the clay particles. This increase in negative charge intensifies the repulsive forces between the particles, enhancing the colloidal properties of the soil. As a consequence, the soil exhibits finer grain behavior in the presence of moisture, leading to an increase in the cohesion or adhesion between soil particles. If by increasing the amount of pollution in the soil and creating a reaction between pollution molecules and water, the cations of the pollution will establish an ionic bond with the charged particles of clay and cause the repulsive force between the particles to disappear. This causes clumping of clay particles, which is called soil coagulation. In this situation, the soil starts to behave like sandy soil, which reduces its adhesion.

Figures 12 to 14 show the changes in the internal friction angle of the soil by increasing the organic load of the leachate in the life of the sample for one day, in the humidity percentages of 8%, 13%, and 18%. The results of the direct shear tests, as seen in the Figure, the changes in the amount of adhesion in the 8% and 13% moisture percentages have the same trend and in the 18% moisture percentage, it is observed that the graph has a slightly different trend. With careful examination and comparison of the three graphs, it becomes apparent that the graph corresponding to the 18% moisture percentage encompasses the trends observed in the previous two graphs. Particularly, after the organic load reaches 67000, the graph for 18% moisture presents a more comprehensive trend. This is attributed to the larger volume of leachate in the soil, facilitating a more pronounced reaction between clay particles and pollution. Consequently, this reflects an additional step in the process of geotechnical soil changes. At first, pollution with less organic charge starts to react with dipolar water molecules. This causes the water molecules of the diffusion double layer, which formed a bond with the anions around the colloidal clay particles, to gradually begin to form a bond with the pollution ions. As a result, the thickness of the double layer is reduced, and the clay particles become more negatively charged. As a result of the increased repulsive force between particles, the colloidal property of the soil is enhanced. The soil exhibits a finer-grained behavior in the presence of moisture, and there is a reduction in its internal friction. With an increase in pollution in the soil and the ensuing reaction between pollution molecules and water, the cations from the pollution establish ionic bonds with the charged particles of clay. This interaction causes the repulsive force between particles to diminish. This causes clumping of clay particles, which is called soil coagulation. In this situation, the soil starts to behave like sandy soil, which increases its internal friction angle.

3.5.2. Effects of time

Figures 15 and 16 respectively show the changes in adhesion and internal friction values of soils contaminated with leachate 3 at moisture percentages of 8%, 13%, and 18%. The duration of the

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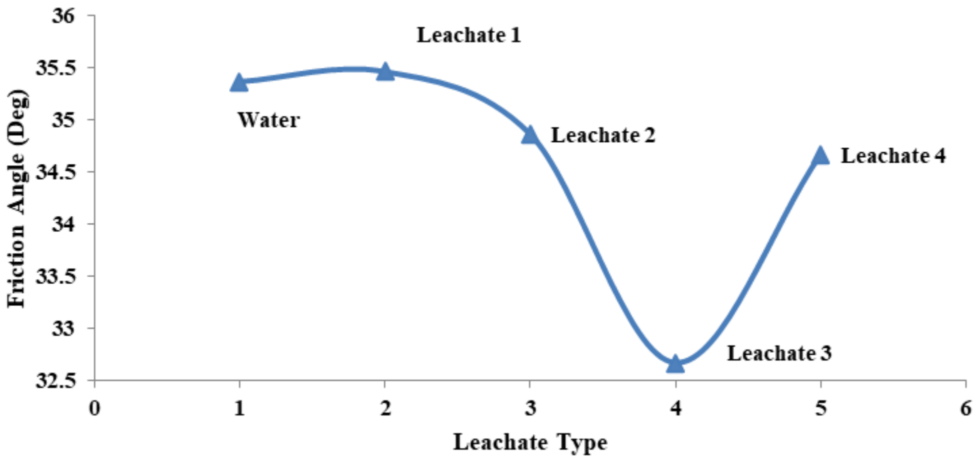

Figure 12. The amount of pollution - internal friction for the sample with 8% humidity

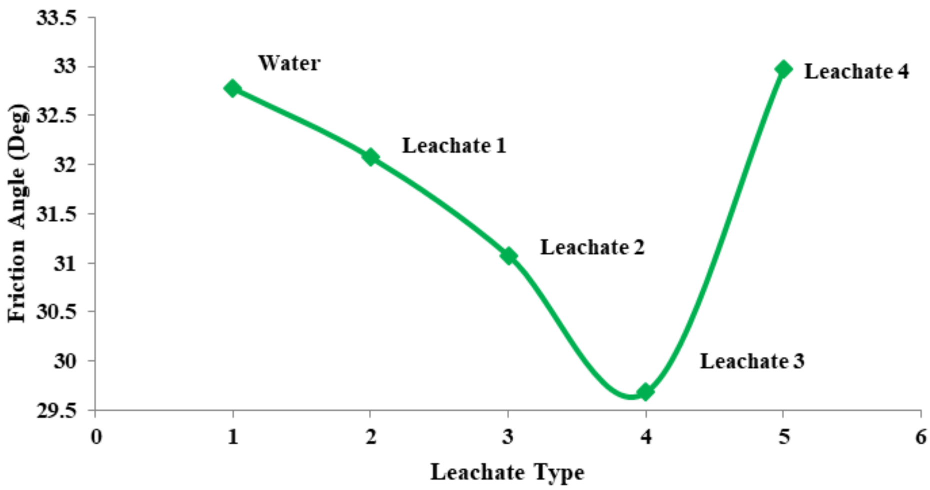

Figure 13. The amount of pollution - internal friction for the sample with 13% humidity

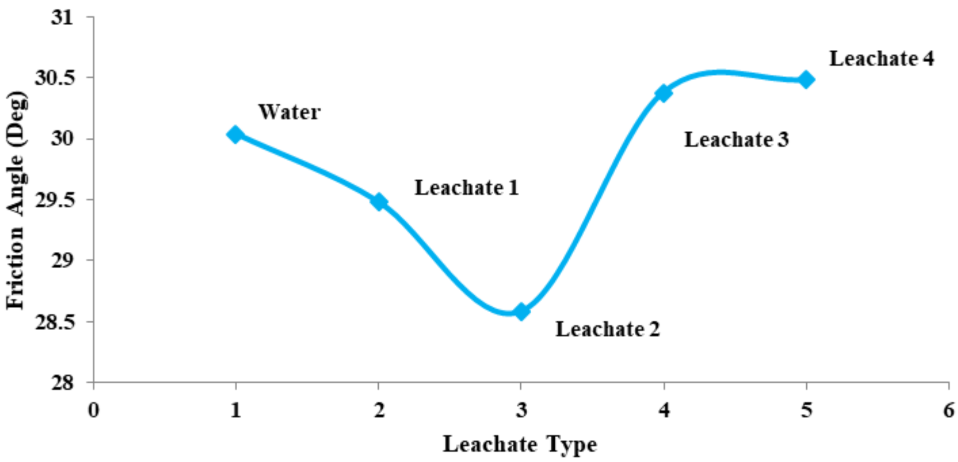

Figure 14. The amount of pollution - internal friction for the sample with 18% humidity

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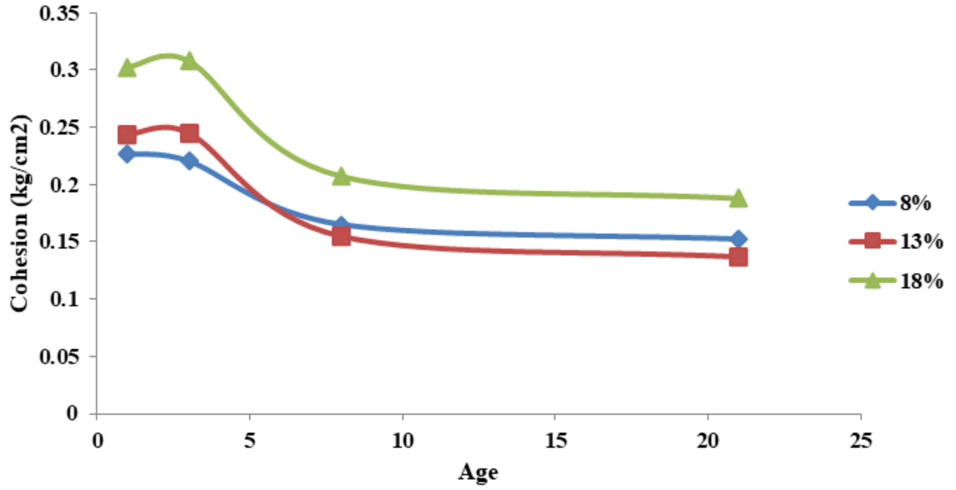

Figure 15. The life-adhesion curve of the soil sample contaminated with leachate 3

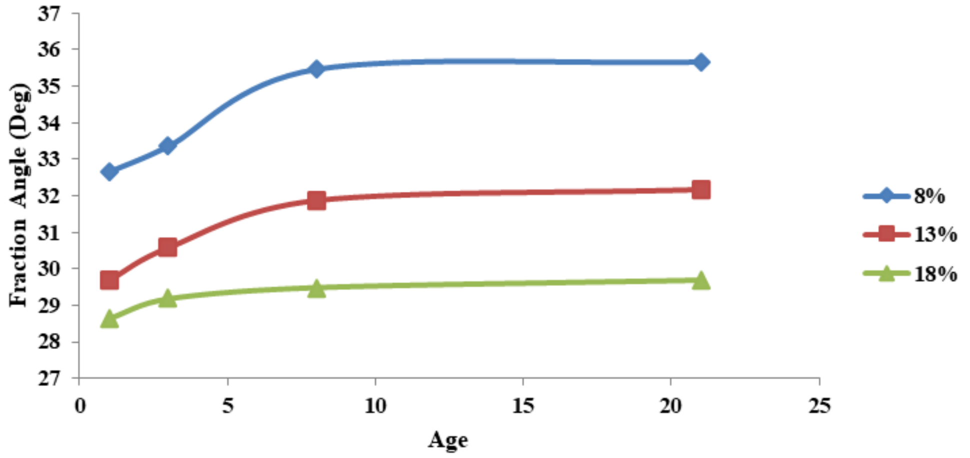

Figure 16. The life-internal friction angle curve of the soil sample contaminated with leachate 3

presence of leachate in the samples is 1 day, 3 days, 8 days, and 21 days. As can be seen in Figures 15 and 16, the amount of adhesion between particles decreased with time, while the amount of internal friction angle increased. The more the pollution is given a chance to be present in the soil, the greater the amount of reaction between the leachate and the clay particles in the soil, and this causes coagulation or clumping of the clay particles. This change of state in the clay particles adds to the sandy nature of the soil, reduces the adhesion, and increases the internal friction angle of the soil.

4. Conclusion

In general, soil contamination with leachate causes changes in its geotechnical characteristics. With the increase in the amount of contamination, there is a decrease in the fermentation limit and the mental limit. This can be seen as a result of creating ionic bonds of positive and negative charges of pollution with all dipolar molecules of water, which starts to destroy the double layer, and positive ions replace themselves with H+ ions of water, and this itself causes the creation of van der Waals attraction between clay particles and causes the phenomenon of clay coagulation. With the increase in contamination, the percentage of moisture decreases from 16.32 to 14.02 and the dry weight remains almost unchanged. This indicates the reduction of fine-grained soil in the soil. This life is mainly caused by chemical changes in clay and pollution. The results of the direct shear test show a decrease in adhesion in the soil with an increase in the percentage of contamination. The occurrence of coagulation phenomenon can be considered as the cause of this. The results of the direct shear test show an increase in the friction coefficient in the soil with an increase in the percentage of contamination. Chemical reactions and clumping of fine-grained soil can be considered as

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the cause of this.

The direct shear test results at low moisture percentages reveal a nuanced pattern of adhesion fluctuating both upward and downward with an increase in contamination percentage. Initially, pollution with a lower charge reduces the thickness of the double layer, causing clay particles to acquire a more negative charge. This leads to an increase in repulsive forces between particles, enhancing the colloidal properties of the soil. Consequently, the soil exhibits finer grain behavior in the presence of moisture, resulting in an increase in adhesion. The subsequent decrease in adhesion is attributed to the phenomenon of coagulation and the loss of the double layer. Similarly, the results of the direct shear test at low moisture percentages show a fluctuation in the friction coefficient, both decreasing and increasing with the rise in pollution percentage. This suggests that soil with a lower contamination percentage displays finer grain behavior in the presence of moisture. Conversely, at higher contamination percentages, the friction coefficient increases due to the loss of the double layer of clays and their propensity to clump. As the sample›s lifespan increases, there is a decrease in adhesion and a slight increase in the angle of internal friction.

The results of the electrical conductivity test and the number of dissolved solids (EC and TDS) indicate the increase of EC and TDS values with the increase in the percentage of pollution. This increase can be considered due to the increase of positive and negative ions due to the increase in the concentration of pollution in the soil, which increases the ability to carry electrons in the soil.

The results of the pH test show that, with the increase in pollution, the pH of the soil remains almost constant and decreases slightly. The results of the experiments show that pollution affects the fine-grained soil, thus it affects the adhesion and pasty properties of the soil more.

Author Contribution

Conceptualization, Mohammad-Taghi Ebadi. and Erfan Nabavi.; Methodology, Erfan Nabavi and Ghorban Ali Dezvareh; Formal Analysis, Ghorban Ali Dezvareh.; Writing – Original Draft Preparation, Erfan Nabavi.; Writing – Review & Editing, Ghorban Ali Dezvareh and Erfan Nabavi.; Visualization, Erfan Nabavi.; Supervision, Mohammad-Taghi Ebadi.;

Data Availability

The data presented in this study are available upon reasonable request to the corresponding author.

Conflict of interest

The authors declare that there is no conflict of interest.

[DOI: 10.22034/jaert.1.3.1]

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[DOI: 10.22034/jaert.1.3.1]