J. ENVIRONMENTAL SYSTEMS, Vol. 33(1) 1-18, 2011

EFFECTS OF LEACHATE-SOIL INTERACTION ON SHEAR STRENGTH, PERMEABILITY, COMPACTION, AND CHEMICAL CHARACTERISTICS*

RANA AL-FARES

College of Engineering & Petroleum, Kuwait University

ABSTRACT

This article presents the results of an investigation program, consisting of laboratory tests, carried out to determine the short-term effects of leachate contamination on the geotechnical and chemical properties of clean silty sandstone soil locally known as Gatch. Leachate is released due to the decay, oxidation, and corrosion of waste discarded carelessly in old abandoned pits of opencast mining or quarries with minimal use of manual waste separation techniques and no use of liners. In some cases, this results in the percolation of contaminated leachate causing severe risk to the surrounding soil, groundwater, and community health. An extensive laboratory-testing program was carried out to determine the properties of the clean weakly cemented calcareous/gypsiferous silty sandstone material obtained from Al-Jahra city, located 37 Km northwest of Kuwait City. Real municipal solid waste leachate obtained from a waste disposal site, known as Al-Qurain landfill, was used in this study to prepare the soil-leachate mixtures. Contaminated specimens were prepared by mixing the natural soil with the real leachate in the increments of 5%, 10%, 15%, and 20% by weight of soil to vary the degree of contamination. The chemical characteristics of the leachate used were also determined. A general deterioration of soil properties attributed to the chemistry of the leachate formed is noted.

*This work was supported by Kuwait University, Research Grant No. [EV02/09]. The author expresses her appreciation to Kuwait Environmental Public Authority (KUEPA) for their fruitful corporation in providing real leachate samples. Special thanks are also due to Eng. Ziad Abdulsalam for his help with leachate sample collection.

doi: 10.2190/ES.33.1.a
http://baywood.com

INTRODUCTION

Land filling, which is considered the most popular form of solid waste treatment in many countries, requires substantial virgin lands and leads to serious pollution to its surroundings [1]. Waste discarded into landfills undergoes decay, oxidation, and corrosion resulting in the release of organic and inorganic material causing potential risk to the surrounding soil, groundwater, and community health [1]. Hence, any negligence in waste management will without doubt lead to various environmental problems.

In several countries, waste is disposed inadequately and carelessly in old abandoned pits of opencast mining or aggregate and other building materials quarries with minimal use of manual waste separation techniques and no use of liners, resulting in some cases to the percolation of contaminated leachate to the groundwater and in other cases to the generation of harmful gases.

The State of Kuwait has a very high daily waste production rate per capita compared to other countries, where the daily average municipal waste is estimated to be around 1.4 kg/person [2]. The main disposal system commonly used in the State of Kuwait is land filling. There are currently 16 active and abandoned/decommissioned disposal sites occupying large areas distributed at different locations around the country. Tests conducted in some of those dumpsites revealed that several chemicals, such as chlorine, and sulfate were way above the maximum allowable limits as well as high levels of oil and pH [3].

The study area, which is considered one of the largest and most alarming waste disposal sites known as Al-Jahra dumpsite, is situated very close to the highly populated Al-Jahra city and has extensive dense to very dense weakly cemented calcareous/gypsifereous silty sandstone material formation locally known as Gatch. Such formation was encountered immediately below the so-called "windblown" sand deposit. Due to the high shrinkage limit and low cohesion of such soils, open waste dumping in such formations may well lead to serious environmental and health problems.

Al-Jahra dumpsite is a non-engineered facility consisting of an abandoned sand quarry that is centered at a latitude N 29° 19′ 38.8" and a longitude E 47° 36′ 59.2" and covers an area of about 1.98 Km^2. The dumpsite started operating in 1986 and has been receiving liquid, construction and demolition (C&D), household, agricultural, and commercial waste during its 23 years of service. Waste received was deposited in a chaotic manner and covered by sand with neither the use of efficient compaction nor the use of protection systems commonly used in well-managed and designed landfills. The average rainfall according to Al-Jahra weather station that is centered at a latitude N 29º 18' 32" and a longitude E 47º 31′ ranged from about 94 mm to 304.2 mm for the years 1994-2005 with a mean annual precipitation of about 137.6 mm. Although precipitation levels in Kuwait are low, waste degradation with leachate and gas production continues for decades after closing the dumpsite due to the rise of the water table. This phenomenon is a statewide problem caused by artificial recharging activities such as irrigation and gardening [4]. Large amounts of leachate are also expected to generate due to the improper disposal of industrial wastewater, sewage sludge, and chemical waste with municipal solid waste at waste disposal sites [5].

The behavior of soils is extensively affected by contamination with leachate. Research conducted by local and international studies has revealed that the physical and chemical characteristics of soils contaminated with leachate have a tendency to degrade as a result of the chemical reactions between the soil and the leachate [1, 6-10]. It is very important to study the effect of contamination with leachate on the behavior of soil to confirm its suitability for diverse applications.

It was not possible to obtain real leachate samples from the waste disposal site at Al-Jahra due to the absence of a leachate collection system. However, real leachate samples were collected from a decommissioned waste disposal site located at Al-Qurain city and used in the present study. This site was used for the disposal of municipal solid and C&D waste during its 9 years of service with disposal depths of up to 24 m below existing ground level according to plans held by the local municipality officials. The site started operating in 1976 and covered an area of about 0.7 Km^2. This site, that is located adjacent to a huge residential area, is currently rehabilitated where more than 100 boreholes were installed for gas flaring [5].

SCOPE OF THE PROBLEM

In the study area, residual deposit of in-situ weathered and degraded weakly cemented calcareous/gypsiferous silty sandstone material is predominant and about two square kilometers of land is currently used as a waste disposal site since 1986.

The soil at the waste disposal site revealed extensive contamination due to leachate formation and percolation. Due to the proximity of this specific waste disposal site to a large residential city (that will undergo future expansion in land use due to the expected increase in resident population), geotechnical engineers were concerned with the short and long-term effect of such processes on the geotechnical and chemical characteristics of the soil. The present investigation was carried out for that objective. Therefore, evidence showing the degradation of the natural host soil due to contamination with leachate may encourage Kuwaiti decision makers to enforce environmental regulations.

METHODOLOGY

This section incorporates the description of experiments carried out at laboratory scale. An extensive experimental program has been carried out to investigate the short-term effect of contamination with leachate on the geotechnical and chemical characteristics of residual deposit of in-situ weathered and degraded weakly cemented calcareous/gypsiferous silty sandstone material.

Representative soil samples from three sources off the Al-Jahra waste disposal site boundary were obtained from test pits (TP1, TP2, and TP3) of 0.5 to 1 m depth. The soil samples were air-dried in preparation for laboratory testing. The selected samples were used to investigate the short-term effect of contamination with leachate on the shear strength, permeability, compaction characteristics, and chemical characteristics of the soil obtained. A comprehensive analysis of the collected soil samples has been carried out for physical and chemical parameters.

In the absence of a leachate collection system at the study area, it was difficult to obtain real leachate samples. However, real leachate was obtained from the waste disposal site located at Al-Qurain city (Latitude 29° 13′ 30 N, Longitude 48° 04′ 22 E) about 15 kilometers southeast of Kuwait City. The samples were collected in a dry season, mid August to early October of 2009, from the leachate collection pond of the facility. Clean sterilized 500 ml glass bottles were used to collect the samples and were filled to the brim and tightly sealed. These were immediately stored in an icebox and transported to the laboratory. Once the samples arrived at the laboratory, they were preserved well and kept at 4°C. Analyses were carried out within 8 hours of sampling.

The leachate analysis was done in triplicates following the standard methods for water and wastewater examination [11]. The pH, Total dissolved Solids (TDS), Chemical Oxygen Demand (COD), Electrical Conductivity (EC), Chloride content (Cl^-), Magnesium content (Mg^{2+}), Calcium content (Ca), Nitrate content (NH_4N), and Cation Exchange Capacity (CEC) of leachate were measured. Table 1 shows the concentration of each constituent of the leachate used for this study. Also given in Table 1 are the chemical analysis results of leachate for the same site collected between January to December of 2003 [3] in 2001 [5]. It is important to note that the chemical composition of leachate may vary significantly during different seasons due to different dilution rates caused by precipitation, irrigation and gardening and other factors. One can notice that the concentration of a few chemicals and other characteristics of leachate collected by researchers back in 2001 and 2003, such as Mg^{2+}, Ca, NH_4N, and COD were generally lower than those collected in 2009. However, a few chemical concentrations and characteristics such as Cl^-, TDS, pH, and EC are greater than those encountered in previous work. This result indicates that the pollution caused due to the formation and percolation of leachate is still taking place; nevertheless, rehabilitation measures carried out at the site has, by some means, helped in reducing such pollution.

The natural soil, soil-leachate mixtures and leachate samples analysis were performed in triplicates for accuracy. Furthermore, for shear strength, permeability characteristics assessment, soil samples were prepared and tested at maximum Standard Proctor dry unit weight [$\gamma_{dry\text{-}max}$] and optimum water content w_{opt} as illustrated in Table 2.

Table 1. Chemical Characteristics of the Leachate Samples Used in the Present Study and Previous Studies

	Concentration (mg/l)					Other characteristics		
	Cl^-	Mg^{2+}	Ca	NH_4N	TDS	pH	COD	EC m^2/cm
Al-Fares [12]	4298-	51-54	132-136	133.7-140	14240-14650	10.9-	3154	23.6-24.4
[3]	2340	60	276	710	11290	8.9	—	18.99
[5]	—	86-268	52-122	—	1100-9910	7.82-8.06	6400-8800	6.21-21.9

Table 2. Specific Gravity, Grain Size Distribution, and Compaction Characteristics of Uncontaminated Soil

		Grain size distribution			Standard Proctor characteristics	
Specimen #	Specific gravity	Gravel (%)	Sand (%)	Fines (%)	$\gamma_{dry\text{-}max}$ (kN/m^2)	w_{opt} (%)
1	2.55	24.6	59.9	15.5	17.51	11.6
2	2.56	60.6	30.8	8.6	18.4	11.8
3	2.57	16.2	74.2	9.6	16.76	12

Shear Strength Characteristics

Compaction tests were conducted on the natural soil samples obtained to determine the compaction characteristics. The soil samples were then mixed thoroughly in a tray with leachate in increments of 5%, 10%, 15%, and 20% by dry weight of soil, respectively. The soil-leachate mixture was stored for 48 hours for the mixture to reach moisture equilibrium. After equilibrium was reached, soil specimens were remolded to the maximum proctor unit weight using the optimum water content, as shown in Table 2, to carry out direct shear tests. The shear strength characteristics of the uncontaminated soil and soil-leachate mixtures were determined using the standard direct shear apparatus as per the British Standard procedures (BS 1377:Part 7:1990).

Permeability Characteristics

The hydraulic conductivity characteristics of uncontaminated soil and soil-leachate samples were studied in the laboratory compacted to Standard Proctor maximum dry unit weight in the permeability mould using the ELE falling head test apparatus as per the American Standards for Testing and Material (ASTM D2434). Distilled water/leachate was allowed to flow continuously through the sample from the standpipe to saturate the soil. Saturation of the soil sample was ensured under steady state flow conditions.

Compaction Characteristics

The compaction characteristics of the uncontaminated soil and soil-leachate mixtures were investigated using the Standard Proctor compaction tests as per the American Standards for Testing and Material (ASTM D698). A cylindrical mould that is attached to a base plate at the bottom and to an extension at the top was used. The soil is mixed with the optimum water content and is compacted in three equal layers (25 blows per layer) using a 2.5 kg hammer with a 304.5 mm height of drop.

Chemical Characteristics

The chemical properties of the soil investigated included pH, Electrical Conductivity (EC), Cation Exchange Capacity (CEC), Organic Matter (OM), Total Soluble Sulphate (SO_4), Iron Content (Fe_2O_3), Silica Content (SiO_2), Calcium Carbonate Content ($CaCo_3$), and Aluminum Content (Al_2O_3). The chemical characteristic results of the natural uncontaminated soil are illustrated in Table 3.

Table 3. Chemical Characteristic Results of the Natural Uncontaminated Soil

Sample	pH	EC (m^2/cm)	CEC (meq/100g)	OM (%)	SO_4X10^{-3} (%)	Fe_2O_3 (%)	SiO_2 (%)	$CaCo_3$ (%)	Al_2O_3 (%)
1	7.89	2.72	6.34	0.027	5.78	0.95	68.42	7.18	8.57
2	8.56	2.52	8.30	0.027	0.57	1.11	71.48	8.37	8.73
3	9.03	1.50	9.10	0.014	0.1	0.85	71.76	3.19	9.00

RESULTS AND DISCUSSION

Since contaminants change the properties of their host soil, the effects of soil-leachate interaction on the shear strength, permeability, compaction characteristics, and chemical characteristics of soil are investigated, presented, and discussed in the following sections.

Effects of Leachate on Shear Strength Characteristics of Soil

Direct shear tests were conducted on the uncontaminated silty sandstone material and soil-leachate mixture. All specimens were prepared at Standard Proctor maximum dry unit weight and were saturated prior to the test. Table 4 illustrates the shear strength parameters for 0%, 5%, 10%, 15%, and 20% added leachate, respectively. Figures 1 and 2 illustrate the results in a graphical format. The results indicate an increase in the value of cohesion accompanied by a decrease in the angle of internal friction as a result of increasing leachate concentration up to 5% by weight of dry soil. However, when the concentration of leachate increased to 10%, an opposite behavior of soil-leachate mixture was noted, where a decrease in cohesion was accompanied by an increase in the value of angle of internal friction. Furthermore, the ascending trend of the angle of internal friction continued when leachate concentration was increased to 15% accompanied by a slight decrease in the value of cohesion at the same concentration. This behavior changed yet again when the concentration of leachate reached 20% by weight of dry soil as shown in the figures. At that concentration a sudden increase in the value of cohesion occurred, accompanied by a sudden decrease in angle of internal friction. When comparing these final

Table 4. Shear Strength Characteristic Results of Natural Uncontaminated Soil and Soil-Leachate Mixtures

Sample	Shear strength characteristics	Soil-leachate mixture (leachate % by weight of dry soil)				
		0	5	10	15	20
1	c (kpa)	10	24	14	12	22
	ϕ (degree)	35	35	38	40	34
2	c (kpa)	8	11	12	16	17
	ϕ (degree)	39	39	35	34	33
3	c (kpa)	12	16	9	10	17
	ϕ (degree)	33	32	35	39	34

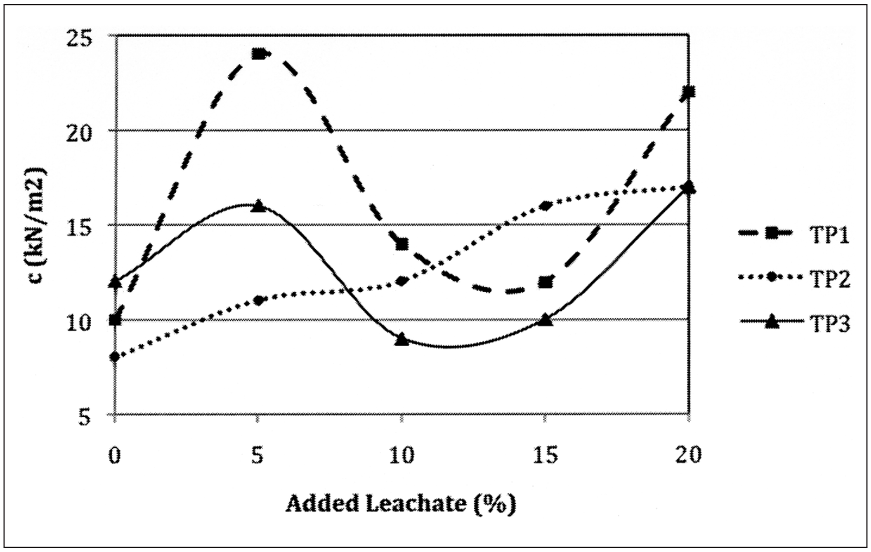

Figure 1. Variation of cohesion with % of leachate added.

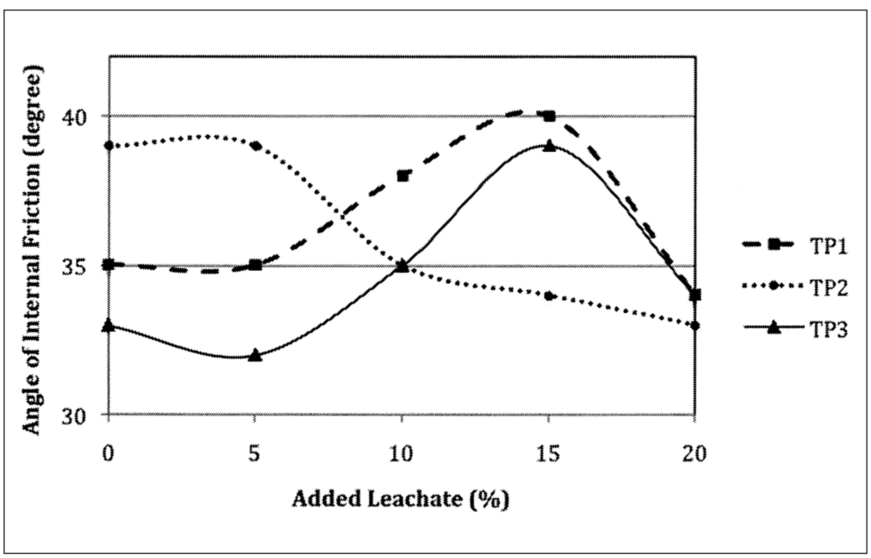

Figure 2. Variation of angle of internal friction with % of leachate added.

values with original shear strength characteristics, one can notice that contamination by leachate increased the value of cohesion and slightly decreased the angle of internal friction as a consequence. This might be attributed to the increase in fines content of the soil as a result of soil-leachate interaction. Similar results were reported for acidic leachate interaction with lateritic soil [10].

Effects of Leachate on Permeability of Soil

The results of the falling head permeability test conducted on the uncontaminated silty sandstone soil and soil-leachate mixture are presented in Table 5 and Figure 3. These results show that the hydraulic conductivity of the soil increased dramatically with the increase in leachate concentration when compared

Table 5. Permeability Characteristic Results (in cm/sec) of Natural Uncontaminated Soil and Soil-Leachate Mixture

	Soil-leachate mixture (leachate % by weight of dry soil)				
Sample	0	5	10	15	20
1	5.324×10^{-7}	1.218×10^{-6}	1.34×10^{-6}	1.243×10^{-6}	1.32×10^{-6}
2	1.75×10^{-6}				
3	1.273×10^{-6}				

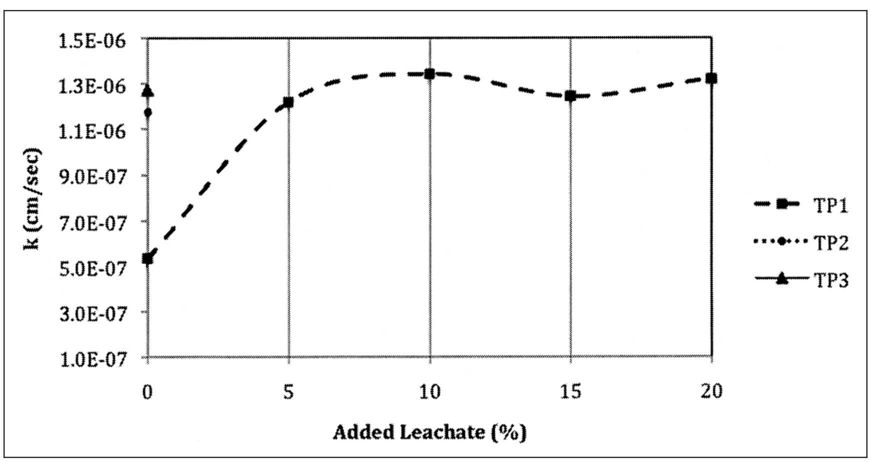

Figure 3. Variation of a soil permeability with % of leachate added.

to the soil's original hydraulic conductivity value. This increase in the hydraulic conductivity value is attributed to chemical reactions as a result of soil-leachate interaction. It is reported in the literature that changes in soil structure occur after contamination with leachate and that the void ratio of a soil increases when the pore water is replaced by leachate as pore fluid [9, 13].

It is also reported in the literature that strongly acidic and strongly basic liquids can dissolve clay minerals [13]. The effective pore voids and hence the value of hydraulic conductivity rise as a result of dissolution of clay minerals by leachate. Moreover, similar behaviors were reported by researches investigating the change of lateritic soil properties due to soil-leachate interaction [9, 10].

Effects of Leachate on Compaction Characteristics

Standard Proctor tests were conducted on uncontaminated soil samples and soil-leachate mixtures after 48 hours of mixing. The results are illustrated in Table 6. The results are also plotted in Figure 4, in the form of maximum dry unit weight versus % of leachate added and Figure 5, in the form of optimum water content versus % of leachate added. The maximum dry unit weight of the silty sandstone material was in the range of 17.55 kN/m^2 at the optimum moisture content of about 11.8%. A slight increase in maximum dry unit weight of the soil accompanied by a general ascending trend of optimum moisture content was noted as a result of increasing the leachate concentration up to 10%. However, when the concentration of leachate increased to 15%, by weight of dry soil, a sudden drop in maximum dry unit weight was experienced. This change in compaction characteristics is attributed to the chemical reactions between the leachate and soil particles due to soil-leachate interaction. Such interaction and

Table 6. Compaction Characteristics Results of Natural Uncontaminated Soil and Soil-Leachate Mixture

Sample	Compaction characteristics	Soil-leachate mixture (leachate % by weight of dry soil)				
		0	5	10	15	20
1	$\gamma_{dry\text{-}max}$(kN/m^2)	17.51	17.83	18.03	17.87	17.95
	w_{opt}(%)	11.6	14.0	14.0	15.0	14.3
2	$\gamma_{dry\text{-}max}$ (kN/m^2)	18.40	18.64	18.73	18.33	18.46
	w_{opt}(%)	11.8	10.8	13.4	14.4	14.0
3	$\gamma_{dry\text{-}max}$ (kN/m^2)	16.76	17.55	17.61	17.65	17.73
	w_{opt}(%)	12	15.4	15.4	15.3	15.5

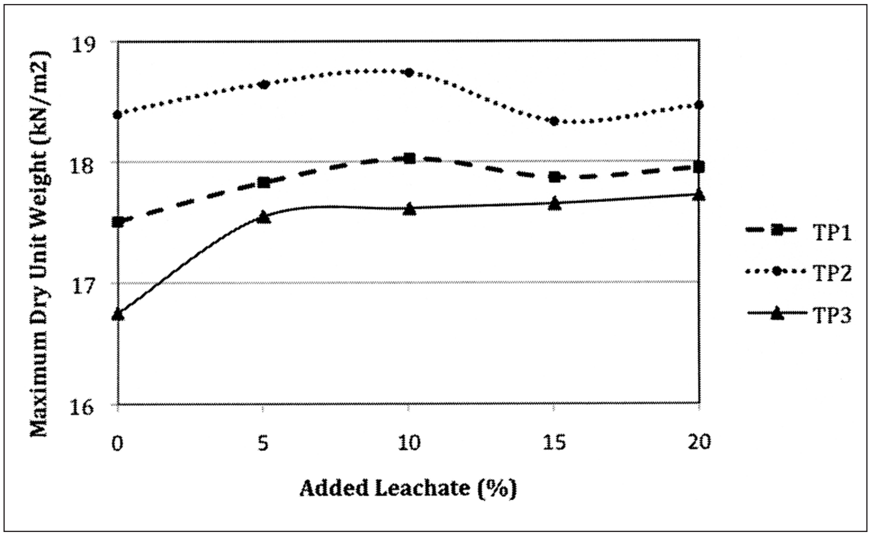

Figure 4. Variation of maximum dry unit weight with % of leachate added.

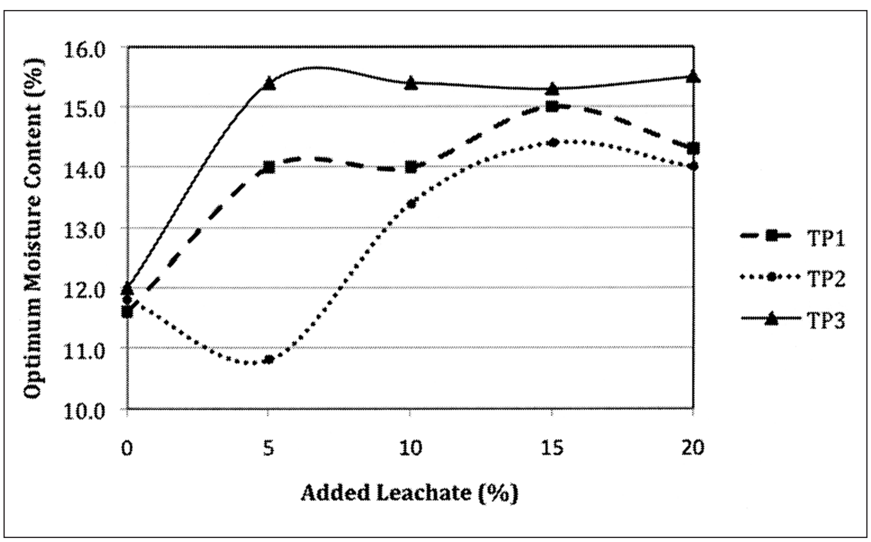

Figure 5. Variation of optimum moisture content with % of leachate added.

change in the nature of pore fluid causes changes in the geotechnical properties of the soil.

Effects of Leachate on Chemical Characteristics

Effects of Leachate on Soil pH

The results of the pH of the three clean soil samples issued indicated that the soil at the site is slightly alkaline (ranging from 7.89–9.03). Since pH determination is crucial as excessive acidity or alkalinity can be detrimental, the effect of soil-leachate interaction was investigated. The experimental results of the soil pH as a function of % of leachate added are illustrated in Table 7 and Figure 6. The results obtained indicated a general descending trend of pH value. The probable reason for this behavior may be due to the very high concentration of Chloride anions content in the leachate used (Table 1) that is absorbed on the soil particles surface.

Effects of Leachate on Electrical Conductivity of Soil

Electrical Conductivity of the uncontaminated silty sandstone material and the soil-leachate mixtures were investigated in the laboratory. The results are illustrated in Table 8 and Figure 7. The results clearly show an increase in the EC when compared to its original value. This influence is attributed to the chemical characteristics of leachate rather than that of soil due to the absorption of chemical constituents of leachate on the soil's particle surface. Similar trends of increase in EC due to the contamination of lateritic soil with leachate were reported [10].

Table 7. pH Results of Natural Uncontaminated Soil and Soil-Leachate Mixture

	Soil-leachate mixture (leachate % by weight of dry soil)				
Sample	0	5	10	15	20
1	7.89	8.03	7.7	7.69	7.58
2	8.56	9.04	7.78	8.13	7.85
3	9.03	9.72	8.75	8.79	8.64

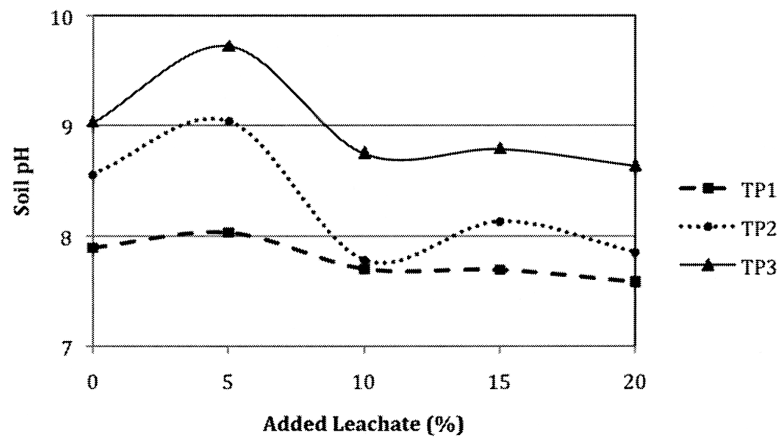

Figure 6. Variation of soil pH with % of leachate added.

Table 8. Electrical Conductivity Results (m^5/cm) of Natural Uncontaminated Soil and Soil-Leachate Mixture

	Soil-leachate mixture (leachate % by weight of dry soil)				
Sample	0	5	10	15	20
1	2.72	3.25	5.36	6.24	6.63
2	2.52	3.73	2.11	2.68	2.96
3	1.50	2.02	1.51	1.05	2.49

Effects of Leachate on Cation Exchange Capacity of Soil

The soil's capacity to absorb and exchange ions is greatly dependent on the amount of clay present in the sample, where exchange of ions takes place due to isomorphous substitution [10]. Cation Exchange Capacity of the uncontaminated silty sandstone material and the soil-leachate mixtures were investigated in the laboratory. The results are illustrated in Table 9 and Figure 8. The results show a fluctuation in the value of CEC as a result of increase in leachate concentration. It is noted that, in general, a maximum value of CEC occurs at leachate concentration of 10–15%. This increase in CEC is attributed to the acquisition of extra negative

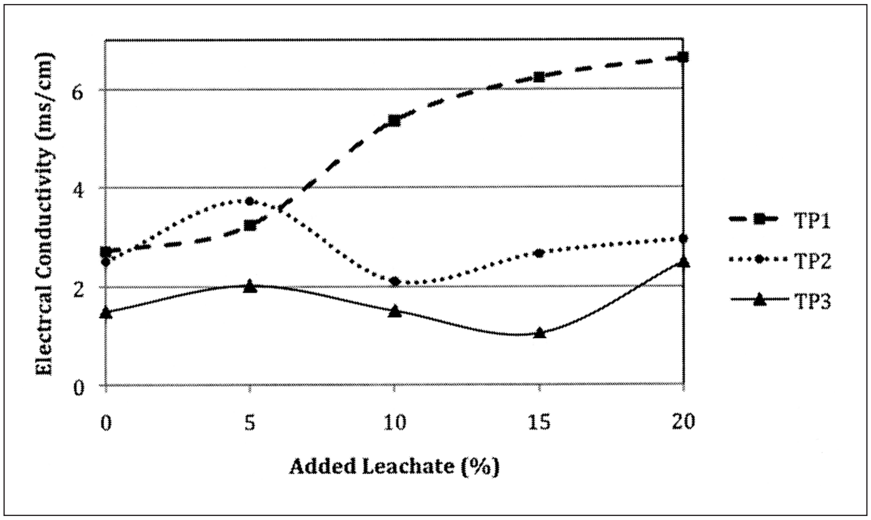

Figure 7. Variation of soil electrical conductivity with % of leachate added.

Table 9. Cation Exchange Capacity Results (in meq/100g) of Natural Uncontaminated Soil and Soil-Leachate Mixture

	Soil-leachate mixture (leachate % by weight of dry soil)				
Sample	0	5	10	15	20
1	6.34	5.80	6.71	7.24	6.22
2	8.30	7.14	6.33	8.21	8.30
3	9.10	9.46	9.91	7.58	8.30

charge as a result of high pH values of the soil and the leachate used as reported by Mathew and Rao [14]. The development of the negative charge is mainly ascribed to the disassociation of hydrogen of SiOH groups in the sample with the negative charge of the oxygen ions [14]. Furthermore, Mathew and Rao [14] affirmed that at high pH Silica and Alumina present in the soil dissolve and form non-crystalline compounds of Silicates and Aluminates that acquire a negative charge and increase the soil's CEC.

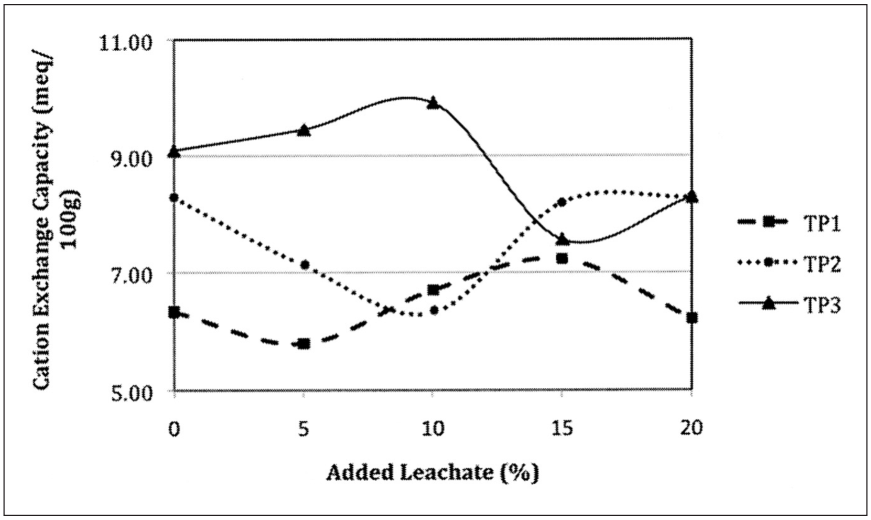

Figure 8. Variation of soil cation exchange capacity with % of leachate added.

Effects of Leachate on Other Chemical Characteristics of Soil

Organic Matter (OM), SO_4, Fe_2O_3, SiO_2, $CaCo_3$, and Al_2O_3 content of the uncontaminated silty sandstone material and the soil-leachate mixtures were investigated in the laboratory. The results are illustrated Table 10 and Figure 9. It is observed that the OM, SO_4, and Fe_2O_3 content in the soil increases. It is also noted that SiO_2, $CaCo_3$, and Al_2O_3 content decreases. This is mainly attributed to the characteristics of the leachate used. The adsorption of the chemical constituent of leachate on the soil surface influences the chemical characteristics of the soil.

CONCLUSION

The preceding results present the short-term effect of leachate contamination on the geotechnical and chemical characteristics of silty sandstone material soil. To vary the degree of contamination, different leachate concentrations were used (0–20%). The results indicate a 41–120% increase in soil cohesion; a 2.8–15.4% decrease in angle of internal friction; a 147% increase in the hydraulic conductivity; a 17.5–144% increase in Electrical Conductivity and a 533–1250% increase in Organic Matter. However, the effect was not significant on the compaction characteristics, the soil pH, the soil Cation Exchange Capacity, SO_4 content, Fe_2O_3 content, SiO_2 content, $CaCo_3$ content, and Al_2O_3 content.

Table 10. Other Chemical Characteristics Results (as a %) of Natural Uncontaminated Soil and Soil-Leachate Mixture

Sample	Chemical characteristics	Soil-leachate mixture (leachate % by weight of dry soil) 0	5	10	15	20
1	OM	0.027	0.089	0.184	0.184	0.171
	SO_4	5.78	5.60	7.06	5.47	7.10
	Fe_2O_3	0.95	0.94	0.98	1.12	1.26
	SiO_2	68.42	69.04	68.7	66.42	66
	$CaCo_3$	7.18	3.59	4.90	5.59	8.50
	Al_2O_3	8.75	5.96	6.34	6.13	6.43
2	OM	0.027	0.10	0.175	0.175	0.183
	SO_4	0.57	0.64	0.72	0.65	0.68
	Fe_2O_3	1.11	1.04	1.26	1.42	1.42
	SiO_2	71.48	71.9	70.16	71.63	70.69
	$CaCo_3$	8.37	3.19	2.19	3.59	4.99
	Al_2O_3	8.73	7.02	6.25	6.27	6.08
3	OM	0.014	0.093	0.151	0.174	0.189
	SO_4	0.10	0.129	0.128	0.14	0.132
	Fe_2O_3	0.85	0.98	1.42	1.57	1.57
	SiO_2	71.76	71.09	70.48	71.1	70.24
	$CaCo_3$	3.19	2.20	2.08	1.19	2.59
	Al_2O_3	9.00	7.23	7.45	6.93	6.45

Open dumping is the general practice of the waste management system in the State of Kuwait and the presented results indicate that pollution due to leachate formation and percolation is still taking place. This pollution could extend over a large area in the incident of heavy rains or heavy irrigation due to the absence of a leachate collection system and flow of water mixed with leachate horizontally causing contamination of soil and groundwater of neighboring areas. In addition, since the dumpsites in the State of Kuwait receive industrial and chemical waste, contamination by heavy metals that is of high concern is also expected.

Evidence showing the occurrence of the degrading affect of contamination with leachate may encourage Kuwaiti officials and decision makers to enforce environmental regulations. It is highly recommended that the Kuwaiti government launch a development program incorporating the construction of landfills and the closure of the contaminated sites issued from solid waste land rising practice to minimize the serious problems of environmental pollution caused mainly by the inadequate and inefficient final disposal of the generated solid waste.

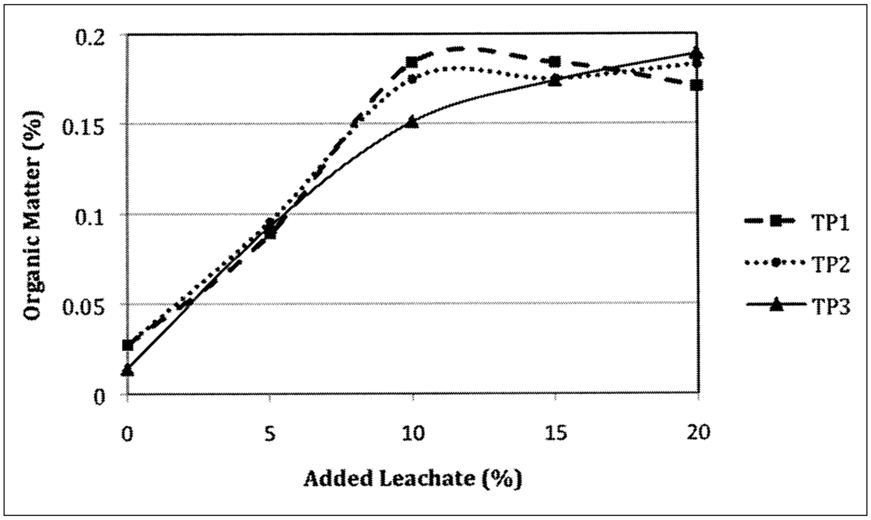

Figure 9. Variation of soil organic matter with % of leachate added.

REFERENCES

1. E. Bahaa-Edin, I. Yusoff, S. Abdul Rahim, W. Zuhairi, and M. Abdul Ghani, Heavy Metal Contamination of Soil Beneath a Waste Disposal Site at Dengkil, Selangor, Malaysia, *Soil Sediment Contamination, 17,* pp. 449-466, 2008.
2. M. Al-Meshan and F. Mahrous, Management of Municipal Solid Waste Landfills in the State of Kuwait, *Proceedings of the 2nd Asian Pacific Landfill Symposium,* Seoul, Korea, 2002.
3. S. Al-Muzaini, Characteristics of Leachate at the Qurain Dumping Site, *Journal of Food, Agriculture, and Environment, 4*:2, pp. 251-254, 2006.
4. J. Al-Medeij and F. Al-Ruwaih, Periodic Behavior of Groundwater Level Fluctuations in Residential Areas, *Journal of Hydrology, 328,* pp. 677-684, 2006.
5. A. Al-Yaqout and M. Hamoda, Evaluation of Landfill Leachate in Arid Climate—A Case Study, *Environment International, 29*:5, pp. 593-600, 2003.
6. M. Anikwe and K. Nowbodo, Long Term Effect of Municipal Waste Disposal on Soil Properties and Productivity of Sites Used for Urban Agriculture in Abakaliki, Nigeria, *Bioresource Technology, 83,* pp. 241-250, 2002.
7. M. Zairi, M. Ferchichi, A. Ismail, M. Jenayeh, and H. Hammami, Rehabilitatión of El Yahoudia Dumping Site, Tunisia, *Waste Management, 24,* pp. 1023-1034, 2004.
8. A. Roque and G. Didier, Calculating Hydraulic Conductivity of Fine-Grained Soils to Leachates Using Linear Expressions, *Engineering Geology, 85,* pp. 147-157, 2006.
9. S. Nayak, B. Sunil, and S. Shrihar, Hydraulic and Compaction Characteristics of Leachate-Contaminated Lateritic Soil, *Engineering Geology, 94,* pp. 137-144, 2007.

10. B. Sunil, S. Shrihari, and S. Nayak, Shear Strength Characteristics and Chemical Characteristics of Leachate-Contaminated Lateritic Soil, *Engineering Geology, 106,* pp. 20-25, 2009.
11. WPCF, *Standard Methods for the Examination of Water and Wastewater* (20th Edition), American Public Health Association, Washington, D.C., *41,* pp. 231-235, 1998.
12. R. Al-Fares and R. Al-Jarallah, Geo-Environmenal Site Characterization at a Waste Disposal Site Using Traditional in Situ Techniques, *The State of Kuwait, Kuwait—Journal of Science and Engineering, 38*:1B, pp. 33-47, 2011.
13. J. Uppot and R. Stephenson, Permeability of Clays Under Organic Permeants, *Journal of Geotechnical Engineering, ASCE, 115*:1, pp. 115-131, 1989.
14. P. Mathew and S. Rao, Influence of Cations on Compressibility Behavior of a Marine Clay, *Journal of Geotechnical Engineering, 123*:11, pp. 1071-1073, 1997.

Direct reprint requests to:

Rana Al-Fares
College of Engineering & Petroleum
Kuwait University
P.O. Box 5969
SAFAT 13060, Kuwait
e-mail: r.alfares@ku.edu.kw