DETERMINATION OF THE COLLAPSE POTENTIAL OF SABKHA SOIL AND DUNE SAND ARID SURFACE SOIL DEPOSITS IN KUWAIT

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Graphical abstract

Abstract

Ensuring the sustainability of critical and limited natural soil resources is a major challenge in arid regions such as Kuwait. Investigations should be performed to identify and characterise collapsible surface soil deposits, and collapse potential should be assessed if possible in order to evaluate suitable stabilizing techniques. The cementation effect of different types of salts gives arid soils their considerable strength and stiffness in dry conditions. The collapse in these soils may occur due to the reduction of the chemical or physical bonds between the soil particles under wet conditions. Collapse Potential (CP) is an indication of the collapsibility of these soils. This paper presents the results of experimental work that was carried out to evaluate the collapse potential of two types of surface soil: sabkha soil and dune sand. The experimental program included physical and chemical soil characterization alongside a modified compaction test. The collapsibility of the soil at a stress of 200 kPa was obtained by performing a Single Collapse Test (SCT) via a conventional odometer device in a temperature- and humidity-controlled environment. Collapse potential index tests were performed on the tested soil samples collected from eight locations in two study areas. The results suggest the problem severity is slight to none. However, the CP was higher for the sabkha soil samples than for the dune sand samples. The increase in collapsibility of the sabkha soil samples may be attributed to the removal of bonding between cementing particles upon wetting, leading to softening due to the rearrangement of soil particles.

Keywords: Sabkha soil, dune sands, collapse potential (CP), Single Collapse Test (SCT), Odometer

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1.0 INTRODUCTION

As Kuwait is located in the north of the Arabian Peninsula’s hot arid desert zone, it has a dry and arid climate with temperatures ranging from 3°C –15°C in winter and 25°C –45°C in summer. As noted by [1], the mean annual rainfall is approximately 105 mm, with November and May experiencing the most rains. Flowing predominantly from the northwest, the winds tend to be dust-ridden and followed by rain and thunderstorms during March and April (Figure 1) [2].

Kuwait’s desert plains are flat and gently undulating [3]. The following major groups are part of its surface deposits: aeolian, playa, residual, desert plain, alluvial fine sand, coastal deposits, and slope deposits [4]. Moreover, windblown dune sand covers some areas of northeast Kuwait, which is uniform soil that has high permeability. The surface windblown dune sands are easily influenced by saturation [5, 6] and are described as poorly graded soil that has high permeability [7], [8] and [9]. Sabkha flats are a major part of northern and southern coastal deposits. Sabkha, an Arabic term, refers to the large, flat, salt-encrusted terrain that is deposited in arid conditions and is made up of clays, sand, silts, and saline mixtures [10].

Kuwait’s low rainfall and high temperatures have led to extremely high evaporation potential that surpasses precipitation by a 30:1 ratio [2]. This has resulted in the saline ground water’s upward movement [11] and an increased concentration of soluble material at or near the ground surface, which then leads to the formation of a cemented crust on the latter [12] as well as the formation of collapsible soils. Gypsum, chlorides, and carbonates form the major precipitated salts that function as cementing agents [13], [14], and [15]. Furthermore, previous cementing agents remain in the surface soil layer, which adds to the occurrences of soil collapse [16], [17], [18], [19] and [20]. As stated by [19], most natural collapsible soils are primarily wind-deposited sand and/or silts, including loess, volcanic dust deposits, and eolian beaches.

Collapsible soils are any unsaturated soils whose particles are drastically rearranged accompanied by significant loss of volume when they are wetted, with or without additional loading [5], [8] and [21].

Kuwait’s collapsible surface soil deposits mean it is necessary to carefully consider and assess the characteristics and properties of collapsible soils. Saturation impacts Kuwait’s surface windblown dune sands and sabkha soils, and ground wetting can also result in their collapse [6] and [13]. Although the sabkhas have low compressibility, test findings suggest that there is high collapsibility for these arid, saline soils. This is mainly because of the dissolution of sodium chlorides, soil grain adjustment, and leaching of calcium ions [13], [14] and [15]. In most cases, the collapsibility process is either instantaneous or short-lived [22]. Collapse behavior causes significant distress as well as damage to man-made structures [23].

Several researchers observed that the construction industry’s lack of knowledge concerning the identification, treatment, and behavior of the collapsing soils has resulted in several cases of foundation problems [24], [25], [26] and [27]. Though several studies have focused on the geotechnical properties of various surface soil deposits in Kuwait and the surrounding region, the geotechnical behavior and the differences in their chemical composition indicates the need for further research in this field to improve our understanding of the behavior of these soils in different conditions. Several researchers have evaluated collapse potential using experimental procedures, including single oedometer tests by [28] and double oedometer tests by [29]. Single oedometer tests are used extensively to assess the collapse potential, which can help in measuring soil collapse settlement. When a small quantity of clay and/or CaCO3 functions as the cementing agent, inundation in oedometer is sufficient to measure the collapse potential [27].

The method outlined above can be used for soils whose matrix has a low percentage of soluble minerals. However, with soils which contain high concentrations of soluble minerals or salts, the conventional inundation of the oedometer’s soil specimen may result in the collapse potential being underestimated. This is because the amount of water may be insufficient for dissolving the present salts, making the water ‘salt saturated’ [27].

This paper will evaluate or quantify the collapse potential of Kuwait’s two primary surface soil deposit types, including sabkha and dune sands. This paper seeks to address the problematic nature of these soils to gain a fundamental understanding of their geotechnical and engineering properties.

An oedometer test can help identify the collapse potential after inundation with water at a 200 kPa stress. This test was conducted as per the procedure proposed by [30] and further described by [12].

2.0 METHODOLOGY

2.1 Material Used

The sampling areas selected for this paper are located in southern Kuwait, and represent the two major types of surface deposit. The first sampling location was Mina Abdullah, which is 60 km to the south of Kuwait City and includes the southern sabkha soil flats. The second sampling location was 80 km to the south of Kuwait City, and includes dune sand accumulations in Al-Wafra Area. Figure 1 shows the two selected sites.

To ensure that the salt-bearing soils were not affected, the disturbed soil samples that were collected were oven-dried for three days in the laboratory at a maximum temperature of 60°C [6], [13] and [31]. First, the soil particles were gently crushed and then screened using a 4.75 mm sieve. The
sieved materials were mixed rigorously, homogenized, and then used to identify the soil index properties.

Figure 1 Sampling location map [30]

2.2 Laboratory Program

The engineering characteristics of the tested soil samples were then measured via a variety of laboratory tests. These included mechanical sieve, liquid limit, hydrometer analyses, plastic limit, compaction, collapse, and chemical tests.

2.2.1 Index Properties

To classify the soil samples as per the unified soil classification system (USCS), tests concerning grain size distribution and Atterberg limits were conducted [31]. Because only the collected sabkha soil sample included a substantial quantity of fines, mechanical sieve as well as hydrometer analyses were conducted as per [32], while mechanical sieve analysis alone was used to examine the dune sand soil samples. Particle size distribution D10, D30, D60, the coefficient of curvature (Cc), and the uniformity coefficient (Cu) were identified.

The plastic and liquid limits tests were conducted for sabkha soil samples as per the [33]. Following this, these two values were used to calculate the plasticity index (PI).

A pycnometer was used as per [34] to determine the specific gravity (Gs) or particle density of different soil samples, while values were assessed considering the average of the two tests. Furthermore, as per [35], modified Proctor compaction tests were conducted to obtain the compaction characteristics, including the maximum dry density (MDD) and optimum moisture content (OMC) for the dune and sabkha sand soil samples. Because of this study’s limited budget, chemical characterization tests were conducted on only two samples from each location.

2.2.2 Collapse Tests

Standard front-loading oedometer tests were performed on the tested soil samples in order to characterize their collapse potential, as per the standard [37] proposed by [38].

This test included a soil specimen being placed in a stainless-steel ring 70 mm in diameter and 20 mm in height, and compacting it to its maximum dry density. Silicone gel was used to lubricate the inside of the ring and decrease the ring’s side friction with the soil specimen. The stainless-steel ring’s compacted sample was then placed between two porous stones. These two stones were saturated by keeping them in distilled water for 24 hours, which would also help in avoiding water absorption from the sample. The specimen was then kept in the consolidation, following which the seating pressure was applied and the load doubled when there was asymptotic monitored dial gauge reading against time. The sample was loaded to a 200 kPa stress and then bombarded with distilled water for 24 hours. Next, calibrated dial gauges were used to calculate additional vertical displacements. The collapse problem severity was classified by the [35], adopting a 200 kPa stress level. Another loading cycle was then applied, and the test was completed.

Each data point represents the average of the two tests performed to check the repeatability of the data.

3.0 RESULTS AND DISCUSSION

3.1 Chemical Analysis

The chemical compositions of the tested sabkha and dune sand soil samples are shown in Tables 1 and 2 respectively. The main component of the Sabkha soil samples is silicon dioxide, with an average value of 32.86%. The second major component is calcium oxide at a 30.50% average value, followed by sulphate at 19.68%. In the dune soil samples, the major component is silicon dioxide at an 86% average, and its other components of predominantly aluminium oxide and calcium oxide are at lower percentages. The pH values of the soils suggest that the tested soil samples have moderate to strong alkaline, with the sabkha soil samples having higher pH values. This may be because of the substantial quantities of carbonates found in the samples.

The findings of this study are similar to those of other studies on sabkha soils in southern Kuwait [36], [37], [38] and [39] as well as on dune sands [7], [8] and [12].
Table 1 Chemical characteristics of sabkha soil samples

| Soil Sample | pH | Organic Content | SiO₂ | CaO | MgO | Fe₂O₃ | Al₂O₃ | K₂O | Na₂O | SO₄²⁻ |
|-------------|----|----------------|------|-----|-----|------|------|-----|------|-------|
| Sbk-1       | 8.2| 1.75           | 34.39| 28.95| 2.13| 1.76 | 4.51 | 0.97| 1.24 | 18.95 |
| Sbk-2       | 8.15| 2.05           | 29.38| 29.65| 1.95| 1.79 | 4.83 | 0.99| 1.51 | 21.95 |
| Sbk-3       | 8.18| 1.96           | 34.3 | 32.38| 1.86| 1.52 | 3.69 | 0.81| 0.89 | 18.78 |
| Sbk-4       | 8.25| 1.25           | 35.86| 31.99| 2.68| 1.95 | 2.96 | 0.91| 1.26 | 19.55 |

*Sbk = Sabkh

Table 2 Chemical characteristics of dune sand soil samples

| Soil Sample | pH | Organic Content | SiO₂ | CaO | MgO | Fe₂O₃ | Al₂O₃ | K₂O | Na₂O | SO₄²⁻ |
|-------------|----|----------------|------|-----|-----|------|------|-----|------|-------|
| Dns-1       | 7.9 | 0.55           | 86.05| 2.2 | 1.2 | 0.85 | 5.15 | 0.85| 0.95 | 0.855 |
| Dns-2       | 7.9 | 0.75           | 87.15| 2.95| 1.1 | 0.65 | 3.85 | 0.85| 0.65 | 0.25  |
| Dns-3       | 8.1 | 0.65           | 87.25| 2.65| 0.95| 0.47 | 4.74 | 0.85| 0.75 | 0.55  |
| Dns-4       | 8.0 | 0.55           | 86.95| 2.2 | 1.07| 0.55 | 4.25 | 0.85| 0.93 | 0.45  |

*Dns = Dune Sand

3.2 Physical Soil Properties

The grain-size distribution curves for the sabkha samples, as illustrated in Figure 2, suggest that the fines passing No. 200 sieve varied from 10 – 18%, and that the collected sabkha samples consisted of sand and no gravel. Further, the dune sand soil samples, as seen in Figure 2, were uniform medium-to-fine sands and contained less than 3% fines. Table 2 shows the tested soil samples’ soil gradation analysis:

The results of the soil gradation are similar to the results noted by [36], [37] as well as [39] regarding southern Kuwait’s sabkha soils, along with the findings of [7], [8], [12] and [40] regarding dune sands. The consistency limits values, as presented in Table 1, indicate that sabkha and dune soil samples were low-plastic and non-plastic, respectively. The sabkha soil’s low plasticity is considered to be a result of its low fine contents and low clay particle count. According to the Unified Soil Classification System (USCS), the sabkha sand soil samples are regarded as poorly graded silty sand (SP-СМ), while the dune sand soil samples are poorly graded sand (SP). The results of the soil classification tests are similar to the findings of other studies investigating soils from Kuwait and the Gulf region, such as those by [37], [38], [39], and [39]. The specific gravity values of the sabkha and dune sand soil samples were 2.65 and 2.8 respectively. The specific gravity values of the sabkha soils are lower than the specific gravity values of typical or silty sands. This is supposed to be caused by the combined impact of the specific gravity’s low oven temperature (60°C) and the high salt content of the sabkha soils [41].
3.3 Compaction Characteristics

Figures 4 and 5 illustrate the findings from the modified Proctor compaction tests regarding the selected sabkha and dune sand soil samples. They demonstrate that there are defined peaks in the compaction curves from the sabkha soil samples, and double peaks in the flatter compaction curves of the dune sand soil samples. Table 3 presents the optimum moisture content (OMC) as well as maximum dry density (MDD) values.

The sabkha soil has higher dry density values than the dune sand samples because of the cementation effect of the sabkha soil particles, while the compacted dune soil's higher void may be caused by its lower fines content. The MDD and OMC values observed in this study are similar to the findings of other studies concerning sabkha soils in Kuwait and the Gulf region, such as those by [38] and [39].

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3.4 Collapse Potential Test

This test’s primary aim is to assess the collapse potential of both the sabkha and dune sand soil samples, which is the collapse strain at a 200 KPa applied pressure [25].

Figures 6 and 7 illustrate a collapse test’s e-log p relationship concerning the sabkha and dune sand soil samples respectively, regarding a 200kPa normal pressure. The 200 kPa loading mark’s vertical line indicates the sudden compression followed by inundation. The vertical line’s length under a 200 kPa normal pressure refers to the measure of the soil’s collapsibility, as presented in Figures 8 and 9 for the sabkha and dune sand soil samples. The figures show that the 200 kPa reading mark’s vertical line is longer for the sabkha soil samples than for the dune sand soil samples.
Collapse potential is calculated using the following equation:

\[
CP = \Delta e / (1 + eo)
\]  \hspace{1cm} (1)

Where:

\( \Delta e \) is the difference in void ratio of the two samples at a specific stress, while \( eo \) is the natural void ratio.

Table 4 presents the calculated collapse potential concerning the tested soil samples.

The collapse potential of the four sabkha soil samples varies from 0.136 – 0.54%, while the dune sand soil sample’s collapse potential ranges from 0.095 – 0.16%.

As per [27] recommended severity rating, no problems were observed in any tested soil samples regarding slight with collapse. While the collapse potential was highest for the sabkha soil samples, it was the lowest for the dune sand soil samples, which is primarily because of their chemical composition. Because the soil composition of the dune sand is low in fine and salt content, it involves a more competent and stable matrix. Overall, the sabkha soil’s cementation that the salts provide may be weakened by the moisture present in sabkha soils, which decreases the strength and increases the soil’s compressibility. According to laboratory and field evidence, the fine-grained matrix causes the collapse phenomenon, and this collapse behavior can be caused by as little as 5 – 20 % fines [43].
apparent at certain locations that are compacted at low relative density because of ground wetting [46]. However, it has been noted that when the coarse-grained soils present in a geologically susceptible environment are wetted, they can collapse despite having significantly high SPT blow counts and high densities [43].

4.0 CONCLUSION

This study examined the collapse potential of Kuwait’s two major soil surface deposits: sabkha soil and dune sands. The results of the soil characterization as well as the standard front-loading odometer tests allow us to draw several conclusions. It was noted that the sabkha soil and dune sand samples contained high levels of silicon dioxide, at 32.86% and 86.0% respectively. While the sabkha soil had higher compaction characteristics and its peaks were clearly defined, the dune sand soil had flatter compaction curves and double peaks.

Moreover, although the sabkha soil’s collapse potential was higher than for dune sand, it is not regarded as a problematic soil. This may be because of its higher concentration of salts compared to those found in dune sand samples, which can result in higher collapse potential. Further studies on other sabkha locations that have higher salt content are therefore necessary.

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References

[1] Al-Ruwaili, F. M. 1995. Hydrogeochemical Variation of Carbonate Aquifer Al Sulabiya [South] Kuwait. Journal of Water, Air and Soil Pollution. 90: 489-505. DOI: 10.1007/BF00282664.
[2] Al-Kulaib, A. A. 1984. The Climate of Kuwait, Directorate General of Civil Aviation (DGA). Meteorological Department. 178.
[3] Al-Saleh, S. and Khalaf, F. I. 1982. Surface Texture of Quartz Grains from Various Recent Sedimentary Environments in Kuwait. Journal of Sedimentary Petrology. 52(1): 215-225. DOI: 10.1306/212F7F18-2B24-11D7-8648000102C1865D.
[4] Khalaf, F. I., Gharib, I. M. and Al-Hashash, M. Z. 1984. Types and Characteristics of Recent Surface Deposits of Kuwait Arabian Gulf. Journal of Arid Environments. 7(1): 9-33. DOI: 10.1016/S0140-1963(84)80001-4.
[5] Ismael, N. F. 1984. Cement Stabilisation of Kuwait Soils. Arab Gulf Journal of Scientific Research. 2(1): 349-360.
[6] Ismael, N. F. and Mollah, M. A. 1998. Leaching Effects on Properties of Cemented Sands in Kuwait. Journal of Geotechnical and Geoenvronmental Engineering.
Development, Journal of Transportation Engineering, 128(3): 295-300. DOI: 10.1061/(ASCE)0733-947X(2002)128:3(295).

[25] Ayadat, T. and Hanna, A. M. 2013. Design of Foundations Built on a Shallow Depth (Less than 4 m) of Egyptian Macra-
Porous Collapsible Soils. Open Journal of Geology. 3(3): 209-215. DOI: 10.4236/ojg.2013.33024.

[26] Hawraa, Y. M., Al-Musawi, H. M. and Salman, A. F. 2012. Treatment of Collapsibility of Gypseous Soils by Dynamic 
Compaction. Geotech Geol Eng, 30(6): 1369-1387. DOI: 10.1007/s10706-012-9552-z.

[27] Mansour, Z. M., Chik, Z. and Taha, M. R. 2008. On the Procedures of Soil Collapse Potential Evaluation. Journal of 
Applied Science. 8(23): 4434-4439. DOI: 10.3923/jas.2008.4434.4439.

[28] Jennings, J. K. and Knight, K. 1975. The Additional Settlement of Foundation Due to Collapse of Sandy Subsoils 
on Wetting. Proceeding of 4th International Conference on Soil Mechanics and Foundation Engineering.

[29] Houston, S. L., Houston, W. N., and Spadola, D. J. 1988. Prediction of Field Collapse of Soils Due to Wetting. 
Journal of Geotechnical Engineering, ASCE. 114(1): 40-58.

[30] Knight, K. 1963. The Origin and Occurrence of Collapsing Soils. Proceedings of the Third Regional Conference for 
Africa 1963 on Soil Mechanics and Foundation Engineering. 127-130.

[31] Ismael, N. F. 1993. Geotechnical Characteristics of Salt Bearing Soils in Kuwait. Transportation Research Board 72nd 
Annual Meeting. Paper No. 930035. Washington, D. C.

[32] ASTM D2487. 2000. Standard Classification of Soils for Engineering Purposes (Unified Soil Classification System). 
West Conshohocken, PA, USA: American Society for Testing and Materials (ASTM) International.

[33] ASTM D422-63. 1998. Standard Test Method for Particle-Size Analysis of Soils. West Conshohocken, PA, USA: 
American Society for Testing and Materials (ASTM) International.

[34] ASTM D4318. 2005. Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils. West 
Conshohocken, PA, USA: American Society for Testing and Materials (ASTM) International.

[35] ASTM D854-14. 2014. Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer. West 
Conshohocken, PA, USA: American Society for Testing and Materials (ASTM) International.

[36] ASTM D1557-12. 2012. Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified 
Effort (56,000 ft lbf/ft³ (2,700 kN-m/m³)). West Conshohocken, PA, USA: American Society for Testing and Materials 
(ASTM) International.

[37] ASTM D5333. 2003. Standard Test Method for Measurement of Collapse Potential of Soils. West Conshohocken, PA, USA: 
American Society for Testing and Materials (ASTM) International.

[38] Aidaifani, H. M. Z. 2017. A Geotechnical, Geochemical and Human Health Risk Assessment of a Dry Oil Lake Site in 
Kuwait. Doctoral Thesis, University of Portsmouth, Portsmouth, England, U.K. Retrieved from: 
https://researchportal.port.ac.uk/portal/en/theses/a-geotechnical-geochemical-and-human-health-risk-assessment-of-a-dry-oil-lake-site-in-kuwait/97d40f4a-4b60-4c92-b82d-1a7999b0b729.html

[39] Al-Otaibi, F. A., Wegian, F. M., Alnai, A. A., Almutairi S. K. H. and Singhd, R. M. 2012. Effect of Bitumen Addition on 
the Long-Term Permeability of Sabkha Soil. Kuwait J. Sci. Eng. 39: 131-148.

[40] Al-Otaibi, Fahad Abeerad. 2020. Variation of Sabkha Soil Permeability Associated with IonicSi½ Dissolution during 
Distilled Water Leaching. Jordan Journal of Civil Engineering, 14(2).

[41] Al-Otaibi, F. A. 2020. Dissolution Behavior of Corrosive Anions from Sabkha Soil Southern Kuwait Under Long Term 
Leaching. International Journal of GEOMATE. 19(74): 138-144.

[42] Al-Hurban, A. and Gharib, I. 2004. Geomorphological and Sedimentological Characteristics of Coastal and Inland 
Sabkhas, Southern Kuwait. Journal of Arid Environments. 58(1): 59-85. DOI: 10.1016/S0140-1963(03)00128-9.

[43] Al-Taie, A. J., Al-Shakarchi, Y. J. and Mohammed, A. A. 2013. Investigation of Geotechnical Specifications of Sand 
Dune Soil: A Case Study Around Basji in Iraq. IJEM Engineering Journal. 14(2): 121-132. DOI: 
https://doi.org/10.31436/ijenje.v14i2.408.

[44] Al-Sanad, H. A. 1986. Characterisation of Salt-Bearing Soils (Sabkha) for Pavement Design Purposes in the State of 
Kuwait. Journal of the University of Kuwait-Science. 13(1): 29-41.

[45] Al-Amoudi, O. S. B., Abduljuwaad, S. N., Al-Naggar, Z. R. and Rasheeduzzafar. 1992. Response of Sabkha to Laboratory 
Tests - A Case Study. Engineering Geology. 33(2): 111-125. DOI: 10.1016/0013-7952(92)90003-H.

[46] Rollins, K. M., Rollins, R. L., Smith, T. D. and Beckwith G. H. 1994. Identification and Characterization of Collapsible 
Gravels. Journal of Geotechnical Engineering. 120(3): 528. DOI: 10.1061/(ASCE)0733-9410(1994)120:3(528).

[47] Al-Amoudi, O. S. B. and Abduljuwaad S. N. 1995. Compressibility and Collapse Characteristics of Arid Saline 
Sabkha Soils. Engineering Geology, 39(3-4): 185-202. DOI: 10.1016/0013-7952(95)00016-9.

[48] Al-Otaibi, F. A. and Aldaifani, H. M. 2018. Influence of Bitumen Addition on Sabkha Shear Strength Characteristics 
Under Dry and Soaked Conditions. American Journal of Engineering and Applied Science. 11(4): 1199-1209. DOI: 
10.3844/ajeassp.2018.1199.1208.

[49] Ismael, N. F. 2019. Properties and Behavior of Arid Climate Soil Deposits in Kuwait. Project from Civil Engineering 
Department, Kuwait University retrieved on 5 April 2019 from http://reprints.kfupm.edu.sa/1798/1/343-
384_PROPERTIES_AND_BEHAVIOR_OF_ARID_CLIMATE_SOIL_DEPOSITS_IN_KUWAIT_Nabil_F_Ismail_Kuwait_University.PDF.

[50] Al-Amoudi, O. S. B. and Abduljuwaad, S. N. 1995. Compressibility and Collapse Characteristics of Arid Saline 
Sabkha Soils. Engineering Geology. 39(3-4): 185-202. DOI: 10.1016/0013-7952(95)00016-9.