Tikrit Journal of Pure Science Vol. 29 (5) 2024

TJPS

https://doi.org/10.25130/tjps.v29i5.1676

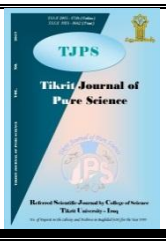
IASJ

المجلات الاكاديمية العراقية

Tikrit Journal of Pure Science

ISSN: 1813 – 1662 (Print) --- E-ISSN: 2415 – 1726 (Online)

Journal Homepage: http://tjps.tu.edu.iq/index.php/j



Effect of Chloride Solution on Liquid Limit, and Plasticity Index of Soil in Selected Sites in Erbil /North Iraq

Nadhmia Najmaddin Majeed

Department of Earth sciences and petroleum, College of Sciences, University of Salahaddin, Erbil, Iraq

ARTICLE INFO.

Article history:

-Received: 9 / 7 / 2024

-Received in revised form: 12/ 7 / 2024

-Accepted: 17 / 8 / 2024

-Final Proofreading: 27 / 8 / 2024

-Available online: 25 / 10 / 2024

Keywords: Chloride solution, Atterberg Limit, Swelling soil, Clay mineral and Grain size analysis

Corresponding Author:

Name: Nadhmiah Najmaddin Majeed

E-mail: Nadhmia.Majeed@su.edu.krd

Tel: + 964 07504686583

ABSTRACT

This study is an attempt to investigate the effect of NaCl, $CaCl_2$, KCl, and NH_4Cl solutions with different concentrations (2.5%, 5%, 7.5%) on the liquid limit, plastic limit, and plasticity index of Sarbasty and Mamwastayan soil samples /Erbil Governorate. The soil samples' liquid and plastic limits were found by using the cone penetrometer method. The Results showed that the soil's liquid, plastic limits, and Plasticity index decreased with increasing salt solution concentration. Maximum reduction of liquid limit and plastic limit in Sarbasty was from 53.6 to 34.3 and in Mamwastayan from 35.9 to 27.2, both accomplished by adding a concentration of 7.5% of KCl and $CaCl_2$ respectively. According to the Unified Soil Classification System, the Sarbasty soils were classified as high plasticity clay (CH), and Mamwastayan low plasticity clay (CL). After adding different concentrations of salt solution to the soil, the Sarbasty soil classification changed from CH to CL. Mineralogically these soils are composed of non-clay minerals of calcite and quartz and clay minerals consisting of Montmorillonite, Chlorite, swelling Chlorite, Kaolinite, Illite, Palygorskite, and Illite- Chlorite. Sarbasty soil was the most effective salt chloride solution than the Mamwastayan soil sample swelling.

Tikrit Journal of Pure Science Vol. 29 (5) 2024

TJPS

https://doi.org/10.25130/tjps.v29i5.1676

تأثير محلول الكلوريد على حد السيولة ومؤشر اللدونة للتربة في اربيل

نظمية نجم الدين نجيد

قسم علوم الأرض والنفط، كلية العلوم، جامعة صلاح الدين، أربيل، العراق

الملخص

هذه الدراسة هي محاولة لمعرفة تأثير محاليل NaCl، $CaCl_2$، KCl، وNH_4Cl بتراكيز مختلفة (2.5%، 5%، 7.5%) على حد السيولة وحد اللدونة ومعامل اللدونة لعينات تربة سربستي وماموستايان في مدينة اربيل. تم تحديد الحدود السيولة واللدونة ومعامل اللدونة لعينات التربة باستخدام طريقة الاختراق المخروطي. أظهرت النتائج أن قيم السيولة وحدود اللدونة ومعامل اللدونة للترب تتناقص مع زيادة تركيز المحلول الملحي. الحد الأقصى لتخفيض حد السائل وحد اللدونة في سربستي كان من 53.6 إلى 34.3 وفي ماموستايان من 35.9 إلى 27.2، وقد تم تحقيق كليهما بإضافة تركيز 7.5% من كلوريد الصوديوم وكلوريد الكالسيوم على التوالي. تم تصنيف تربة سربستي إلى طينية عالية اللدونة (CH)، وماموستايان الى طينية قليلة اللدونة (CL) حسب نظام تصنيف التربة الموحد. تغيرت تصنيف تربة سربستي من CH إل CL بعد إضافة تراكيز مختلفة من المحلول الملحي إلى التربة، من الناحية المعدنية تتكون هذه الترب من معادن غير طينية من الكالسيت والكوارتز ومعادن طينية تتكون من المونتموريلونيت والكلوريت والكلوريت المنتفخ والكاؤلينيت والإيليت وباليجورسكيت والإيليت كلوريت. وكانت تربة سربستي اكثر تاثيرا بمحلول كلوريد الملح من تربة ماموستايان

1- Introduction

Soil is unconsolidated accumulations of solid particles or sediments produced by the physical and chemical weathering of rocks. Soil properties vary from one region to another, and different forms of soils act differently in the construction works. The soil type of a construction site has an enormous influence on the design and costs of the building to be constructed. Also, different kind of soil requires various foundations to ensure a stable construction process. Clay soil requires additional materials in the foundation as the clay might swell or shrink, depending on the water content in the foundation, thus leading to cracks in the walls and foundation of the construction building [1]. Many problems have been noticed when structures were constructed on expansive soil. Fly ash powder could be used as an enhancement material for expansive soil in different locations in Erbil city that has destroyed various structures [2].

The effect of, NaCl, $CaCl_2$, and $MgCl_2$ on the hydraulic conductivity, compaction and free swelling, and consolidation characteristics of two types of clay-bentonite mixtures. The hydraulic conductivity and the maximum dry

https://doi.org/10.25130/tjps.v29i5.1676

density of the soils increase and the optimum water content and swelling volume decrease with increases in salt concentration Investigated by [3]. The effect of water salinity on compression index, swelling index, and Atterberg limits of fine-grained soil decreased and shear strength parameters and consolidation coefficient increased as pore water salinity increased studied by [4] The effect of different concentrations of NaCl and $CaCl_2$ on the different soil-bentonite mixtures show that the hydraulic conductivity (k) increase, liquid limit and compressibility of the mixtures decreases with an increase in the salt concentration. [5,6]. Effect of different concentrations of Salt Solution on Shear Strength of Clays with varied plasticity. Results show that solution form and its concentration affect the shear strength properties of the clay with varied plasticity [7,8]. The addition of salt-lake solution affects the expansive soil. The cohesion, internal friction angle, free expansion rate, liquid limit, plastic limit, and plastic index of expansive soil were decreased by increasing the concentration of salt-lake solution [9].

The effects of varying sodium chloride percentages on various expansive soil geotechnical properties were examined. The findings showed that while the California bearing ratio, maximum dry density, and unconfined compressive strength values increased, the specific gravity, Atterberg limits, free swell index, and optimum water content values of the stabilized soil decreased as the salt concentration increased. [10,11,12,13]. The Effect of saline water decreases soil compressibility, swelling index, plasticity index, and optimum moisture content while increasing the permeability, maximum dry density, consolidation coefficient, shear strength, and bearing capacity of soil [14, 15].

This study aims to investigate the potential of saline water obtained by mixing distilled water and salts at different concentrations as an efficient chemical stabilizer in expansive soils by examining its effects on liquid, plastic limit, and plasticity index. Clay minerals are soil particles that adhere tightly in dry conditions and shift once wet. These modifications influence engineering features such as liquid and plastic limits. The salt solution will be used to simulate the liquid. Clays are more sensitive to liquid fluctuations, affecting liquid and plastic limits.

1.1- Geology of the study area

For this investigation, two locations—Sarbasty and Mamwastayan—in the Erbil Governorate were selected (Fig. 1). Both sample locations were found in the Foot Hill Zone. Thick, unconsolidated quaternary sediments of clay, silt, sand, and gravel with both fine and coarse grain materials dominate the area [16].

https://doi.org/10.25130/tjps.v29i5.1676

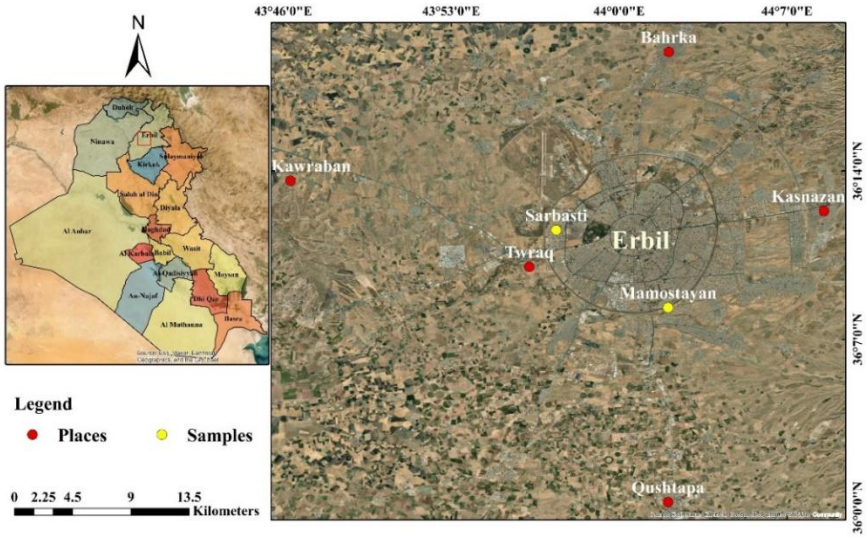


Fig. 1: Location map of soil sample of the study area

2- Materials and methods

In the present study, two different disturbed soil samples were taken at depth 0.5m from the Sarbasty and Mamwastayan areas

2.1- Samples Preparation:

sample of soil was divided into 13 parts. The first part of each sample was left in its natural state, while the other 12 parts of each sample which include dry natural soil, were mixed with different concentrations (%2.5, %5, %7.5) of solution of (NaCl, $CaCl_2$, KCl and NH_4Cl). These were used as additive materials to the disturbed samples of soil taken from two locations, the Sarbasty and Mamwastayan location

2.2- Test program

Samples of both natural soil and those mixed with the three different percentages of chloride solution were analyzed for grain size, liquid limit, plastic limit, specific gravity, and x-ray diffraction. Grain size analysis for soil specimens uses sieve analysis and hydrometer to measure the percent of gravel, sand, silt, and clay was performed according to the standard American Society Test Method [17]. The test procedure of liquid limit was done by using the cone penetration method according to BS 1377:1990, test No.2A [18]. The plastic limit test was performed according to BS 1377:1990, test No.3 [18].

The specific gravity (GS) was determined according to the standard method of the American Society for Testing and Material [19]. Mineralogy was made by analysis carried out using X-ray diffraction (XRD) on soil samples to identify bulk mineral components and clay minerals [20].

3- Results and Discussion

3.1- Grain size analysis

The grain size analysis of the soil particles by using a sieve and hydrometer method for two samples of soil. The results showed that the percentage of the particles in Sarbasty and Mamwastayan soil contained clay percent about (51.3%, 34.19%) where the silt percent is (44.3%, 57.51%) and sand percent is (4.4%, 8.3)) respectively (Fig.2, 3).

https://doi.org/10.25130/tjps.v29i5.1676

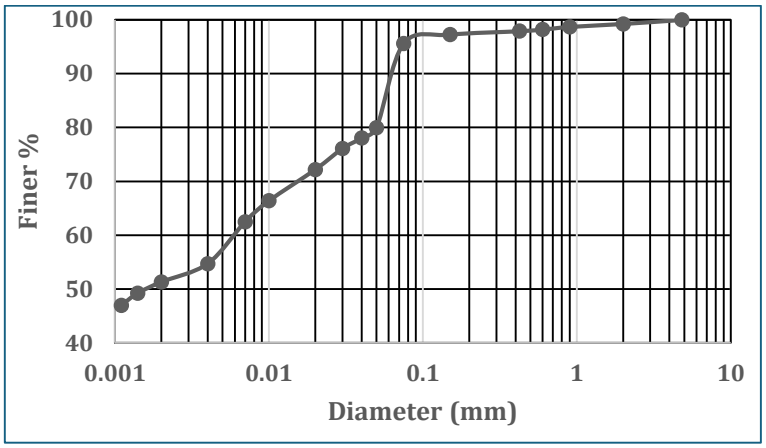


Fig. 2: Grain size analysis of Sarbasty soil

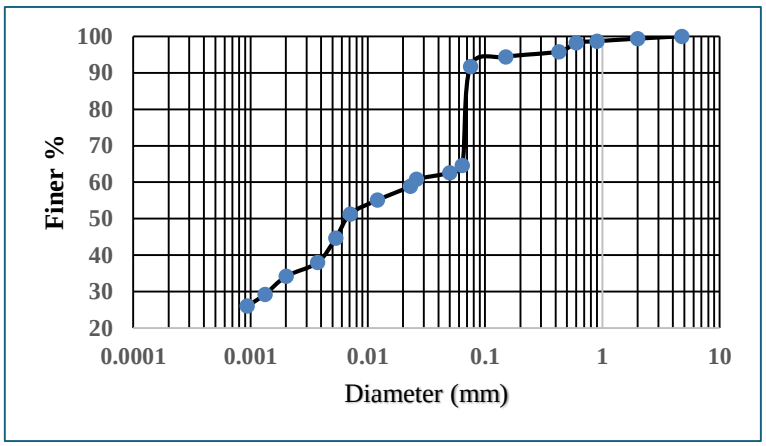


Fig. 3: Grain size analysis of Mamwastayan soil

3.2- Atterberg limit

3.2-1 Liquid limit

From (Table 1, 2) and (Fig. 4, 5) below shows that the liquid limit of Sarbasty and Mamwastayan for untreated soil is (53.6) and **(**35.9) respectively by adding the percent (2.5, 5, 7.5)gm/100ml of NaCl, $CaCl_2$, KCl, and NH_4Cl to normal soil the liquid limit decreased as the concentration increased. The maximum reduction of liquid limit in Sarbasty was from 53.6 to 34.3 and in Mamwastayan from 35.9 to 27.2, both accomplished by adding a concentration of 7.5% of KCl and $CaCl_2$ respectively. The sarbasty untreated soil is classified as clay of high plasticity (CH) and Mamwastaya**n** untreated soil of low plasticity(CL) according to the unified soil classification system(USCS) (Fig. 6a, 6b).

https://doi.org/10.25130/tjps.v29i5.1676

Table 1: Liquid limit of normal and treated soils by adding the different percentages of salt solution in the Sarbasty area

Position	Chloride Salts	LL			
		Normal	Normal soil with adding Salt Solution		
			2.5gm/100ml	5gm/100ml	7.5gm/100ml
		53.6			
Sarbasty	NaCl		52.6	40.5	38.6
	CaCl		48.03	46.2	45.4
	KCl		50	42.1	34.3
	NH_4Cl		50.75	46.3	42.5

Table 2: Liquid limit of normal and treated soils by adding the different percentages of salt solution in Mamwastayan area

Position	Chloride Salts	LL			
		Normal	Normal soil with adding Salt Solution		
			2.5gm/100ml	5gm/100ml	7.5gm/100ml
		35.9			
Mamwastayan	NaCl		35.2	32.5	30.8
	CaCl		31.6	29.04	27.2
	KCl		33.6	31.8	31.2
	NH_4Cl		35.6	32.45	31.7

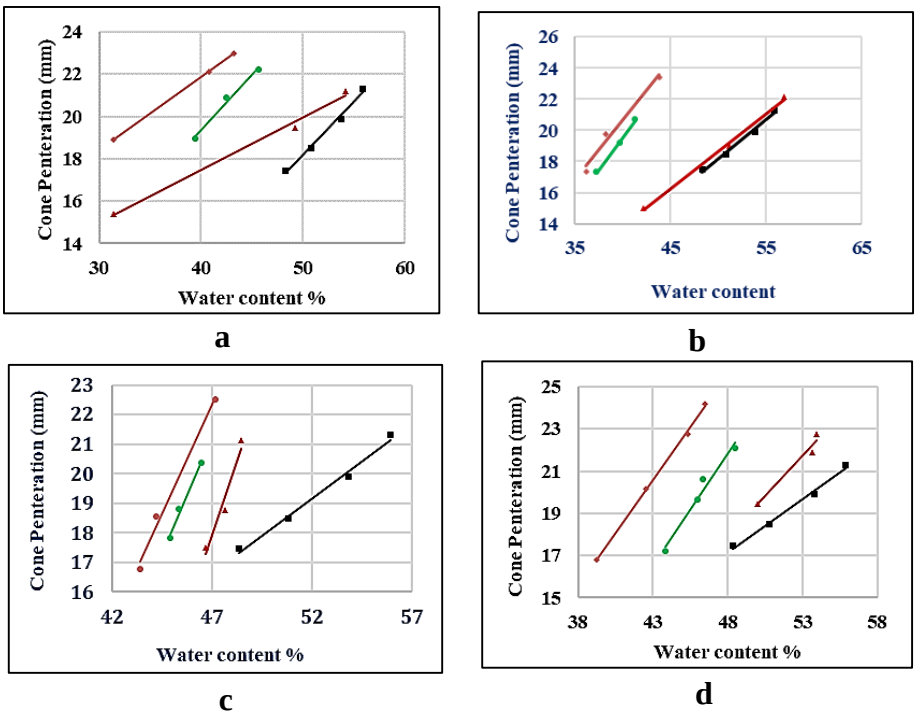


Fig. 4: Liquid limit of normal and treated with different percentages of salt solution in Sarbasty soil (a) NaCl (b)KCl (c) $CaCl_2$ (d) NH_4Cl

https://doi.org/10.25130/tjps.v29i5.1676

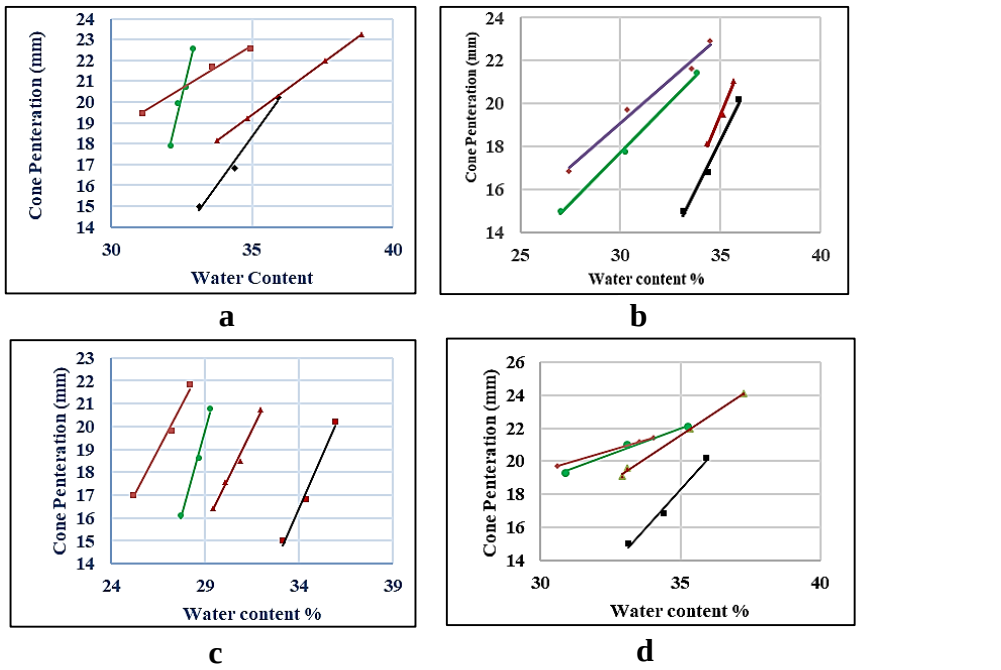


Fig. 5: Liquid limit of normal and treated with different percentages of salt solution in Mamwastayan soil (a) NaCl (b)KCl (c) $CaCl_2$ (d) NH_4Cl

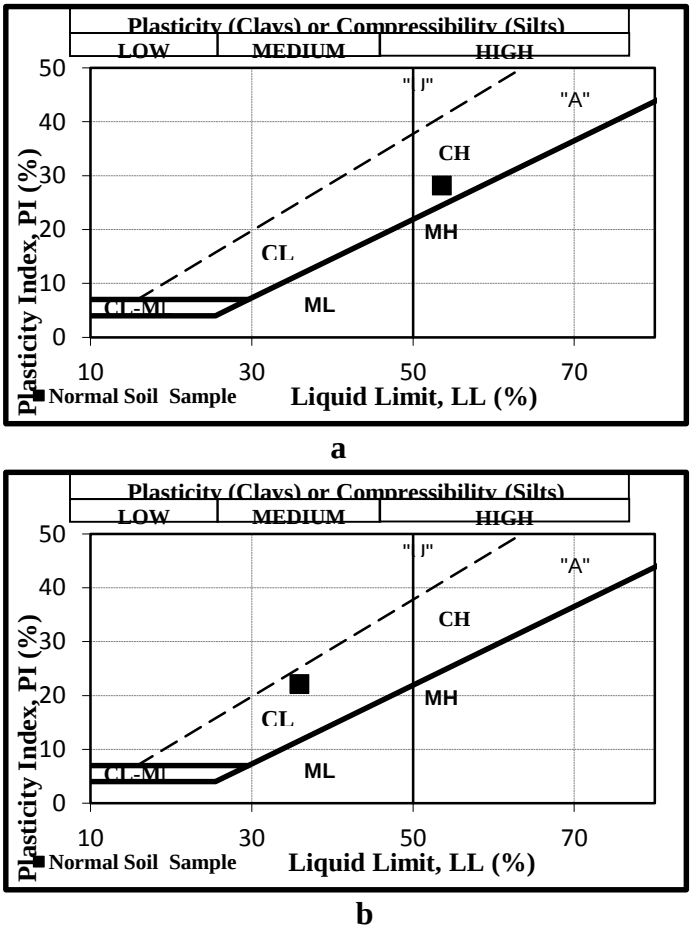
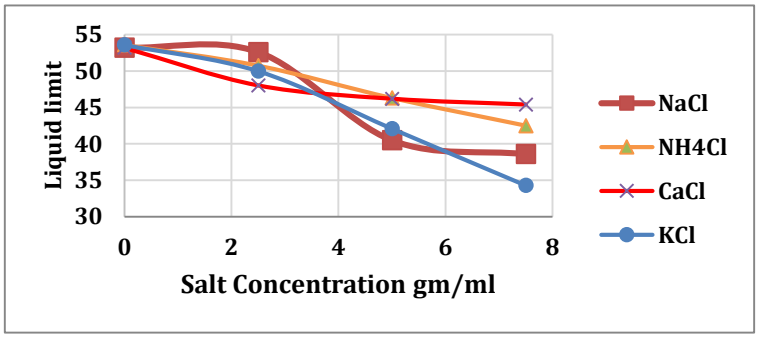


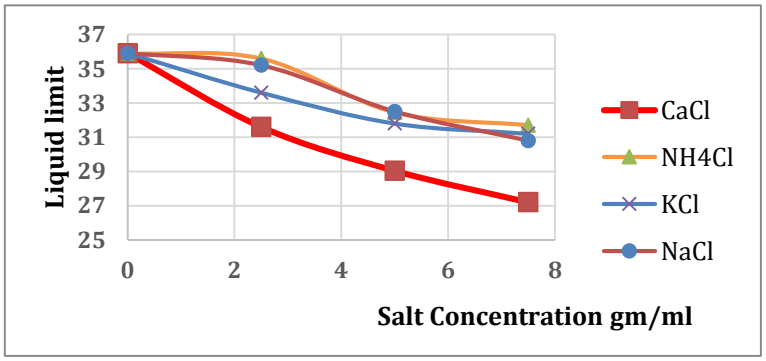
Fig. 6: Plasticity chart of normal soil sample of (a) Sarbasty (b) Mamwastayan

https://doi.org/10.25130/tjps.v29i5.1676

The variation of the liquid limit of soils with various concentrations of different chlorides is shown in (Fig. 7a, 7b). liquid limit decreases with higher chloride concentration.



a



b

Fig. 7: Variation of the liquid limit of various concentration of different chlorides a) sarbasty soil b) Mamwastayan soil

3.2-2 Plastic limit

Plastic Limit as a result of the addition of the concentration (2.5%,5%,7.5%)gm/100ml of NaCl, $CaCl_2$, KCl, and NH_4Cl to normal soil samples, the plastic limit value (PL) of both Sarbasty and Mamwastayan samples decreased as the concentration percentage increased. The maximum reduction of plastic limit in Sarbasty soil was from 25.38to 10.63 (Table, 3), while in Mamwastayan soil it was from 13.76 to 7.95 (Table, 4), both achieved by the addition of 7.5 % of the KCl and $CaCl_2$ respectively.

Table 3: Platic limit of normal and treated soils by adding the different concentrations of salt solution in Sarbasty

Position	Chloride Salts	PL			
		Normal	Normal soil with adding Salt Solution		
			2.5gm/100ml	5gm/100ml	7.5gm/100ml
Sarbasty		25.38			
	NaCl		24.8	15.87	14.49
	CaCl		21.08	20.07	19.85
	KCl		23.17	17.65	10.63
	NH_4Cl		22.99	19.45	17.16

https://doi.org/10.25130/tjps.v29i5.1676

Table 4: Plastic limit of normal and treated soils by adding the different concentrations of salt solution in Mamwastayan

Position	Chloride Salts	PL			
		Normal	Normal soil with adding Salt Solution		
			2.5gm/100ml	5gm/100ml	7.5gm/100ml
Mamwastayan		13.76			
	NaCl		13.57	13.45	13.37
	CaCl		10.3	8.92	7.95
	KCl		12	10.9	10.8
	NH_4Cl		13.7	11.32	10.89

3.2-3 Plasticity index

The maximum reduction value of the plasticity index (PI) of Sarbasty soils was 23.67 (Table 5), while Mamwastayan was 17.43 (Table 6), both caused by adding 7.5% of KCL and NaCl respectively. These results indicate that the plasticity index decreased by increasing the salt solution concentration.

Table 5: Plasticity index of normal and treated soils by adding the different concentrations of salt solution in Sarbasty

Position	Chloride Salts	PI			
		Normal	Normal soil with adding Salt Solution		
			2.5gm/100ml	5gm/100ml	7.5gm/100ml
Sarbasty		28.22			
	NaCl		27.8	24.63	24.11
	CaCl		26.95	26.13	25.55
	KCl		26.83	24.45	23.67
	NH_4Cl		27.76	26.85	25.34

Table 6: Plasticity index of normal and treated soils by adding the different concentrations of salt solution in Mamwastayan

Position	Chloride Salts	PI			
		Normal	Normal soil with adding Salt Solution		
			2.5gm/100ml	5gm/100ml	7.5gm/100ml
Mamwastayan		22.14			
	NaCl		21.63	19.05	17.43
	CaCl		21.3	20.12	19.25
	KCl		21.6	20.9	20.4
	NH_4Cl		21.9	21.13	20.81

3.3 Specific Gravity (GS)

The specific gravity of Sarbasty soils was about 2.67 while that of Mamwastayan soils was about 2.61.

3.4 Mineralogical Tests

The soil samples are studied by X-ray diffraction method (XRD). Several XRD runs were prepared for normal soil samples of both

https://doi.org/10.25130/tjps.v29i5.1676

locations to study clay type and non-clay minerals.

The soil samples were treated with ethylene glycol and heated at 500°c for the distinction between the clay minerals constituting a clay mass. The results show that non-clay minerals are quartz and calcite (Fig. 8a, 8b); while the clay minerals are chlorite, montmorillonite, kaolinite, illite, illite-chlorite, swelling chlorite and palygorskite, (Fig. 9a, 9b). The dominant occurrence of palygorskite among the clay minerals reflects the arid and semi-arid climatic conditions.

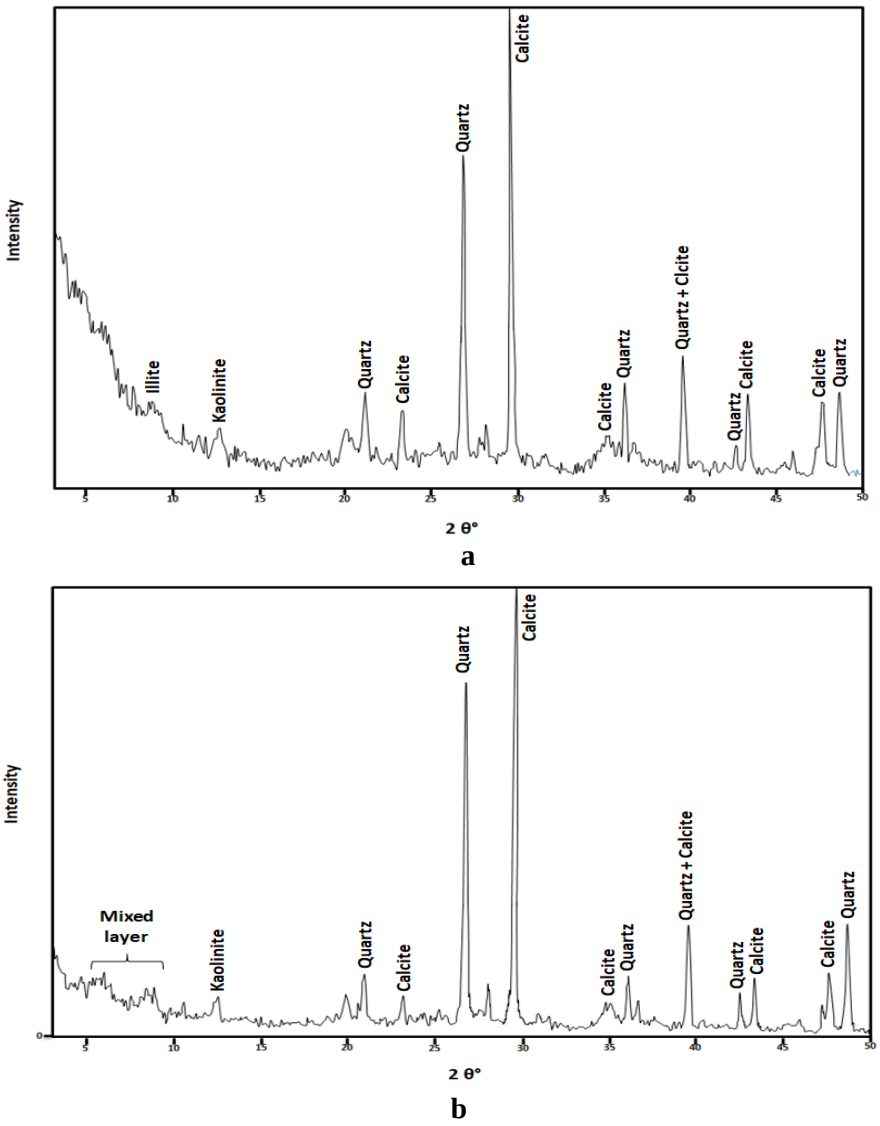
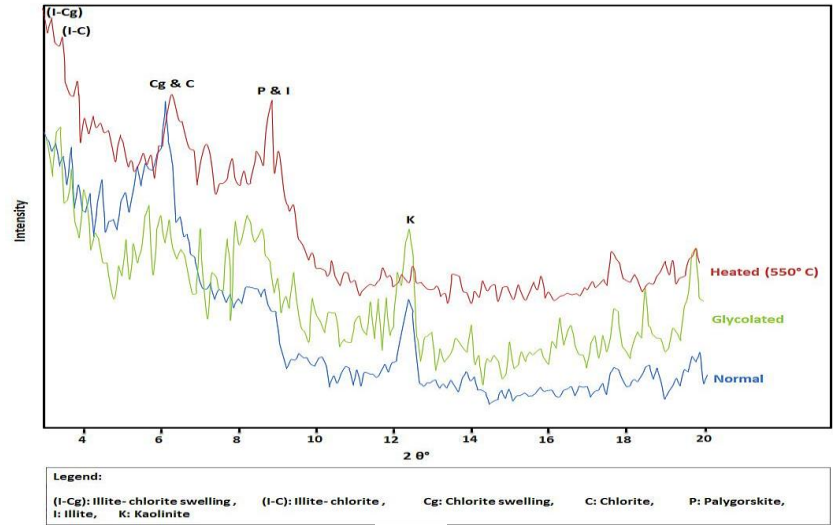
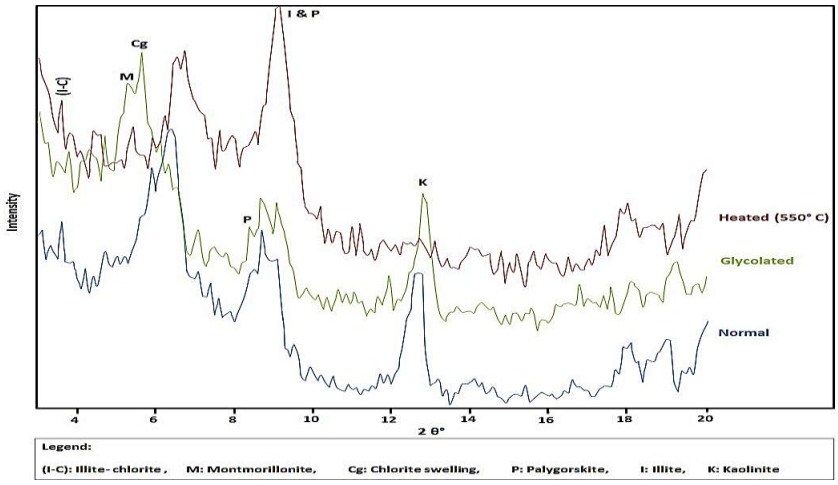


Fig. 8: X-ray Diffractogram of the Bulk normal soils (a) Sarbasty (b) Mamwastayan

https://doi.org/10.25130/tjps.v29i5.1676



a



b

Fig. 9: X-ray Diffraction pattern of the clay fraction of normal soils (a) Sarbasty (b) Mamwastayan

Discussion

The Results of the Atterberg limit existing in (Tables, 1,2,3, 4, 5, 6) and (Fig. 4, 5, 6) show that the liquid, plastic limits, and Plasticity index of the soils decreased with increasing salt solution concentration. According to the Unified Soil Classification System, the Sarbasty soils were classified as high plasticity clay (CH), and Mamwastayan low plasticity clay (CL). After adding different concentrations of salt solution to the soil, the Sarbasty soil classification changed from CH to CL. The maximum reduction of liquid limit and plastic limit in Sarbasty was from 53.6 to 34.3 and in Mamwastayan from 35.9 to 27.2. The maximum reduction of plastic limit in Sarbasty soil was from 25.38 to 10.63, while in Mamwastayan soil it was from 13.76 to 7.95, both accomplished by adding a concentration of 7.5% of KCl and $CaCl_2$ respectively. The maximum reduction value of the plasticity index (PI) of Sarbasty soils was 23.67, while Mamwastayan was 17.43 (Table-6), both caused by adding 7.5% of KCL and NaCl respectively. High effect of salt

solution on the liquid limit than the plastic limit because the soil moisture is higher in the liquid limit than plastic limit, The reduction of the liquid limit and the plastic limit is due to the reduction in the thickness of the diffuse double layer as the salt content increased causing the soil to shrink. The decrease of plastic and liquid limit by using saline water of the Dead Sea was recognized by [21]. Montmorillonite comprises two silica-based tetrahedral sheets with water molecules inside the interlayer sheets and is effectively accessible for the approaching contaminants [22]. The water content of montmorillonite is variable and it increases in the soil volume when it absorbs water. Cation exchange capacity is a property of soil introduced by clay minerals. The capacity of soil to hold cations (Al^{3+}, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Mn^{2+}, Cu^{2+}, Zn^{2+}, Fe^{2+}, H^{+}) [23]. Sarbasty soil was the most effective salt chloride solution than the Mamwastayn soil sample because composed of different compositions of clay minerals such as Montmorillonite which caused soil swelling.

Conclusion

The following conclusions were attained from this study:

1-The grain size analysis of Sarbasty and Mamwastayan revealed different percentages of clay (51.3%, 34.19%), silt (44.3%,57.51%), sand (4.4%, 8.3%), respectively.

2-The specific gravity of Sarbasty normal soil was (2.67), and of Mamwastayan was 2.61.

3-According to the Unified Soil Classification System (USCS), the Sarbasty soils were classified as high plasticity clay (CH), and Mamwastayan low plasticity clay (CL). After adding different concentrations of salt as a solution to Sarbasty soil, the soil classification changed from CH to CL.

4-The addition of salt solution (NaCl, $CaCl_2$, KCl, NH_4Cl) with different concentrations (%2.5, %5, %7.5) in the normal soil of Sarbasty and Mamwastayan led to decreases in liquid limit, plastic limit, and plasticity index value.

5-Maximum reduction of liquid limit, plastic limit and plasticity index in Sarbasty and Mamwastayan by adding a concentration of 7.5% of KCl and $CaCl_2$ respectively. Their results were definite that the effect of salt solution depended on the salt concentration and soil properties.

6-Sarbasty soil was the most effective salt chloride solution than the Mamwastayn soil sample because composed of different compositions clay minerals such as Montmorillonite which caused soil swelling.

References

[1] Richter, D. D., et al. (2020). Soil production and the soil geomorphology legacy of Grove Karl Gilbert. Soil Science Society of America Journal, 84 (1):1-20. http://dx.doi.org/10.1002/saj2.20030

[2] Rashid, T. and Majeed, N. (2022). Effect of Fly ash powder on the physical properties of expansive soils, Tikrit Journal of Pure Science,27(4):51-59. http://dx.doi.org/10.25130/tjps.27.2022.053

[3] Shariatmadari, N., Salami, M. and Fard, M. K. (2011). Effect of inorganic salt solutions on some geotechnical properties of soil-bentonite mixtures as barriers. International Journal of Civil Engineering, 9 (2): 103-110 https://ijce.iust.ac.ir/article-1-570-en.

[4] Ajalloeian, R., Mansouri, H. and Sadeghpour, A. H. (2013). Effect of saline water on geotechnical properties of fine-grained soil. Electron. J. Geotech. Eng, 18: 1419-1435. https://www.researchgate.net/publication/279897636 .

[5] Mishra, A. K., Ohtsubo, M., Lotetta, Y. L., Higashi, T., and Park, J. (2009). Effect of salt of various concentrations on liquid limit, and hydraulic conductivity of different soil-bentonite mixtures, Environmental Geology,57(5):1145-1153. https://doi.org/10.1007/s00254-008-1411-0

[6] Fatahi, B., Khabbaz, H. and Basack, S. (2011). Effects of salinity and sand content on liquid limit and hydraulic conductivity. Australian Geomechanics Journal, 46 (1): 67-76. https://www.researchgate.net/publication/259742432

[7] Naeini, S. A. and Jahanfar, M. A. (2011). Effect of Salt Solution and Plasticity Index on undrained Shear Strength of Clays. World Academy of Science, Engineering and Technology International Journal of Materials and Metallurgical Engineering, 5(1):982-986. https://zenodo.org/record/1058403/files/3054.

[8] Francesco, M., Gemmina, D. E. and Peter, O.V. I. (2010). Diffusion of calcium chloride in a modified bentonite: Impact on osmotic efficiency and hydraulic conductivity Clays and Clay Minerals, 58(3):351–363. https://link.springer.com/article/10.1346/CCMN.2010.0580306

[9] Shaowei, Z. and Dongdong, L. (2022). The Effects of Salt-Lake Solution on the Strength of Expansive Soil, Geofluids, 1(38):1-8. http://dx.doi.org/10.1155/2022/2798281

[10] Durotoye, T.O and Akinmusuru, J.O. (2016). Effects Of Sodium Chloride on The Engineering Properties of Expansive Soils, International Journal of Research in Engineering and Technology, 5 (9): 11- 16. http://ijret.esatjournals.org/

[11] Durotoye, T.O., Akinmusuru, J.O., Ogbiye, A.S., and Bamigboye, G.O. (2016). Effect of common salt on the engineering properties of expansive soil. Int. J. Eng. Technol.,6(7):233-241. https://www.researchgate.net/publication/309012936

[12] Prakhar, D. and Rajesh, J. (2015). Effect of common salt (NaCl) on engineering properties of black cotton soil. Int. J. Sci. Technol. Eng., 2(1): 64 – 68. https://www.ijste.org

[13] Kumar, B.N., Smitha, J., and Uday, K.V. (2015). Effect of salinity on geotechnical properties of expansive soils. Int. J. Innov. Res. Sci. Eng. Technol., 4(7):6008-6015.

https://www.ijirset.com/upload/2015/july/115_36.

[14] Elsawy, M. B. D. and Lakhouit, A. (2020). A review on the impact of salinity on foundation soil of coastal infrastructures and its implications to north of Red Sea coastal constructions, Arabian Journal of Geoscience, 13 (555):1-12 doi:10.1007/s12517-020-05601-6

[15] Ajalloeian, R., Mansouri, H, and Sadeghpour, A, H. (2013). Effect of Saline Water on Geotechnical Properties of Fine-grained Soil, Electronic journal of Geotechnical Engineering, 18:1419-1435. https://www.researchgate.net/publication/279897636_

[16] Jassim, S.Z. and Goff, J.C. (2006). Geology of Iraq. Dolin, Prague and Moravian Museum, Brno, Czech Republic, 341PP.

[17] ASTM, D, 422-63. (2007). Standard test method for particle-size analysis of soils. Annual book of ASTM standards, 4: 10-16. www.astm.org

[18] British Standard Institution. (1990). Method of test of soils for civil engineering purpose (BS 1377 part :2), London, https://bayanbox.ir/view/4017830864152809913/BS-1377-Part-2.

[19] ASTM D 854. (2000). Standard test methods for specific gravity of soil solids by water pycnometer, Designation D854-00, American Society for Testing and Materials, West Conshohocken, PA. https://webstore.ansi.org/standards/astm/astmd85400?gad_source=1&gclid=Cj0KCQjwhb60BhClARIsABGGtw9zTMc4uXemcq6kIWSrnIKVSewYhgHdaRDyb1awde3f51eC5jtQ4SAaArCdEALw_wcB

[20] Brindly, G.W. and Brown, G. (1980). Crystal Structures of Clay Minerals and their X-ray Identification, Miner. In Society, London, 5: 495PP. https://doi.org/10.1180/mono-5

[21] Mahasneh, B., Z. (2004). Dead Sea Water as a Soil Improvement Agent, Electronic Journal of Geotechnical Engineering, 9(1):1-14 https://www.researchgate.net/profile/Bassam-Mahasneh-3/publication/290054709

[22] Moore, D. E., and Lockner, D. A. (2010). Comparative deformation behavior of minerals in serpentinized ultramafic rock: Application to the slab- mantle interface in subduction zones, Int. Geol. Rev., 49(5): 401–415, https://doi.org/10.2747/0020-6814.49.5.401

[23] Anonymous, Agronomy Fact sheet Series (fact Sheet 22). (2007). Cation Exchange Capacity, Cornell University Cooperative Extension. Available from:1-2 http://www.css.cornell.edu