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

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## ABSTRACT

This study is an attempt to investigate the effect of NaCl, CaCl<sub>2</sub>, KCl, and NH<sub>4</sub>Cl 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<sub>2</sub> 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.

## تأثير محلول الكلوريد على حد السيولة ومؤشر اللدونة للتربة في أربيل

نظمية نجم الدين نجيد

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## الملخص

هذه الدراسة هي محاولة لمعرفة تأثير محاليل  $\text{NaCl}$ ،  $\text{CaCl}_2$ ،  $\text{KCl}$ ، و  $\text{NH}_4\text{Cl}$  بتركيزات مختلفة (2.5%، 5%، 7.5%) على حد السيولة وحد اللدونة ومعامل اللدونة لعينات تربة سريستي وماموستايان في مدينة أربيل. تم تحديد الحدود السيولة واللدونة ومعامل اللدونة لعينات التربة باستخدام طريقة الاختراق المخروطي. أظهرت النتائج أن قيم السيولة وحدود اللدونة ومعامل اللدونة للتربة تتناقص مع زيادة تركيز المحلول الملحي. الحد الأقصى لتخفيض حد السائل وحد اللدونة في سريستي 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 سريستي إلى طينية عالية اللدونة (CH)، وماموستايان إلى طينية قليلة اللدونة (CL) حسب نظام تصنيف التربة الموحد. تغيرت تصنيف تربة سريستي من CH إلى CL بعد إضافة تراكيز مختلفة من المحلول الملحي إلى التربة، من الناحية المعدنية تتكون هذه التربة من معادن غير طينية من الكالسيت والكوارتز ومعادن طينية تتكون من المونتموريلونيت والكلوريت والكلوريت المنتفخ والكاؤلينييت والإيليت وباليجورسكيت والإيليت كلوريت. وكانت تربة سريستي أكثر تأثراً 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,  $\text{NaCl}$ ,  $\text{CaCl}_2$ , and  $\text{MgCl}_2$  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

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<sub>2</sub> 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].

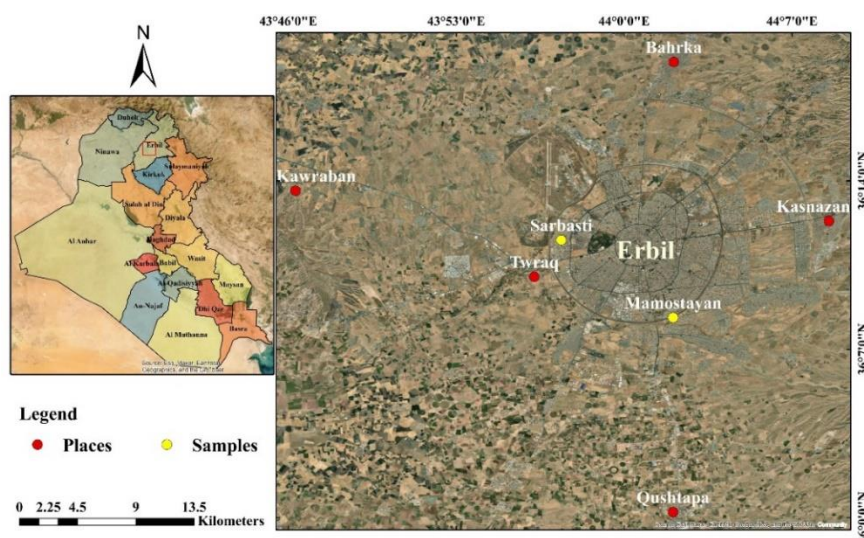


Fig. 1: Location map of soil sample of the study area

## 2- Materials and methods

In the present study, two different disturbed soil samples were taken at depth 0.5m from the Sarbasti 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<sub>2</sub>, KCl and NH<sub>4</sub>Cl). These were used as additive materials to the disturbed samples of soil taken from two locations, the Sarbasti 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 Sarbasti 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).

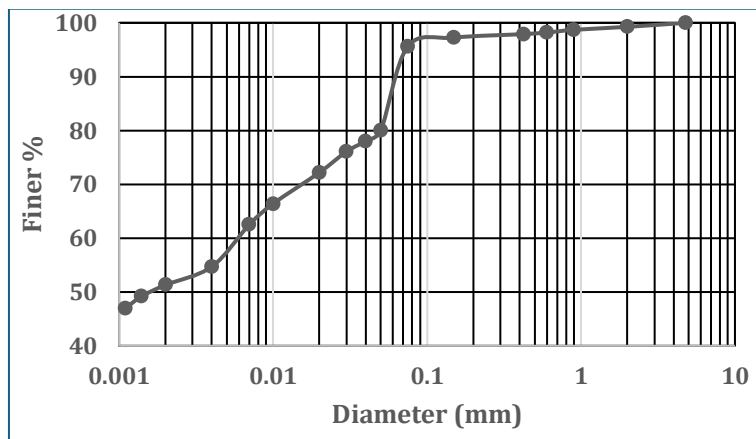


Fig. 2: Grain size analysis of Sarbasty soil

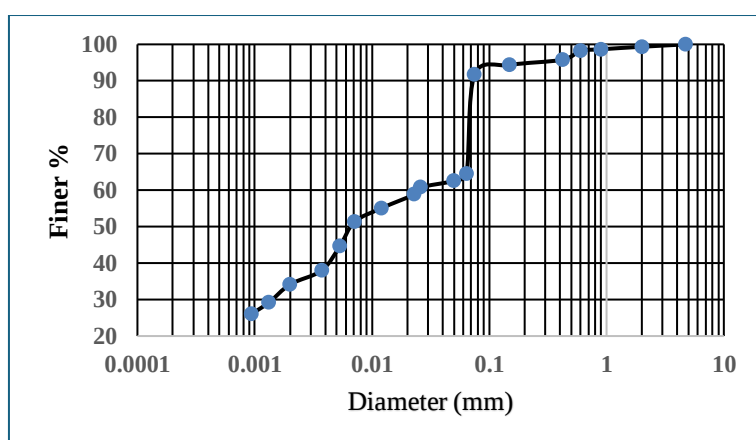


Fig. 3: Grain size analysis of Mamwastayan soil

### 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<sub>2</sub>, KCl, and NH<sub>4</sub>Cl to normal soil the liquid limit decreased as the concentration increased. The maximum

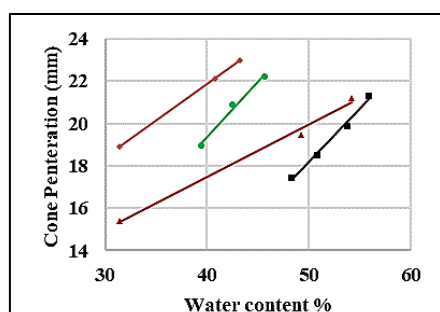
reduction of liquid limit in Sarbasty was from 53.6 to 34.3 and in Mamwastayan from 35.9 to 27.2, both accomplished by adding a concentration of 7.5% of KCl and CaCl<sub>2</sub> respectively. The sarbasty untreated soil is classified as clay of high plasticity (CH) and Mamwastayan untreated soil of low plasticity (CL) according to the unified soil classification system (USCS) (Fig. 6a, 6b).

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

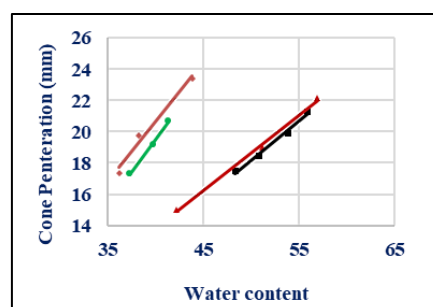
| Position | Chloride Salts     | LL     |                                       |           |             |
|----------|--------------------|--------|---------------------------------------|-----------|-------------|
|          |                    | Normal | Normal soil with adding Salt Solution |           |             |
|          |                    |        | 2.5gm/100ml                           | 5gm/100ml | 7.5gm/100ml |
| Sarbasty |                    | 53.6   |                                       |           |             |
|          | NaCl               |        | 52.6                                  | 40.5      | 38.6        |
|          | CaCl               |        | 48.03                                 | 46.2      | 45.4        |
|          | KCl                |        | 50                                    | 42.1      | 34.3        |
|          | NH <sub>4</sub> Cl |        | 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

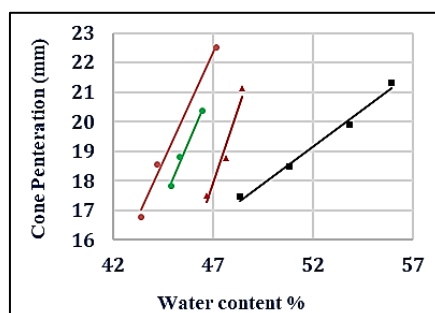
| Position    | Chloride Salts     | LL     |                                       |           |             |
|-------------|--------------------|--------|---------------------------------------|-----------|-------------|
|             |                    | Normal | Normal soil with adding Salt Solution |           |             |
|             |                    |        | 2.5gm/100ml                           | 5gm/100ml | 7.5gm/100ml |
| Mamwastayan |                    | 35.9   |                                       |           |             |
|             | NaCl               |        | 35.2                                  | 32.5      | 30.8        |
|             | CaCl               |        | 31.6                                  | 29.04     | 27.2        |
|             | KCl                |        | 33.6                                  | 31.8      | 31.2        |
|             | NH <sub>4</sub> Cl |        | 35.6                                  | 32.45     | 31.7        |



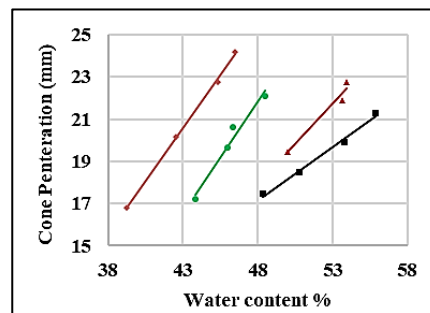
a



b



c

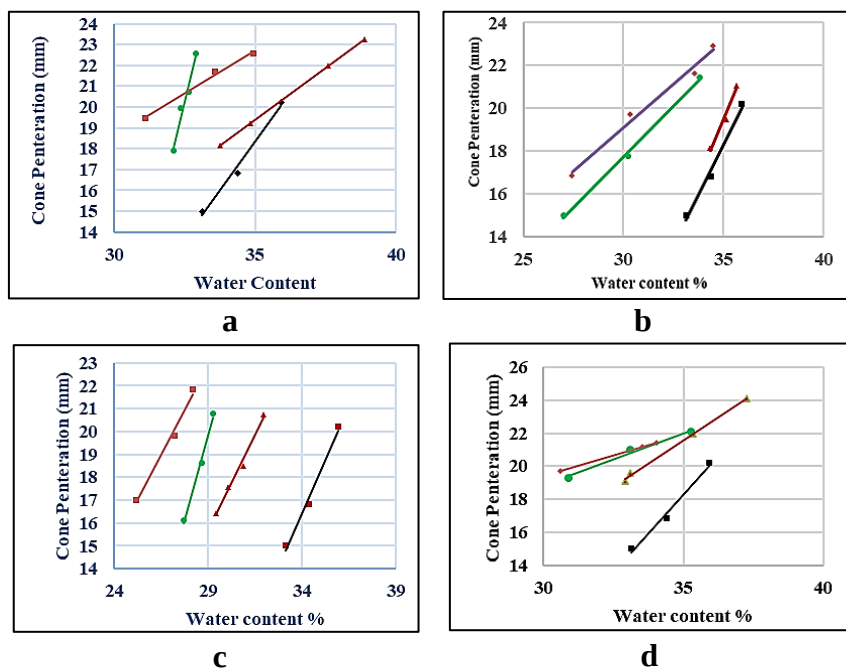


d

— Normal — 2.5 gm/100 ml — 5 gm/100 ml — 7.5 mg/100 ml

Fig. 4: Liquid limit of normal and treated with different percentages of salt solution

in Sarbasty soil (a) NaCl (b) KCl (c) CaCl<sub>2</sub> (d) NH<sub>4</sub>Cl



— Normal — 2.5 gm/100 ml — 5 gm/100 ml — 7.5 gm/100 ml  
 Fig. 5: Liquid limit of normal and treated with different percentages of salt solution in Mamwastayan soil (a) NaCl (b) KCl (c) CaCl<sub>2</sub> (d) NH<sub>4</sub>Cl

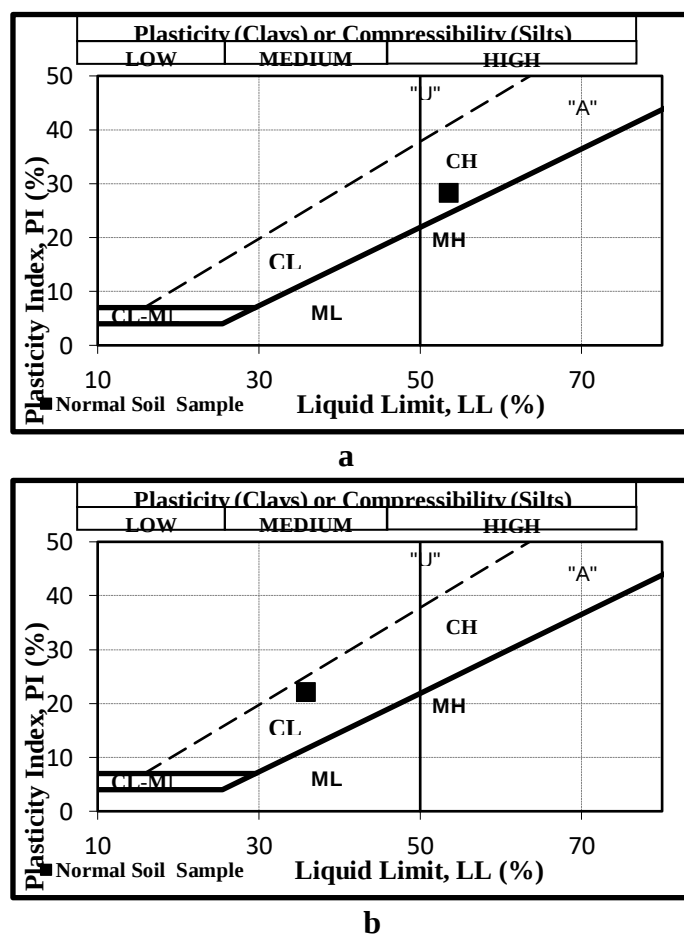
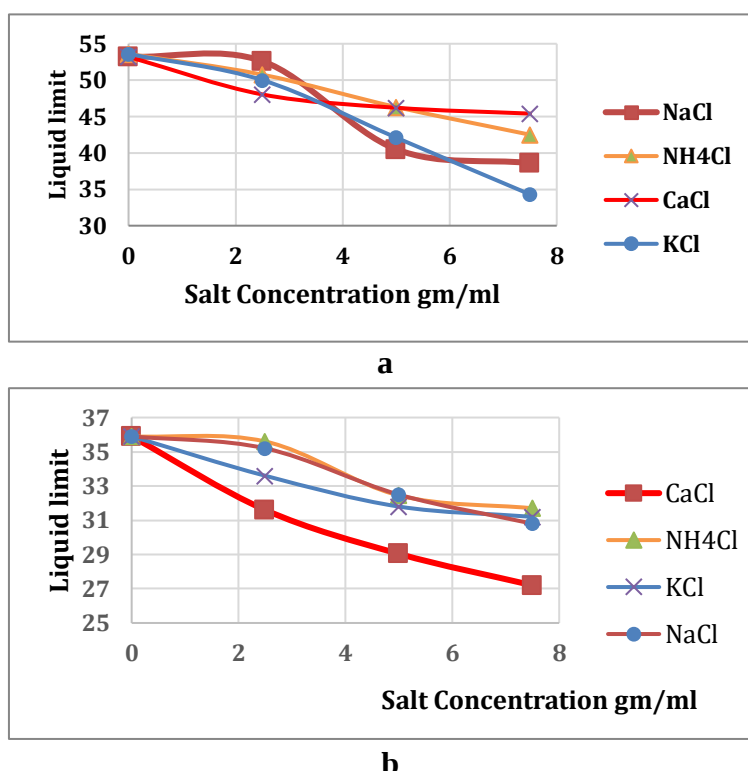


Fig. 6: Plasticity chart of normal soil sample of (a) Sarbasty (b) Mamwastayan

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.



**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<sub>2</sub>, KCl, and NH<sub>4</sub>Cl 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 25.38 to 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<sub>2</sub> 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 <sub>4</sub> Cl |        | 22.99                                 | 19.45     | 17.16       |

**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 |           |             |
| Mamwastayan |                    |        | 2.5gm/100ml                           | 5gm/100ml | 7.5gm/100ml |
|             |                    | 13.76  |                                       |           |             |
|             | NaCl               |        | 13.57                                 | 13.45     | 13.37       |
|             | CaCl               |        | 10.3                                  | 8.92      | 7.95        |
|             | KCl                |        | 12                                    | 10.9      | 10.8        |
|             | NH <sub>4</sub> Cl |        | 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 |           |             |
| Sarbasty |                    |        | 2.5gm/100ml                           | 5gm/100ml | 7.5gm/100ml |
|          |                    | 28.22  |                                       |           |             |
|          | NaCl               |        | 27.8                                  | 24.63     | 24.11       |
|          | CaCl               |        | 26.95                                 | 26.13     | 25.55       |
|          | KCl                |        | 26.83                                 | 24.45     | 23.67       |
|          | NH <sub>4</sub> Cl |        | 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 |           |             |
| Mamwastayan |                    |        | 2.5gm/100ml                           | 5gm/100ml | 7.5gm/100ml |
|             |                    | 22.14  |                                       |           |             |
|             | NaCl               |        | 21.63                                 | 19.05     | 17.43       |
|             | CaCl               |        | 21.3                                  | 20.12     | 19.25       |
|             | KCl                |        | 21.6                                  | 20.9      | 20.4        |
|             | NH <sub>4</sub> Cl |        | 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

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.

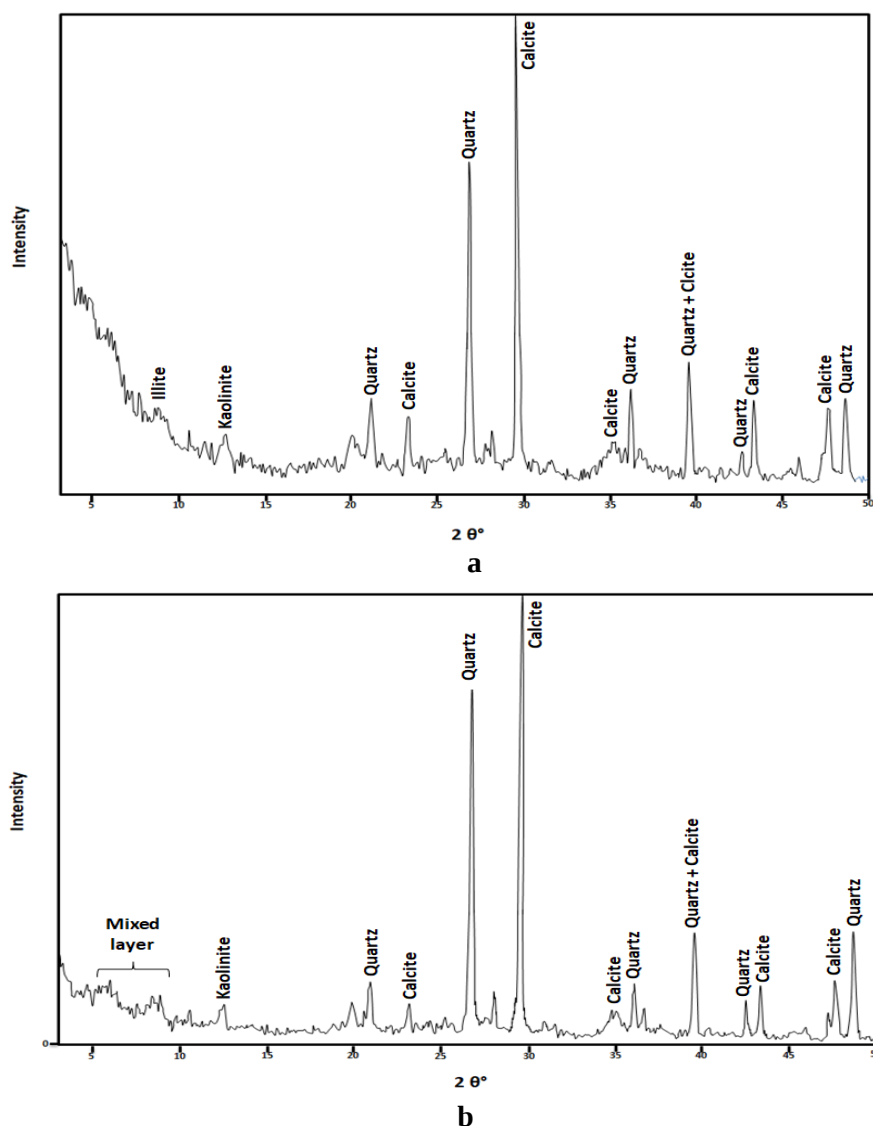
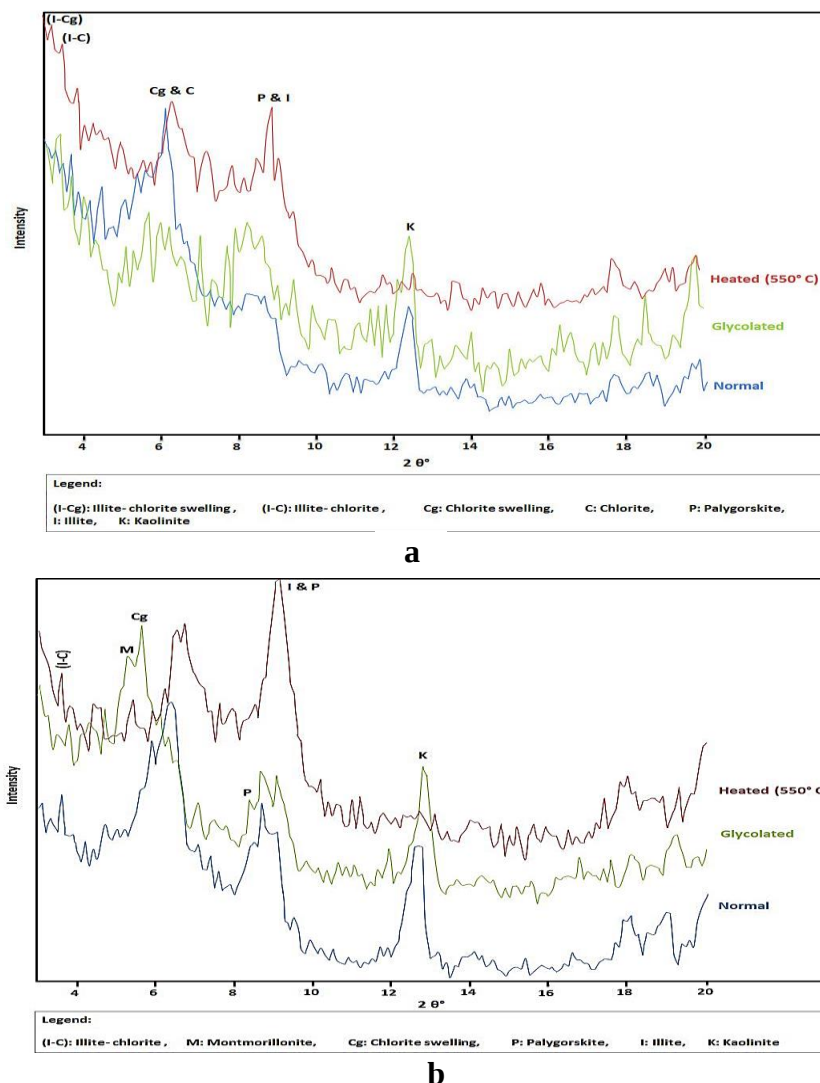


Fig. 8: X-ray Diffractogram of the Bulk normal soils (a) Sarbasty (b) Mamwastayan



**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<sub>2</sub> 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 ( $\text{Al}^{3+}$ ,  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Mn}^{2+}$ ,  $\text{Cu}^{2+}$ ,  $\text{Zn}^{2+}$ ,  $\text{Fe}^{2+}$ ,  $\text{H}^+$ ) [23]. Sarbasty soil was the most effective salt chloride solution than the Mamwastayan 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 ( $\text{NaCl}$ ,  $\text{CaCl}_2$ ,  $\text{KCl}$ ,  $\text{NH}_4\text{Cl}$ ) 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  $\text{KCl}$  and  $\text{CaCl}_2$  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 Mamwastayan soil sample because composed of different compositions clay minerals such as Montmorillonite which caused soil swelling.

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