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Gypseous soils improvement by hydrated lime and montmorillonite from selected locations in Najaf Al-Ashraf city, central of Iraq

A Thesis
Submitted to the College of science University of Babylon in Partial Fulfillment of the Requirements for the Degree of Master of Science in Geology

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1444 **2022**

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

يَعْمَلُونَ لَهُۥ مَا يَشَآءُ مِن مَّحَٰرِيبَ وَتَمَٰثِيلَ وَجِفَانٍۢ كَٱلْجَوَابِ وَقُدُورٍۢ رَّاسِيَٰتٍ ۚ ٱعْمَلُوٓا۟ ءَالَ دَاوُۥدَ شُكْرًا ۚ وَقَلِيلٌ مِّنْ عِبَادِىَ ٱلشَّكُورُ

صدق اللَّهُ العظيم

سبأ – اية 13

Declaration

We certify that the thesis ***"Gypseous soils improvement by hydrated lime and montmorillonite from selected locations in Najaf Al-Ashraf city, central of Iraq"*** has been prepared under my supervision at the Applied Geology Department-College of Science-University of Babylon, as a partial requirementfor a Master's Degree in Geology.

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DEDICATION

- ❖ To whom, ALLAH deputed as a mercy to mankind.
- ❖ To Prophet MOHAMMED, peace be upon him and his descendants, I hope to gain the intercession in the Day of Resurrection.
- ❖ To my FATHER and MOTHER, I ask my ALLAH to prolong their life.
- ❖ To my Husband, for his support and encouragement, for he cared and supported me throughout all my life.
- ❖ To my SONS, I ask ALLAH that keeps them; I hope to gain them to higher ranks in education.
- ❖ To my BROTHERS, with my love and appreciation.

Hadeel

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My sincere thanks and my appreciation are to my husband Dr. Arshad W. Al-Enzy for his support and standing with my.

Finally all thinks are for the ALLAH on all the time.

Hadeel

Summary

This study included the improvement of gypsum soils for three selected sites in Najaf Governorate, by adding the extinguished Hydrated lime with a percentage of 3, 6 and 9% and Nano-clay (Montmorillonite) at a rate of 5, 10 and 15% on the engineering properties of gypsum soil taken from a part of the Najaf-Karbala plateau, and the proportion of gypsum in the natural soil was the samples taken are (52, 48, and 72%) for sites No. 1, 2, and 3, respectively. This study showed an increase in the proportion of gypsum in the soil to the northwest direction of the study area.

This study included studying the effects of using Nano-materials and hydrated lime by using laboratory work to prove the improvement and stabilization of gypesous soil. These gypsum soils are collected from selected sites in the city of Najaf and mixed with Nano-clay (Montmorillonite) and hydrated lime, which were added in small quantities as a percentage of the dry weight of the soil. Test samples are performed to determine several characteristics, such as sieve analysis, specific gravity, maximum dry density, optimal moisture content, and potential for collapse. The results of the experimental work show that there was a modification in the geotechnical properties of the soil samples and that the maximum dry density was (2.065, 2.025, and 2.003) gm/cm3 at the optimum moisture content (15%, 14%, and 15%) for the three samples in the case of adding the hydrated lime While the maximum dry density is found to be (2.059, 2.013, and 2.013) at the optimum moisture content (14%, 14%, and 15%) respectively for the three samples in the case of adding Nano clay. The maximum dry density decreases while the optimum moisture content increases with the addition of the added percentage of hydrated lime and Nano-clay. The results also show that the limits of fluidity are changed and the soil becomes more fluid when treated because the hydrated lime and Nano-clay increase the limits of the liquid significantly.

The cohesion strength (C) increases by increasing the proportion of the hydrated lime from 3% to 6%, and then it decreases to zero when 9% is added. When adding 9% of the hydrated lime, the hydrated lime particles separate the soil particles from each other due to the occurrence of the flocculation phenomenon, which leads to a lack of cohesion strength. It is also observed that the internal friction angle (Ø) decreases with the increase in the proportion of additives from Hydrated lime and Nano clay.

And through laboratory work, we achieved a decrease in the possibility of collapse by increasing the percentage of addition of Nano-clay and hydrated lime. Thus, the addition of montmorillonite and hydrated lime, even in low proportions, can improve the geotechnical properties of gypesous soils. The effect of adding Nano-clay to change the probability of collapse from (12, 11.5 and 13.5%) to (1.5, 1 and 4%) for samples S1, S2 and S3, respectively, as a result of soil treatment. The effect of adding the hydrated lime changed the probability of collapse from (12, 11.5 and 13.5%) to (1.25, 0.5, and 3.5%) for samples S1, S2 and S3, respectively, as a result of soil treatment, and this means that the additive modifies the soil from the state of "serious problem" to a "moderate problem" or a "no problem" state. The results of the breakdown effort were presented using GIS technology.

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List of abbreviations		
No.	Symbol	The Meaning
1	∑Rn	Percentage passing through the sieves
2	SUCS	Unified Soil Classification System
3	PI	Plasticity Index
4	LL	Liquid limit.
5	PL	Plastic limit
6	C.P	Collapse potential
7	Δh	Change in thickness of sample
8	H	The original thickness of the sample
9	T	Shear strength
10	C	Cohesion
11	∑n	Applied vertical stress at failure
12	Ø	internal friction angle
13	M.C	moisture content
14	w_1	Weight of the container when it is empty
15	w_2	Container weight with sample
16	w_3	Container weight with dry sample
17	x	Quantity of material used for installation in tons
18	L	Length
19	W	Width
20	H	Height
21	D	Density
22	P	The perfect fit ratio
23	p. u. h	Peace upon him
24	GCGW	General Commission for Ground Water
25	NCCL	National Center of Construction Laboratories

Chapter One

Introduction

1.1 Preface

Gypsum soils are prevalent in continental and semi-continental climates, and they may form the basis of several infrastructure construction projects. Recent years have witnessed a remarkable interest in studying the geotechnical properties of these soils to stave off the dangers of their collapse due to these properties deteriorate when exposed to water. Iraqi soils contain a different types of salts related to sulfates, carbonates and chlorides. Studies have shown that the ratio of gypsum to the total salts (TSS) level is 96.16% in Tikrit, 94.3% in Anbar and 95.6% in Tharthar, (Jassim & Goff, 2006). Gypsum is the most prevalent type of salt in Iraqi soils and its percentage ranges from 0%-80%, (Razouki and Al-Janabi, 1999). Gypsum is a white or transparent metal with a specific gravity about 2.32 and it's hardness of 2 according to the Moho hardness scale.

An-Najaf province is considered one of the most important cities in Iraq, which is facing a rapid population growth and continuous development in constructions such as hotels, bridges and shopping malls and the investment in the field of housing constructions especially in the study area. Therefore, gypsum content must be known to evaluate the spatial variability of gypsum in the location of constructions due to its unfavorable effects on the engineering structures.

1.2 Location of the Study Area

The research region is located in central Iraq, Najaf city, geographically located between latitude 31°53'15''N - 32°16'33''N and longitude 44° 00'18''E- 44°16'47''E. The study area is a triangle-shaped which it be part of Najaf- Karbala plateau that covers 650 km^2 (Fig. 1-1). The study area is bound by Tar Al-Najaf towards southwest and Najaf – Karbala high road from direction of Northeast. In the northern part of the study area, the Karbla governorate bound is located, and from the South, the shrine of Imam Ali (p. u. h). The plateau's surface is nearly level, with few small flat-floor dips and pebbly or gypsiferous pebbly soil or gypcrete almost covering it (Barwari and Slewa, 1995). The general of land slope is to the East and Northeast towards of Euphrates River.

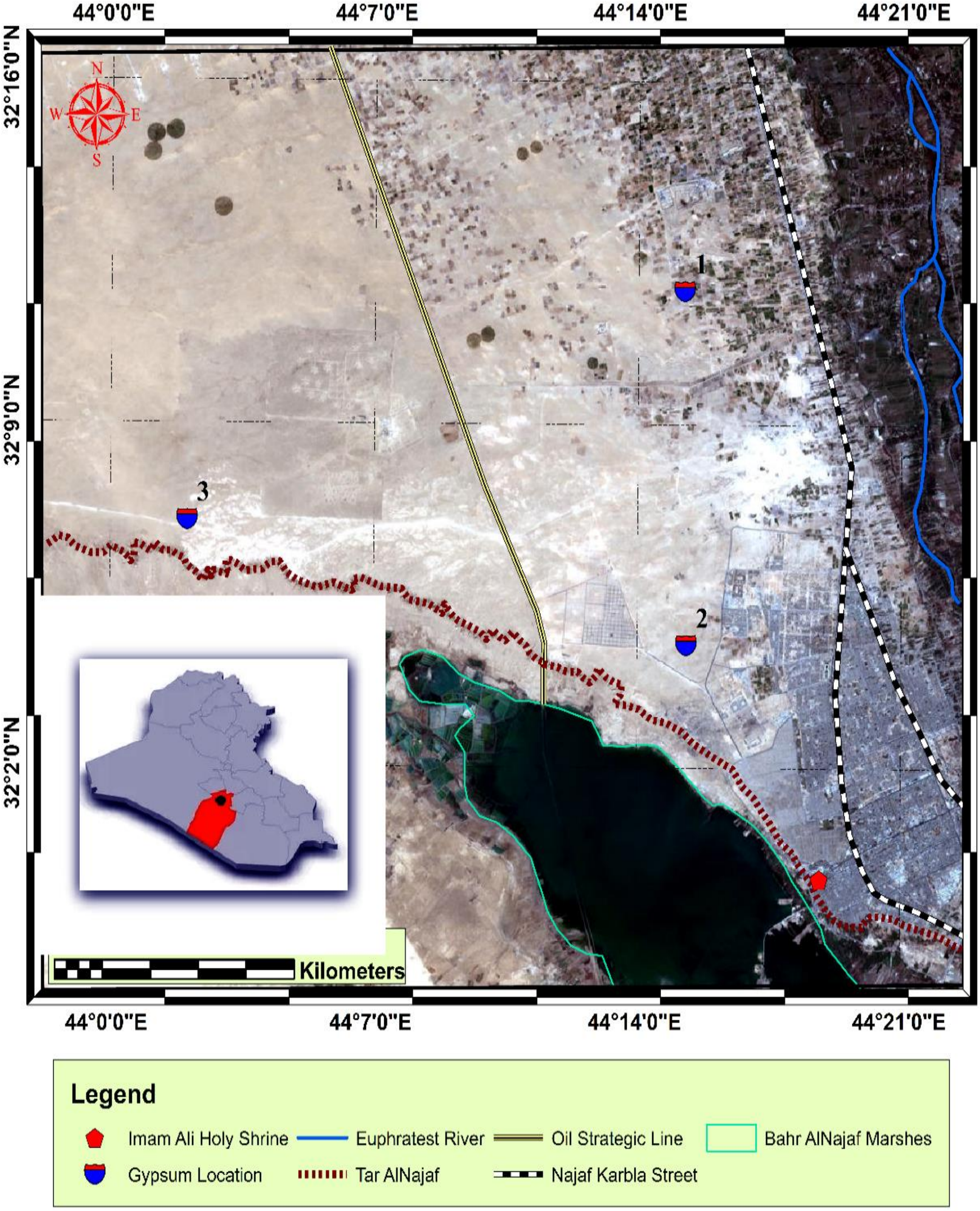


Figure (1-1): Location of the study area.

1.3 Aims of Study

1-Improving gypseous soils for selected location in Al-Najaf Al-Ashraf Governorate by adopting the following two phases.

2- Determination of the geotechnical and chemical properties of soils not treated with additives.

3- Determination of the geotechnical properties of soils treated with additives.

4- Calculation of the Collapse ratios of gypsum soils and their treatment.

1.4 Previous Studies

Various writers deal with previous research of gypseous soil in Iraq like authors as follows:-

- Kovda(1954) state that gypsum accumulation occurs in two ways by the Evaporation of mineralized ground water and by the precipitation within Ground water itself.
- Buringh (1960) states that gypsiferous soil in Iraq are mainly associated with ageological substratum containing gypsum and anhydrite interlayer or with pleistocene terraces connected with such deposits.
- Van Alphen and Romero (1971) reported some data defining the permeability forgypseous soils of the Euphrates basin in Syria. They found large variation between the gypsum content and its permeability.
- Barzanji (1973) concluded that geological formation with the evaporation of the inland seas are the origin of moat gypsiferous soils in Iraq.
- Singh and Layla (1979) had different results. They stated that the increase ingypsum content increased in flocculation tendency of the soil, as aconsequence of the compression of the electric double layer of the clayparticles which resulted in an increase in the liquid limit and the decrease in the plastic limit of the soil, i.e. increasing the plasticity index

- Segalen and Brion (1981) stated that gypsum originates from the material in the catchments areas that has been eroded redeposited.
- Al-Qaissy (1989) observed that the increase in gypsum content of remoldedgypsified soils caused a decrease in liquid limit and plastic limit with no marked change on plasticity index.
- Al-dilaimy (1989) concluded the permeability of compacted clayey soil decreases as gypsum content increases up to 5%. After that, increasing in gypsum leads to an increase in permeability.
- Nashat (1990) investigated the properties and behavior of gypseous soils in Iraq by conducting a series of laboratory tests on undisturbed and disturbed samples. He has showed that soaking and leaching of gypseous soil lead to great reduction in shear strength. This study showed that the gypseous soil exhibited very high shear strength when it is in dry state.
- Abood(1993) studied the compacted clayey and sandy soils with different gypsum content. For clayey soil, her study showed that the compression index Cc decreased with increasing gypsum content, while the sandy soil, the compression index increased with increasing in gypsum content.
- Al-jumaily (1994) stated the increase in strength of dry gypsum leads to the increase in its cohesion while the value of friction varied according to crystal lattice pressure that was caused by confining pressure and additional friction surface obtained from the gypseous substances.
- Saeed (1994) studied the distribution of gypsiferous soils in Iraq and he showed that there is no formal classification for these soils where gypsum may vary from (1 – 70) %.
- Razouki *et al*. (1999) have studied the structural failures caused by gypsiferous soils in Iraq and reviewed the basic geotechnical properties of these soils.

- Zakaria(1995) studied the permeability of compacted Al-Anbar gypseous soils (sandy silt with 39% gypsum content and silt with sand containing 44% gypsum), under different applied stress. From his study he found that the permeability for both types of soil studied is high at beginning of leaching stage, fluctuates for some times in a descending order then reaches a steady state condition. He attributed the cause of high permeability to the enlargement of voids while the cause of low permeability is due to the collapse of soil structure under the influence of applied stress. He also pointed out that if the applied stress is increased, permeability values and soluble salts leached from soil decrease and strain increase for the same soil. He added that if a dry density is increased, permeability, soluble salts leached out, and strains decrease.
- Al-Abdullah (1996) noticed that the effective angle of shear resistance remained almost constant, and the shear strength parameters are not really affected by the existence of gypsum up to 8% of gypsum content.
- Majeed, (2004) studied the geotechnical of gypseous soils in three areas in Kirkuk city, and the relation between geotechnical properties in the study area reveated that when the percentages of clay, silt and soluble salts such as gypsum, is high, the void ratio, compression index and collapsibility index values increase Also the presence of active clay mineral montmorillonite causes the soil expansion, when lead to negative effects on engineering structures.
- Hussain, (2005) studied gypsiferous soils in Najaf, Karbala and Falluja areas. She examined the mineralogy and chemical composition of these soils, as well as the hydrochemistry of the groundwater in the studied areas.
- Yassin, (2006) studied gypsiferous soils in several local sites in central Iraq. He was concerned with mineralogy and hydrochemistry of soil – water extracts and geotechnical characteristics of these soils. A proposal for classification of gypsiferous soils had been attempted.

- Mahmood, (2007) studied the effect of gypsum percentage on geotechnical properties of gypsiferous soil at Basrah governorate (western side).

- Al – Dabbas *et. al.*, (2010) studied the comparison of gypsiferous soils in samarra and karbala areas, Iraq.

1.5 Methodology

The study passed through four different stages which include:-

1.5.1 Data Collection Stage

Concerning the nature of the research area and the scope of past work, it is the first step in this research and culecting maps, reports, scientific articles and theses related to the study area. These were researched in order to acquire a decent idea about the study area.

1.5.2 Field Work

This step includes multiple field trips with the supervisor and with the help of the General Organization for Geological Survey / Najaf branch, to examine and identify the research area in order to obtain samples of gypsum soil from the depths of the soil suitable to cover the entire study area (Fig. 1-1). Where are taken (10) Samples from different sites of Najaf city from the depth of (1.5-2.5) m samples were neglected due to the low percentage of palpation in them. The period of field work lasted for (72) days.

1.5.3 Laboratory Work

1.5.3.1 Physical tests

Physical tests for gypseous soil was included:-

a. Soil moisture content (MC).
b. Atterberg limits (liquid limit (LL) and plastic limit (PL).
c. Specific gravity (GS).
d. Grain size analysis and classifying the soil according to the Unified Soil Classification System (USCS) to determine the soil type depending on the (ASTM) standard.
e. Unit weight (dry and wet).

1.5.3.2 Engineering tests

a. Which was involved:-
b. Compaction Test.
c. Collapsibility Test.

1.5.3.3 Chemical tests

a - Determination of PH value.
b - The percentage of gypsum.
c - The percentage of sulfates, chlorides and calcium carbonate.
d - Total dissolved salts (T.D.S).
e - Total organic material.

1.5.4 Office Work

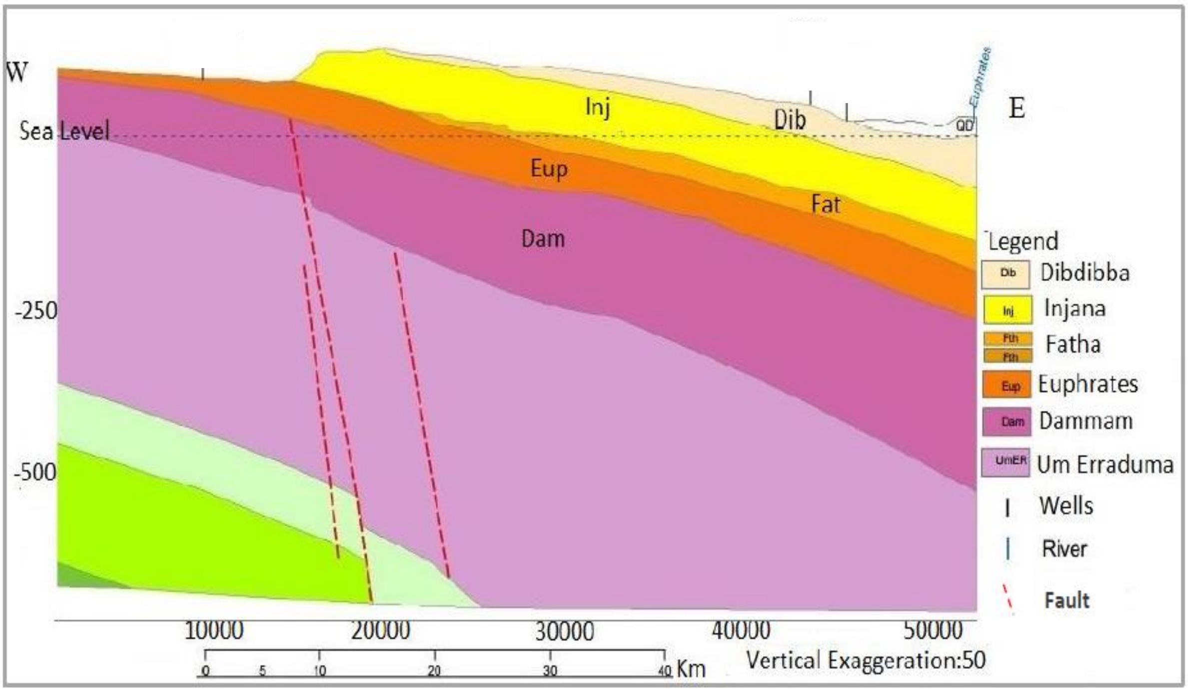
This stage includes the presentation and interpretation of all field and laboratory tests that assisted in the comprehensive analysis of all gypseous soil data and the suggestion of remedial strategies to improve gypseous soil characteristics. Geographic Information System (GIS) is utilized to display the data in the form of maps.

1.6 Geological of the Study Area

Except for Tar Al- Najaf located, the study area is covered by Dibdibba, Injana, and Fatha formations, and it's mostly covered by undifferentiated Quaternary layers with medium permeability (Jassim and Goff, 2006).

1.6.1 Stratigraphy

The following formations (from oldest to youngest) make up the stratigraphic column in the study area: Um Erraduma, Dammam, Euphrates, Fatha, Injana, and Dibdibba, (Alenzy, 2019). The data for this column came from wells dug by the General Commission of Groundwater, as well as information from the Iraqi Oil Exploration Company, (Fig. 1-2) Al-Ghanimy, 2018



Figure, (1-2) Geological stratification formations in the study area, (Al-Ghanimy, 2018)

1.6.2 Structure and Tectonic Settings

The study region is located in the northwest part of the Euphrates subzone, which is the western section of the stable shelf's Mesopotamia Zone (Buday, and Jassim, 1987). The studied area is considered stable, and the sedimentary cover extends over the foundation rocks from 7-8 km. The Permian/Triassic-Lower Cretaceous Periods are influenced by extension deformations and tectonic strain over the Arabian plate (AL Ashoo, 1991). The existence of two groups of faults characterizes the area. The first group, which comprises the Rhaimawi – Hilla Fault which is trending NE-SW and Abou Jir Fault, is trending NW-SE which appears in the western part of the study area and it influence on the study area. (Fig.1-3) (Al- Shemmari, 2012), the area is influenced by recent tectonic movement of subsurface geological features in the middle Pleistocene, which resultes in the alteration of the Euphrates River's flow to its current location (Al-Sakini, 1986).

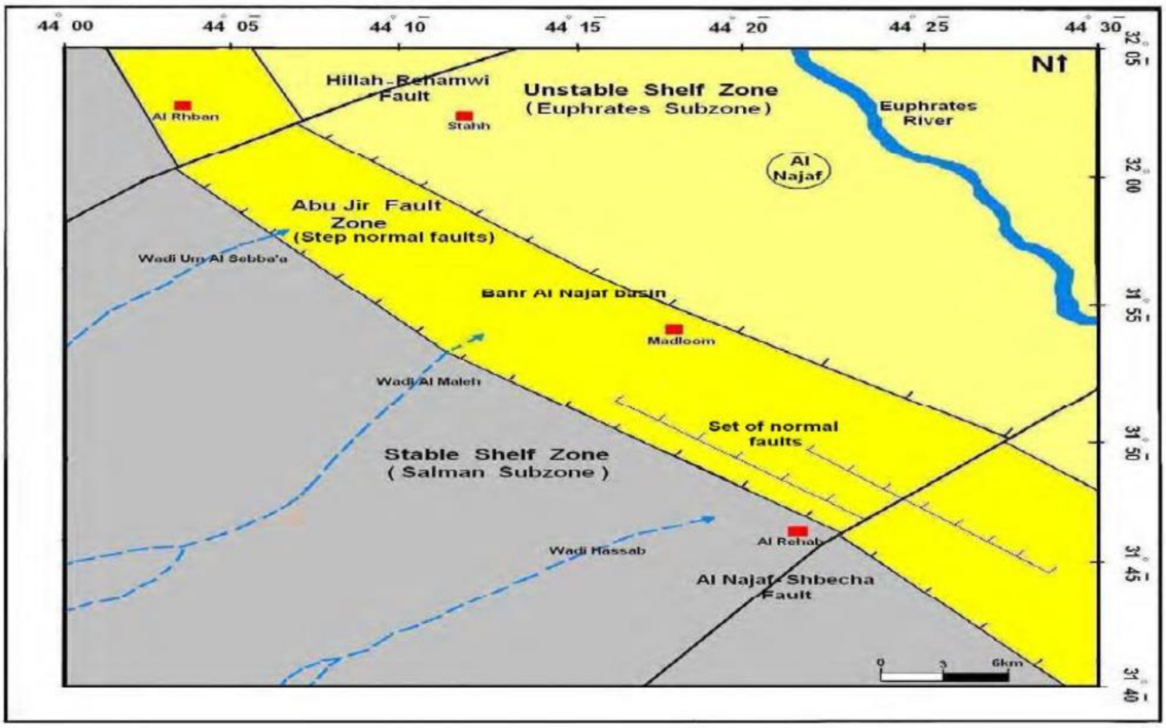


Figure (1-3): Tectonic map shows the tectonic features in the studied area, (Al- Shemmari, 2012).

1.6.3 Hydrogeological Setting

Because of the adequate quantity and quality of groundwater, which have at a depth of (4m - 27m) from the land surface, the Dibdibba and Dammam aquifers are regarded the most important aquifers in the research area. The Dibdibba aquifer unit represents the major shallow top aquifer, whereas the Dammam aquifer unit represents the deeper confined aquifer in the study area. Seasonal flow streams from direct rainfall within the Plateau feed the aquifer of Dibdiba (Al-Jiburi, 2002). The seasonal flow stream, which is directed 40 degrees northward toward the Mesopotamian Basin (GCGW, 2018). The Dibdibba alluvial fan delta evolved in the early Miocene as a result of a drainage system that may still be seen upstream on the carbonate platform of the Western Desert (Jassim and Goff, 2006). The gravels and sand of the Dibdibba formations date from the end of the Pliocene have been altered by calcite and gypsum (Sissakian, 2000). The Dibdibba formation is homogenous and anisotropic, with a laminar groundwater flow similar to that of granular aquifers. The flow direction of groundwater for the Dibdibba aquifer in the research area was generally from southwest to northeast (towards the Euphrates River), which is consistent with the regional groundwater flow direction of Iraq's Western desert (Al –Enzy, 2019).

1.7 Climate of Study Area

The geographic location on the globe plays an important role by affecting on the climate, it is a set of weather conditions which dominates on a particular area and which affecting directly on the water resources for that region, so that the climate is correlating with geology, environment and water resources instantly, (Al-Khafaji,2009).

The weather is the atmospheric conditions for a certain location at a particular time such as day to day or week to week, (Bello *et al*., 2011) .

The climate is what it the expected that based on the historical records and what happened to the previous weather (Trenberth *et al*., 2011).

As a result, the climate is inextricably linked to geology, environment, and water resources. Iraq's climate is characterized by high temperatures, with large differences in hot and cold temperatures between day and night, as well as between summer and winter, and varied degrees of precipitation, ranging from more than

1000 mm in the north to less than 100 mm in the south, (Al-Khafaji, 2009). The studied area could be classified as arid to semi-arid region.

The necessity to preserve gypseuos soils from weather conditions has been identified by studies, as the physical and chemical erosion that this generates is the primary source of these soils' engineering issues, (Jassim & Goff, 2006).

The following are the influencing factors:-

A- Rainfall

Rainwater causes a change in the moisture content of the soil, as well as a rise in ground water levels (Water table). When saline soils are saturated with water, the soluble salts dissolve partially or entirely with the help of the acidic medium of precipitation, causing soil compaction. Long rainy periods of low intensity are more harmful than short periods of high intensity because the amount of water absorbed by the soil will be greater, (Azam *et al*., 1998).

B- Temperature

The temperature potential in the atmosphere has a direct impact on the soil because it causes water to flow from warm to cold locations, changing the soil wetness. In the winter, the temperature difference causes salt water to rise and crystallize salts beneath the surface layer. The crystallization pressure it be great under the surface land due to the evaporation of water across the surface, that causing a major damage to the soil (Goudie and Viles, 1997).

C - Winds

Winds aid in increasing the rate of moisture loss from the soil's surface, causing water to flow towards the surface and the crystallization of additional salts. winds also acts by eroding the soil's surface and transporting the salt particles from the salt crust and depositing them elsewhere(Goudie & Viles, 1997).

From the tables (1-1), (1-2), (1-3), (1-4) and (1-5) show the values of climate elements for the periods from 2014 - 2020, issued by the Iraqi General Authority for Meteorology and Seismic Monitoring. _ Najaf station, and as shown in Figures (1-4), (1-5), (1-6), (1-7), (1-8) and (1-9), shows the rates of some climatic characteristics for Al- Najaf Governorate over the course of seven Years from 2014 to 2020

Table (1-1): Shows the monthly average minimum temperature for the period from (2014-2020) (General Authority for Iraqi Meteorology and Seismic Monitoring - Najaf Station

Year	Dec.	Nov.	Oct.	Sep.	Aug.	Jul.	Jun.	May.	Apr.	Mar.	Feb.	Jan.
2014	21.0	23.9	33.4	41.2	46.2	45.1	42.8	39.2	33.0	26.5	20.5	16.6
2015	17.3	23.6	35.9	43.8	46.5	47.1	43.3	39.9	32.0	26.3	21.4	18.3
2016	17.1	25.5	45.6	41.1	47.5	46.7	44.1	38.9	33.6	26.6	22.2	17.3
2017	22.3	26.4	34.8	44.1	47.4	47.7	43.7	39.4	31.8	25.5	19.1	16.8
2018	19.3	22.5	35.7	43.6	44.8	45.2	43.2	37.2	31.5	30.3	22.2	19.9
2019	19.9	26.6	35.9	42.6	46.1	45.1	45.4	40.1	29.3	23.8	20.2	17.7
2020	19.4	25.9	36.7	44.2	44.6	47.7	43.2	39.1	31.9	25.4	20	18.2

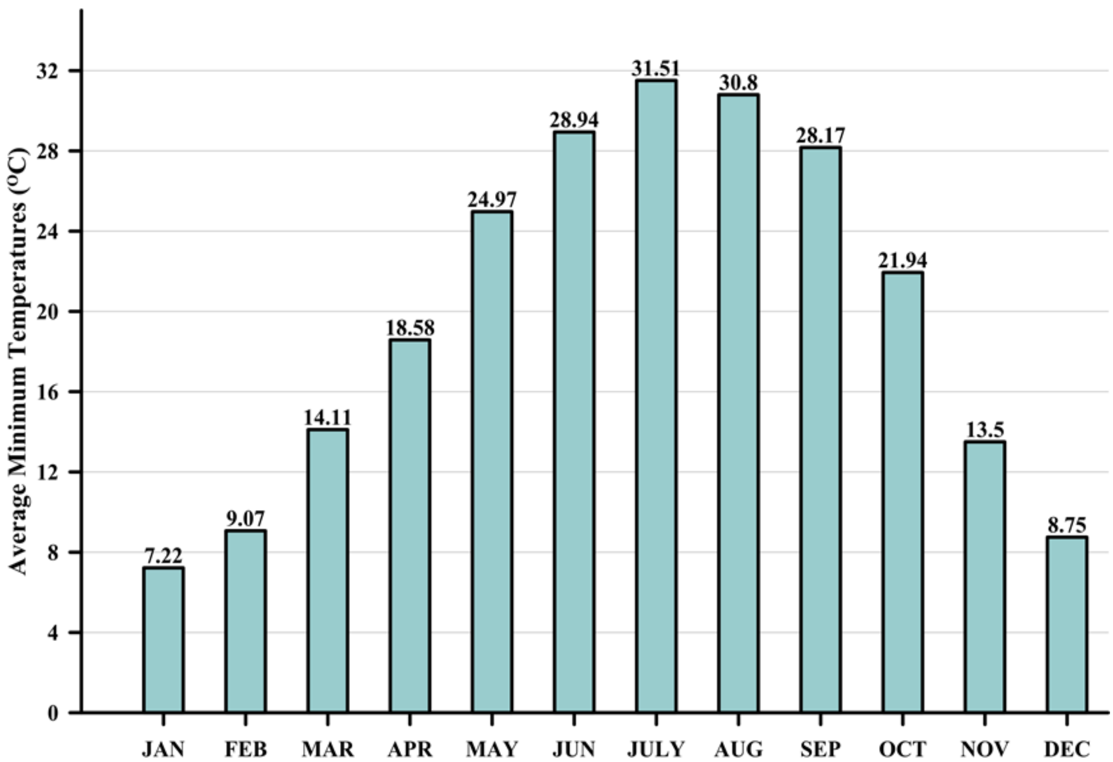


Figure (1-4): Shows the monthly average of minimum temperatures for the period (2014-2020) (the Iraqi General Authority for Meteorology and Seismic Monitoring - Najaf Station).

Table (1-2): Shows the monthly average maximum temperature for the period from (2014-2020) (General Authority for Iraqi Meteorology and Seismic Monitoring - Najaf Station

Year	Dec.	Nov.	Oct.	Sep.	Aug.	Jul.	Jun.	May.	Apr.	Mar.	Feb.	Jan.
2014	21.0	23.9	33.4	41.2	46.2	45.1	42.8	39.2	33.0	26.5	20.5	16.6
2015	17.3	23.6	35.9	43.8	46.5	47.1	43.3	39.9	32.0	26.3	21.4	18.3
2016	17.1	25.5	45.6	41.1	47.5	46.7	44.1	38.9	33.6	26.6	22.2	17.3
2017	22.3	26.4	34.8	44.1	47.4	47.7	43.7	39.4	31.8	25.5	19.1	16.8
2018	19.3	22.5	35.7	43.6	44.8	45.2	43.2	37.2	31.5	30.3	22.2	19.9
2019	19.9	26.6	35.9	42.6	46.1	45.1	45.4	40.1	29.3	23.8	20.2	17.7
2020	19.4	25.9	36.7	44.2	44.6	47.7	43.2	39.1	31.9	25.4	20	18.2

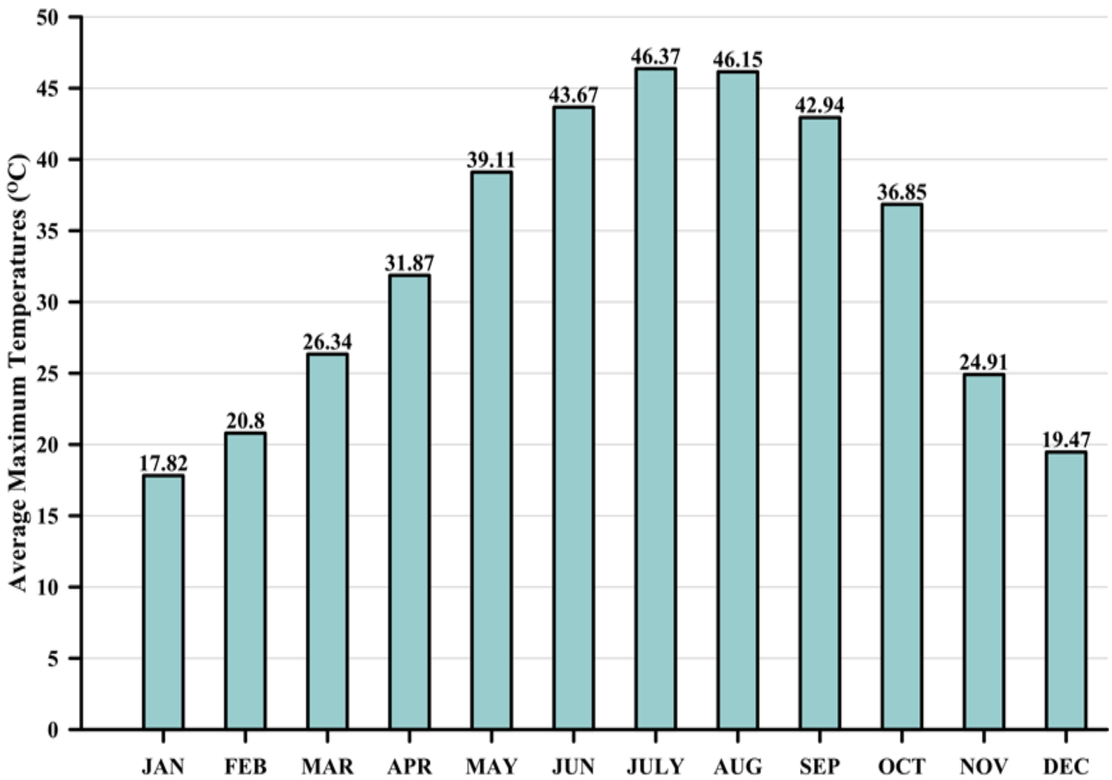


Figure (1-5): Shows the monthly average of maximum temperatures for the period (2014-2020) (the Iraqi General Authority for Meteorology and Seismic Monitoring - Najaf Station).

Table (1-3): Shows the monthly average relative humidity for the period (2014-2020) (the Iraqi General Authority for Meteorology and Seismic Monitoring - Najaf Station)

Year	Dec.	Nov.	Oct.	Sep.	Aug.	Jul.	Jun.	May.	Apr.	Mar.	Feb.	Jan.
2014	69	57	44	31	24	23	24	28	40	51	56	79
2015	70	69	46	26	26	27	26	26	35	44	53	62
2016	64	42	37	28	22	19	22	26	35	47	58	63
2017	49	51	33	23	21	18	22	26	41	50	45	63
2018	77	77	41	30	25	19	21	34	45	35	59	53
2019	67	48	46	27	24	26	23	34	43	51	64	68
2020	70	60	35	28	25	25	25	28	44	53	54	64

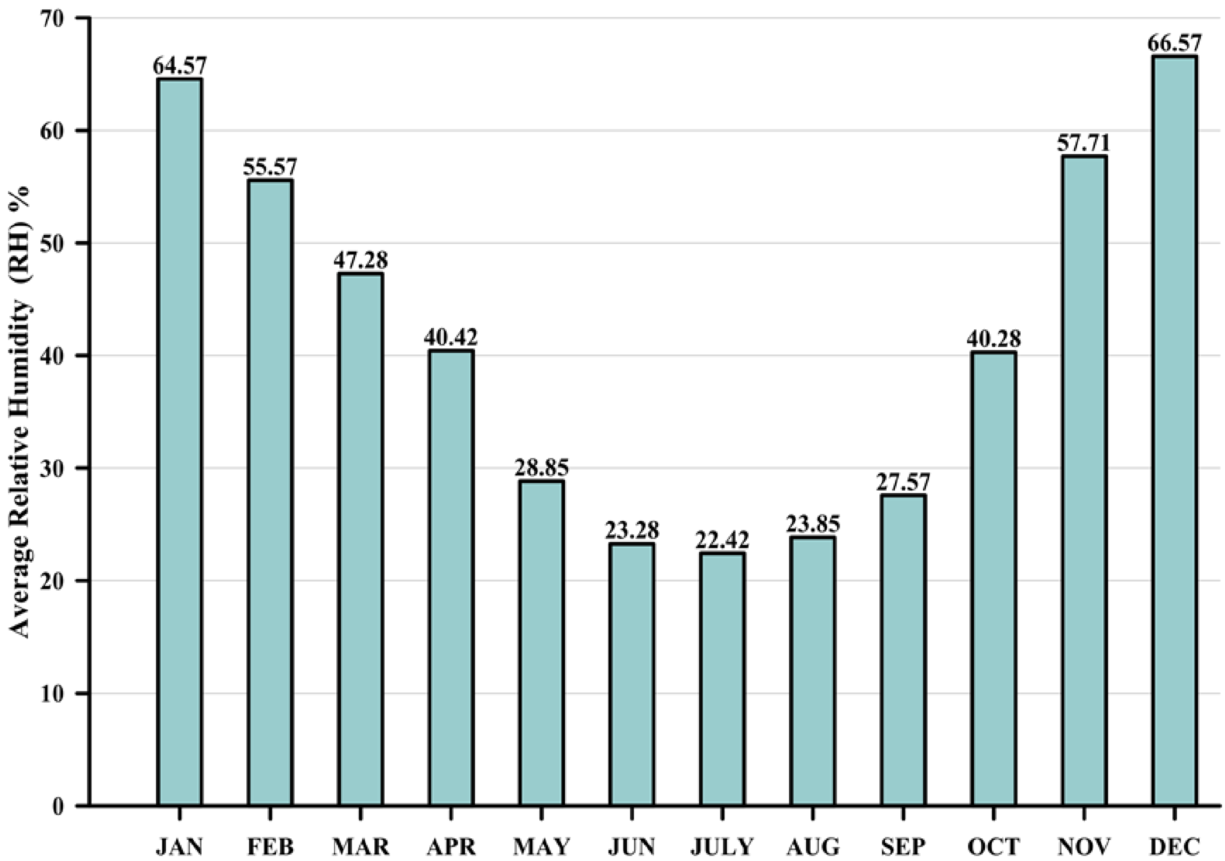


Figure (1-6): Shows the monthly average of relative humidity for the period (2014-2020), (the Iraqi General Authority for Meteorology and Seismic Monitoring - Najaf Station).

Table (1-4): Shows the monthly rate of evaporation for the period (2015-2020) (the Iraqi General Authority for Meteorology and Seismic Monitoring - Najaf Station)

Year	DEC.	NOV.	OCT.	SEP.	AUG.	JUL.	JUN.	MAY.	APR.	MAR.	FEB.	JAN.
2015	47.2	95.5	181.2	293.4	377.3	455.5	376.7	305.6	197.9	124.0	82.1	62.3
2016	53.7	101.1	175.9	286.3	408.6	400.6	362.1	324.2	210.1	126.3	84.7	61.7
2017	83.4	93.6	200.0	308.4	404.6	411.4	406.2	289.9	210.6	134.9	84.8	58.3
2017	54.9	70.4	182.6	267.4	350.5	422.9	365.4	265.3	194.6	188.4	78.9	82.6
2019	41.3	67.0	121.8	222.3	316.7	343.5	368.8	295.2	164.7	120.6	64.4	87.2
2020	37.1	80.0	148.2	239.9	274.5	318.5	256.2	211.5	145.8	107.8	69.7	45.3

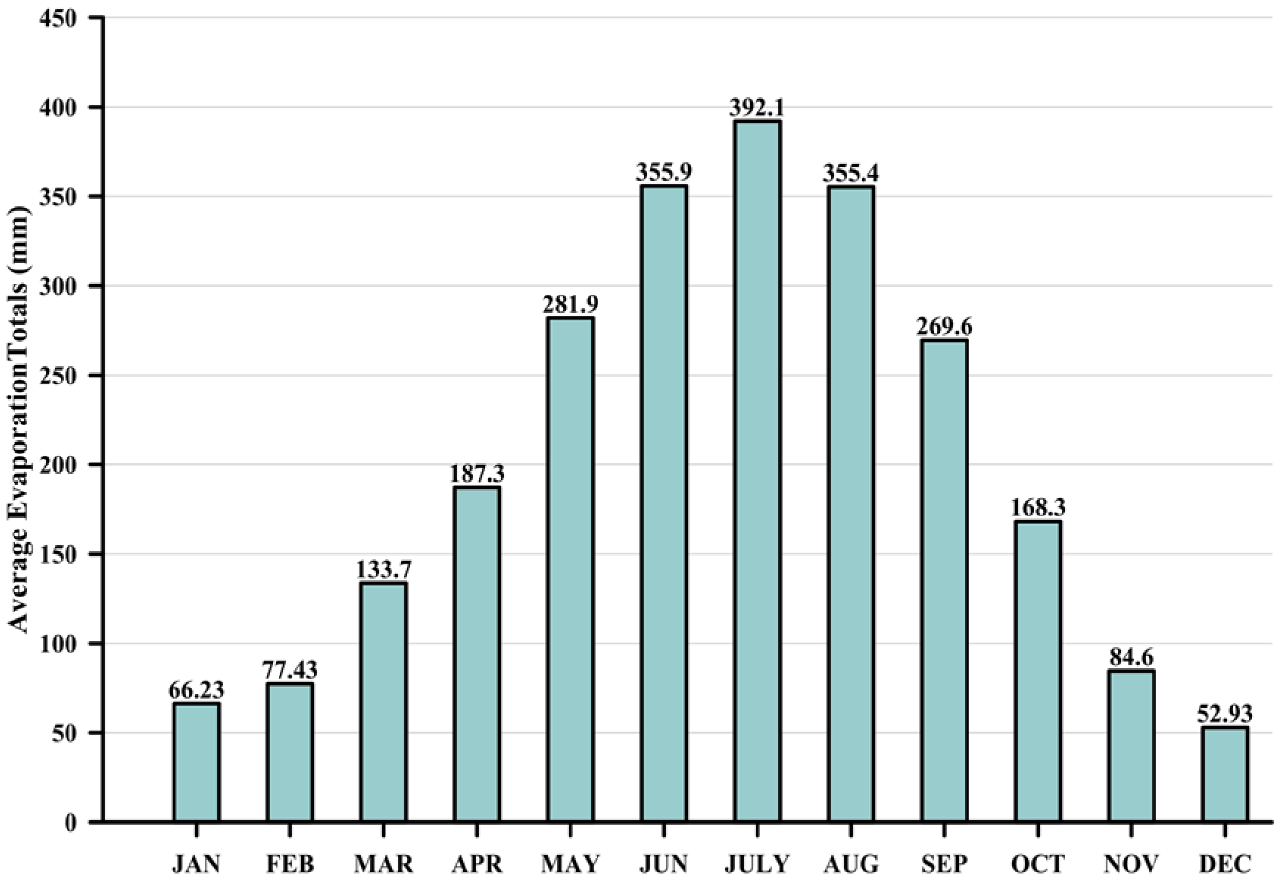


Figure (1-7): Shows the monthly rate of evaporation for the period (2015-2020) (the Iraqi General Authority for Meteorology and Seismic Monitoring - Najaf Station).

Table (1-5): Shows the monthly average wind speed for the period (2014-2020) (the Iraqi General Authority for Meteorology and Seismic Monitoring - Najaf Station)

Year	Dec.	Nov.	Oct.	Sep.	Aug.	Jul.	Jun.	May.	Apr.	Mar.	Feb.	Jan.
2014	1.3	1.5	1.7	1.7	2.3	2.5	2.4	2.4	2.1	2.0	2.0	1.9
2015	1.2	1.2	0.7	1.1	1.5	2.1	1.9	2.1	1.9	1.6	1.7	1.7
2016	0.9	1.8	1.1	1.9	1.3	2.3	1.9	2.0	1.4	2.2	1.4	1.1
2017	0.6	0.4	0.4	0.5	1.4	1.3	1.8	1.7	1.8	1.6	1.5	0.6
2018	0.5	0.2	0.7	0.3	1.1	2.2	1.8	1.6	1	1	0.5	0.8
2019	1	0.1	0.4	0.4	0.7	0.8	0.7	0.5	1.1	1.4	0.9	0.6
2020	0.5	0.8	0.6	0.6	1.1	0.8	0.8	1.2	0.9	1.1	1.1	0.5

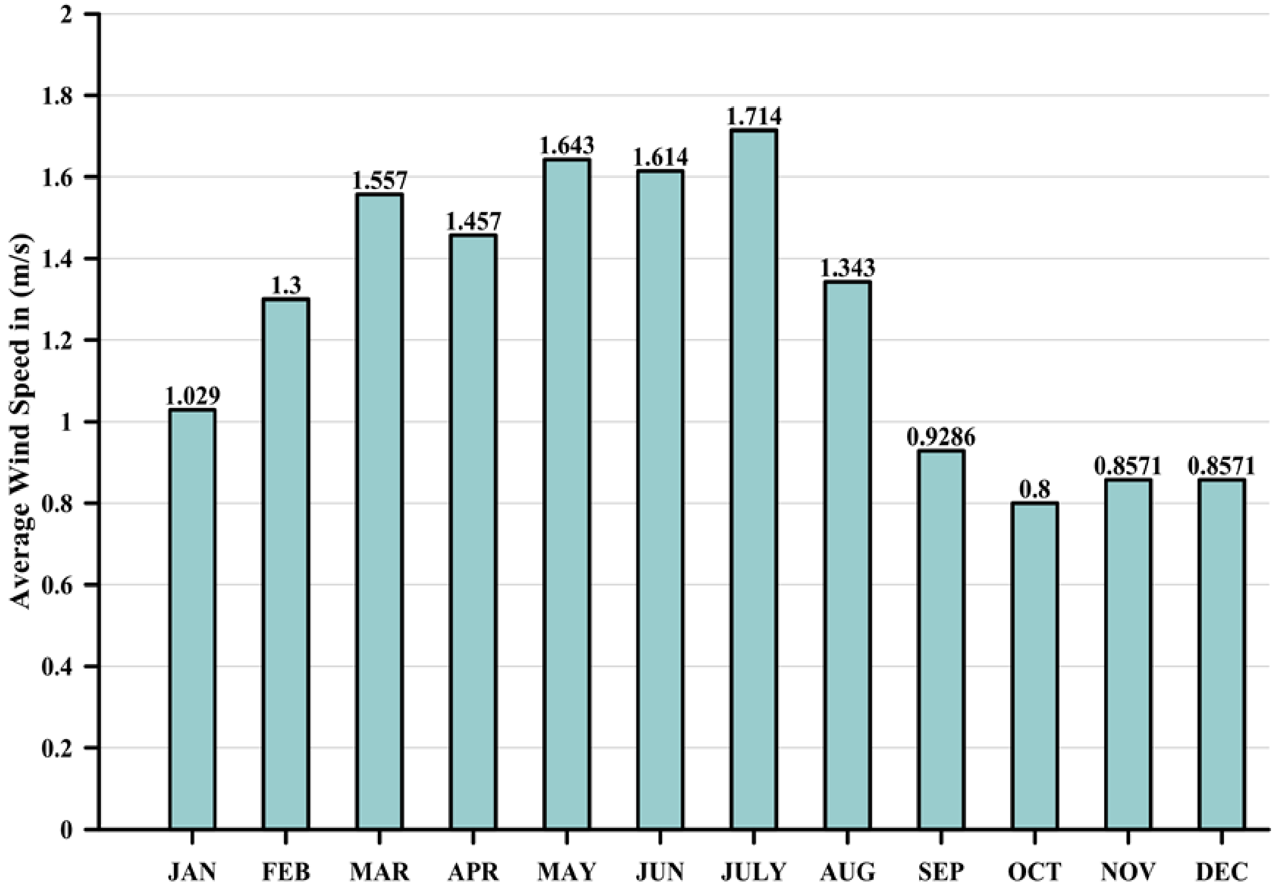


Figure (1-8): Shows the monthly average wind speed for the period (2014-2020) (the Iraqi Meteorological Authority and Seismic Monitoring - Najaf Station). .

Chapter Two

Theoretical Background

2.1 Preface

Gypseous soils are common in continental and semi-continental climate regions, and it may the foundation layer for infrastructure development. In recent years, there has been a surge in interest in researching the geotechnical qualities of these soils in order to avoid the risk of collapse caused by these properties deteriorating when exposed to water, (Jassim, & Goff, 2006).

Gypsum is created by one of two methods, precipitation from aqueous solutions or hydration of anhydrite, it can be found in a variety of geological contexts. Gypsum is deposited chemically from extremely saturated solutions in thick or thin layers, which are alternated with layers of limestone, shale, and mudstone. Different types of gypsum, such as fibrous gypsum, granular gypsum, porphyritic gypsum, selenite, and others, can be found in dry and semi-arid soils (Smart, 1999). Gypsum is either evenly distributed or concentrated in specific parts of soil horizons, gypsum $CaSO_4.2H_2O$, Anhydrite $CaSO_4$, and Basanite $CaSO_4$. $0.5H_2O$ are three mineral phases that include calcium sulfate (Al – Dabbas *et. al.*, 2010).

At temperatures below 40°C, gypsum mineral is the stable phase of calcium sulfate. The other phases arise with an increase in temperature caused by the slow loss of water in normal atmospheric pressure circumstances.

2.2 Natural Sources of Gypseous Soils

Natural sources of gypsum In relation to the deposition of these minerals owing to the evaporation process and the increase in the concentration of elements in sea water, gypsum is one of the evaporated minerals. When sea water evaporates and its initial volume is halved to become a sulfur concentration of calcium high enough, gypsum precipitates from aqueous solutions saturated with calcium and sulfate. This occurs when saline water evaporates in confined and semi-enclosed basins, such as the Arabian Gulf's lagoons or lagoons, and in sabkha locations, where gypsum crystals develop in super tidal mud during the burial stages. The first of bacterial activity's early transformational steps (Syndiagensis) (Smart, 1999; Larsen and Chilingar, 1983). Gypsum is found in some geological formations represented by gypsum rocks, and it is called primary gypsum in this instance while the secondary gypsum is gypsum that has been accumulated in the soil from a variety of sources, including dry and semi-dry locations, resulting in salt concentration and gypsum deposition at the top of the capillary zone (the upper phreatic zone) and the ventilation zone (Vadose zone). The concentration is based on the rate of evaporation, the salinity of the groundwater, the aquifer's hydraulic conductivity, and the depth of the pore water area (Selley, 2000). Secondary gypsum is formed through the oxidation of sulfate-rich rocks such as pyrite (FeS) and the reaction of the oxidation products with calcium carbonate (Al-Ashoo, 1991), as the following formals:-

$$4FeS_2 + 15O_2 + 14H_2O \longrightarrow 4Fe\,(OH)_3 + 16H + 8SO_4 \text{ --------------- } (2\text{-}1)$$

$$CaC0_3 + 2H \longrightarrow Ca^{2-} + H_2O + C0_2 \text{ ---------- } (2\text{-}2)$$

$$CaC0_3 + 2H + SO_4 + H_2O \longrightarrow CaSO_4.2H_2O + CO_2 \text{ ------------ } (2\text{-}3)$$

The erosion and weathering of exposed primary gypsum rocks is a secondary source of gypsum (FAO, 1990). When sufficient sources are available, climatic variables aid the formation of gypsum crystals in arid and semi-arid environments when yearly total rainfall is less than 400 mm (FA0, 1990). Wind can transport gypsum from coastal sabkas, desert playas, and sensory areas in the desert to new locations, forming independent gypsum structures or soil-intertwined deposits (Goudie & Viles, 1997). After eliminating other more soluble salts such as sodium chloride, washing saline soils containing sulfate and calcium causes them to re-establish and accumulate in a good shape in the soil horizons (Mahdi, 2004). The deposition of gypsum and fermentation result from the substitution of calcium ions for sodium and magnesium ions in free sulfates in groundwater, as well as the concentration of other salts and the continuation of the water movement leads to the deposition of large quantities of gypsum, (Al Ashoo 1991).

The highly saturated Brines formed from sea water are thought to be the most likely source for most of the gypsum, with a calcium sulphate content of 3.6 percent. Different amounts of gypsum can be found in hyper saline lakes, hot springs, marshes, and salt pans (Stipho, 1985).

Gypsum is also formed from the interaction between solutions and solid materials, as in the reaction of zinc sulfate Smithsonite and calcium carbonate, and as shown in the equation (2-4).

$$CaCO_3 + ZnSO_4 + 2H_2O \longrightarrow CaSO_4.2H_2O + ZnCO_3 \text{ --------------- } (2\text{-}4)$$

Gypsum is also formed by adding a water molecule to the mineral anhydrite.

2.3 Gypseous and Gypsiferous Soils

Gypseous and gypsiferous soils are soils that have rich gypsum with concentration of more than 2% that have an influence on engineering facilities because they include soluble components, and they are the worst and most destructive of the engineering soils if they are not protected from water. It originates when falling rains are insufficient to eliminate gypsum from the soil section in dry and semi-arid environments (Alphen & Romero, 1971). Barazanji (1973) proposed using the first term to describe gypsum soils with less than 50% gypsum concentration and the second term to describe soils with a higher gypsum content and he also advised that the first group be divided into groups, Table (2-1). Nashat, 1990, also describe and classification of gypseous soil for groups that as shown in Table (2.2).

Table (2-1) Classification of gypseous soils, (Barazanji, 1973).

Gypsum content CaSO4.2H2O%	**Classification**
0.0-0.3	Non – Gypsiferous
0.3- 3.0	Very - Slightly Gypsiferous
3.0- 10	Slightly Gypsiferous
10-25	Moderate Gypsiferous
25-50	Highly Gypsiferous
> 50	Gypsiferous soil to be described the

Table (2-2) Classification of Gypseous soil for NCCL, (Nashat, 1990).

Gypsum content $CaSO_4.2H_2O$%	Classification
0-10	Slightly
10-25	Moderately
25-50	Highly
>50	Gypcrete

2.4 Uses of Gypsum

Gypsum has a lot of advantages, it's utilized in medicine, agriculture, and other fields. Plaster is used as a splint for broken limbs to keep the broken bone in place while the fracture heals and returns to its natural state, after which it can be removed, it's commonly utilized in the construction and design industries. Also is used in the manufacture of blackboard chalk which use in the educational institutions and others. Gypsum boards are commonly known in the construction industry as drywall, wall panels, rock panels, or gypsum boards, and are primarily utilized in the finishing of walls and ceilings, as well as its using in concrete blocks to construction of buildings.

2.5 Distribution of Gypsum Soils in the World and Iraq

Globally, gypsum soils cover an area of 1864,725 km^2 in north-central-eastern Africa and southern Europe, including Spain, southwest Siberia, Georgia, and southwest Asia in Iraq, Syria, and Iran, as well as southern and central Australia and other arid and semi-arid regions (Jafarzadah & Zinck, 2000). The necessity of understanding the geotechnical features of gypseous soils in Iraq is emphasized, as it spans 12,503 km^2, or 28.6% of the country's land area, (Jafarzadah & Zinck, 2000). These soils are distributed in the northern part of Al-Jazirah region with a gypsum content 3-10%, and in the south (south of Sinjar Mountains, southeast of Tal Afar and Qayyarah fold) with a low gypsum content at the surface to more than 60% below the surface. The river terraces of the middle and bottom of the Tigris and Euphrates rivers are characterized by the presence of a high percentage of gypsum up to 80% in the first five meters of soil depth (Barazanji, 1973). The gypsum soils in Iraq are spread in the cities of Mosul, Buji, Tikrit and Samarra and northwest of Baghdad, Anah, Hit, Ramadi, Fallujah, Najaf and Nasiriyah, , figure (2-1). Most of the gypsum soils in Iraq come from geological formations that contain gypsum and anhydrite, such as the Fatha formation formed by the evaporation of water in the inland seas. According to (Buringh, 1960).

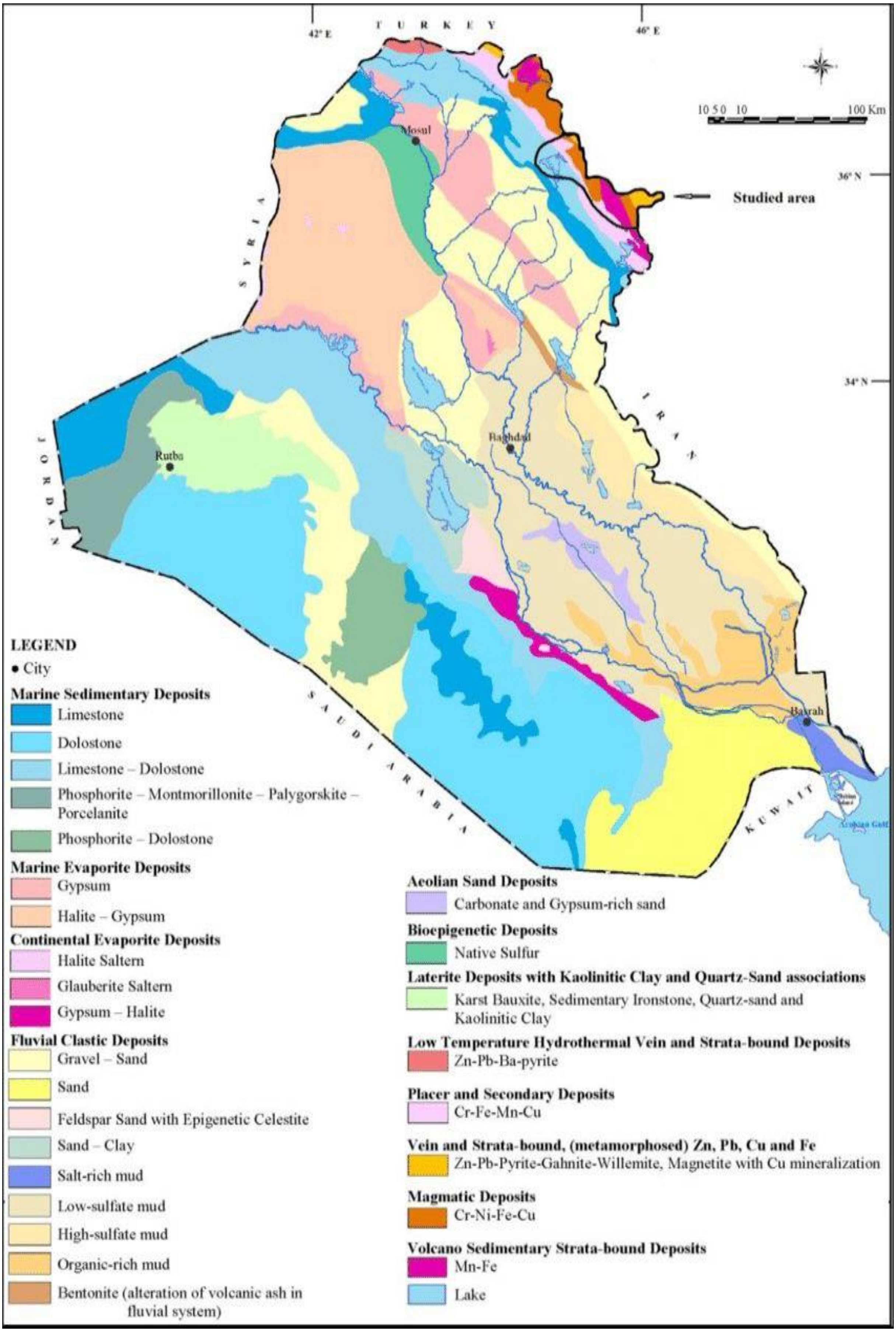


Figure (2-1): Distribution of Gypseous soils positions in Iraq (Al-Bassam, 2007).

2.6 Gypseous Soil Problems

Gypseous soils have an abnormal characteristics within a horizontal and vertical extensions, the following factors are responsible (Al-Neami, 2010): -

a- Due to the deposition of concentrated brine solutions inside diverse soils and which production of gypsum soils is complicated (sandy, silty, clay ... etc.).

b - The chemical composition of gypsum and its limited water solubility.

c - Evaporation processes allow saturated gypsum ion solutions to ascend to the top, resulting in the deposition it of the surface layers.

d - Existence various salts, such as carbonate, chlorides, and other sulfates in gypsum.

e - The creation of new gypsum minerals continues while the old minerals undergo physical and chemical alterations.

Due to the heterogeneous settlement induced by gypsum deposits, many engineering facilities erected in Iraq and around the world have cracked or collapsed. All of the collapses were linked to water leaking into the gypsum foundations' soil, which resulted in the foundations' weakening and the removal of gypsum (leaking) as the push continued, (Nashat, 1990). Leaching has severely damaged the foundations of oil refineries in Shuaiba and Nasiriyah, fertilizer and petrochemical plants in Basra, iron and steel in Mosul, the tourist village in Habbaniyah, the water tank in Karbala, the Samarra Tourist Hotel, and the nitric acid plant in Baghdad, among others. The dissolving of gypsum in the soil, as well as the sports stadium in Saudi Arabia and the dry dock in Dubai, have all been affected.The presence of soluble gypsum salts in the foundations and supports of dams and earthen ramps, or in the materials used in construction, has caused serious problems, and many dams in California, Oklahoma, and New Mexico have been damaged or collapsed so, necessitating extra caution when calculating the bearing capacity of sites with soil or gypsum rock, as well as accurate exploratory investigations to learn what is beneath the surface (Khaled a. A. Al-Haddad, 2008).Also, pipes and water-carrying channels are subjected to some leaching, and their construction in gypsum soils near buildings results in subsidence as the gypsum, which serves as a bonding material for the granules, dissolves in an amount that varies depending on the percentage of nutrient components and the amount of infiltrated water (Plate 2-1).

Plate (2-1): Dissolution of the gypsum layer due to a broken water pipe under the foundations of the mosque in Samarra District in 2007, which caused the dissolution of gypsum and the weld material, which resulted in cracks in the walls and the collapse of the building (Khaled a. A. Al-Haddad, 2008).

2.7 Gypsum Solubility

Gypsum has a solubility of 2 g /liter in pure water at a temperature of 20 ^{0}C, (Dontsova *et al*., 2015). Due to presence of decomposes gypsum, where this mineral separates the calcium ions from the sulfate ions, making it easier for flowing water to be transported from its source via soil gaps formed to other locations (Jassim, & Goff, (2006).

The following factors influence the solubility of gypsum in water (FAO, 1990):-

A- The volume of water and the velocity at which it flows

With increased water velocity and its amount, gypsum shall be more dissolved, where velocity of water by 1m/sec can dissolve 1 m^3 of gypsum in a year, (FAO, 1990).

B- Gypsum minerals and other salts concentration in water

Water saturated with gypsum is unable to dissolve additional gypsum materials, whereas the presence of other salts, such as sodium chloride, causes calcium sulfate to dissolve more readily, (FAO, 1990).

C- Temperature:

Gypsum is most soluble at temperatures between 35 and 50 degrees Celsius, (FAO, 1990).

D- Gypsum's shape and distribution

The solubility of gypsum increases as the amount of surface area exposed to water increases.

E- Time:

Gypsum dissolution increases with increasing time spent of gypsum in the water

2.8 Studying Engineering Gypsum Soils Behavior

The widespread distribution of gypsum soils, as well as the pressing need to construct projects on them or use them as filling materials for paving roads and corridors, prompted researchers to investigate the engineering behavior for gypsum soil under various conditions in order to determine their suitability for engineering purposes. Several factors are harmful effects that gypsum depends it like vertical and horizontal distribution of gypsum and its content in the soil, Presences fresh water sources and Soil texture and its permeability to allow of water movements. (Al-Khafaji, 1990).

The proportion of gypsum in the soil should not exceed 2.5 percent, according to British regulations, (Bowles, 1988). The Iraqi standards specified for a maximum of 10% gypsum concentration in burial soil and a maximum of 10.75 percent gypsum content in mixed gravel used in road construction. According to studies, soils with a gypsum concentration of more than 15% are unstable, while soils with a gypsum content of 10-35 percent are unsafe and inappropriate for irrigation channel construction, (FAO, 1990).

2.9 Influence of Gypsum Content on the Soil's Geotechnical Properties

Researchers were interested in learning more about the impact of gypsum on soil geotechnical qualities, and the results were discrepancies. it is important known the laboratory behavior of gypsum soils ,where its different depending on original soils, or it made in a lab (Gypseous soils) by adding gypsum, as well as whereas check the soil sampling if were interrupted or not and type of soil and check method (Bowles, 1988) .

2.9.1 Impact of Gypsum Contents on the Classification Properties

a. Specific gravity

Gypseous soils have low specific gravity and its decreases with increasing of gypsum content due to the low specific gravity of gypsum mineral, which is 2.35, While anhydrite-containing soils show an increase due to the high specific weight of this mineral, which amounted to 2.96 (Nashat, 1990).

b. Grain size analysis

Gypsum causes two basic problems in the construction of the cumulative curve, firstly, gypsum particles dissolve during preparation or during the examination of hydrometer, secondly, gypsum particles despite their small size may aggregate together in agglomerates with bigger size. So, it is preferable to treat the soil and remove the gypsum according to the analysis by washing the soil with distilled water or using a substance (EDTA) or dilute hydrochloric acid (HCI), Nashat, 1990).

c. Atterberg limits

Atterberg limits affected in cohesive gypsum soils by the gypsum content and clay percentage. When the clay percentage is high, the change in the gypsum content has little effect in these limits, but it is affected in the clay silt soils with an increase in gypsum, (Al-Abdullah, 1996). According to Singh & Al-Layla,1979, when the gypsum content increasing, the fluidity limit rises and the plastic limit falls without any change in plasticity factor. According to studies, the shrinkage limit increases somewhat as the gypsum content rises, (Azam *et al*., 1998).

2.9.2 Gypsum Content Effect on the Resistance Soil

Increase unconfined compression strength (Uc) icreases in dry soils with an increase in the gypsum content, (Abood, 1993; Nashat, 1990; Razouki, 1999). Increase of gypsum content in Gypseous soils leads to a significant reduction in the Soil Streng with increase of the moisture content and immersion of soil with water, (Subhi, 1987).

2.9.3 Gypsum Content Effects on Voids Ratio and Dry Density

The initial voids ratio (e) and initial dry density (γ_a), affected by gypsum content which effects on the compressibility, permeability and resistance, (Petrukhin & Arakelyan, 1985). Because the specific weight of gypsum is less than that of other soil constituents, increasing the gypsum content in sandy soils causes an increase in the proportion of voids and a drop in the dry density. While the proportion of voids in clay soil models with varying content compressed to the same dry density is lower in models with high gypsum concentration, (Al-Qaissy, 1989).

2.9.4 Gypsum Content Effects on Compaction Characteristics

Increasing of Gypseous content in Gypseous soils reducing the maximum dry density and increases of optimum moisture content (Al-Mufty, 1997; Khafaji, 1990).

2.9.5 Gypsum Content Effect on Compressibility

Compression of natural Gypseous soils occurs during the first immersion cycle or during heavy rain or during the short irrigation period, (Al-Mohammedi *et al*., 1987). Gypseous soils show an important secondary compression as a result of the continuous melting, (Nashat, 1990).

2.9.6 Gypsum Effect Content on Collapsibility

Existence of gypsum in dry soils leads to stable structure as a result of gypsum behavior to bonding material to soil particles, and the deterioration (a clear drop in the soil surface) occurs when water passes and gypsum is dissolved, which leads to a weakening of the structure of soil susceptibility and increased collapsibility with increasing gypsum content، (Abood, 1993; Al-Heeti, 1990).

2.9.7 Gypsum Content Effect on Permeability

The ability of water to dissolve gypsum improves the permeability of gypsum soils as the gypsum content rises, (Subhi, 1987).

Due to the expansion of the holes and the collapse of the soil structure, the permeability is high at the start of the washing phase and gradually reduces until it reaches a fixed value.

2.10 Soil Improvements

Soils with inadequate geotechnical requirements for building such as gypsum, swelling and soft soils, force soil engineers to use one of the following options for improvement (Lamb, 1964):

a- Soil avoid by choosing another site for construction.

b - Substituting suitable soils for those that are unsuitable.

c- Accept the geological materials on the site as they are and create foundation designs that meet their characteristics, such as using floating foundations or deep foundations to minimize subsidence and instability issues caused by weak soils.

d- Enhancing soil specifications, also known as (soil stabilization), aims to alter the properties of the soil in order to improve its engineering performance, such as increasing resistance, decreasing compressibility, decreasing permeability, regulating differential landing, lowering lateral soil pressures, increasing bearing capacity, avoiding liquefaction, accelerating joining, and improve cliff stability,

2.11.1 Soil Improvements Methods

3.11.1.1 Mechanical Methods

The mechanical stabilization works to soil improvements by using the techniques and materials without effecting on the soil type via increasing the density (Densification) in order to more stability and increasing of bearing capacity.Some mechanical methods are:-

1. Compaction
2. Vibro-replacement
3. Vertical drains
4. Fibers
5. Meshes

2.11.1.2 Physical Methods

Some of physical methods are:-

1. Thermal methods
2. Electro-osmsis and Electro hardening
3. Pressure stabilization

2.10.1.3 Chemical Methods

Soil characters improvement can be add some of chemical stabilizers other sold or liquid, organic or nonorganic that well changes the physical properties of soil.

Some of these chemical stabilizer are:-

1. Lime stabilizer
2. Sodium chloride
3. Sodium hydroxide and sodium silicate
4. Lignin and Polymers

2.10.2 Additives Material

2.10.2.1 Hydrated Lime

When mixing gypsous soil with Hydrated lime and water, the basicity of the soil rises to more than (pH > 12) and the hydrated lime decomposes in water to calcium (Ca) and hydroxide (OH) at which point the pozzolanic interaction begins between each of the decomposing Hydrated lime ions and the main compounds of the soil represented by silica (SiO) and alumina (ALO) to form hydrated cement compounds such as hydrated calcium silicate ($nCaO.mSiO_2.kHO$) and hydrated calcium aluminate ($nAL203.mSiO2.kH_2O$), addition to other reactions. Where (m,n,k) are the molar ratios of each compound in the final product and its values depend on the mixing conditions between soil, light, water, formation conditions and the surrounding conditions (Sherwood, 1993).

2.10.2.2 Montmorillonite

The effect of Montmrillonite on soil pH values, where it is clear that there is a high significant effect of Montmrillonite in raise the soil pH. Hydroxyl -OH to the soil solution, which increases the number their interaction also, Montmrillonite is formed from sheets of mineral phyllosilicate, which take the form of microscopic platy grains. These give it a very large total surface area, making Montmrillonite a valuable dense material. The boards also stick together when wet. This gives the soil a consistency that makes it useful as a binding agent and as a soil conditioner (Al-Ashoo, 1991)

2.10.3 Interactions between the Gypseous Soil and Additives

The addition of hydrated lime and Montmrilloniteto the soil results in an improvement in the engineering properties due to the following main reactions:-

1- Cation Exchange

2- Agglomeration and Flocculation

3- Lime Carbonation

4- Pozzolanic Reaction

2.10.4 Factors Affecting the Interaction between Gypseous Soil and the Additiv

There are many factors that affect the completion and efficiency of fixation with additives such as lime and Nano-clay used in the study, and the following are some of these factors (Eshoo, 2004):-

1- The Content of Organic Matter

The organic matter hinders the interaction of lime and montmorinite with soil containing more than %2, either because of the absorption of calcium ions as a result of the large ion exchange process, or because it prevents the process of dissolving the silica and alumina in the soil by forming a protective cover around it (Eshoo, 2004).

2- PH-Value

Soil that has a value of (PH) is greater than that of soils that interact well with Hydrated lime (Eshoo, 2004). It was also found that the solubility of silica increases in the environment in which the value of (PH) is high.

3- Dissolved salts

Dissolved salts in the soil on the amount of its resistance when the soil is stabilized by the hydrated lime. Fixation ratio (optimum amount of hydrated lime and Montmrillonite used) decreases as the proportion of salts in the soil increases. The gypsous soil interacts well with the hydrated lime and Montmrillonite to form a soil of high strength, this interaction also leads to a reduction in the percentage of dissolved salts (Eshoo, 2004)

4 - Curing Condition (Hydration period)

The effect of wetting soil at differentness temperature and with a different periods of wet on strength models. The results showed that the strength increases with increasing of temperature and wet time periods, also noted the effect of wetting temperature it be greater than the effect of wetting period (Abood, 1993).

Chapter Three

Materials Used In

Gypseous Soil Improvement

And Laboratory Experiments

3.1 Preface

This chapter deals with the materials that were used in this study for Gypseous soil improvement, and methods for preparing samples, as well as the tests and specifications that have been approved and methodology.

In this study, a numbers of points is selected within city of Najaf, percentages of gypsum were examined. Many locations with low percentages were neglected, and three sites have been chosen. Engineering, physical and chemical tests for untreated soils have been conducted. After that, the samples of soil were treated with the two parts, hydrated lime additive with a percentage (3, 6 and 9%) and Nano-clay with a percentage (5, 10 and 15%). Then, physical and engineering tests were repeated for all of samples that treated to detected of geotechnical changes and improvements that occurred on the samples. Figure (3 -1) illustrates a block diagram showing the methodology that followed in the Procedures during the study.

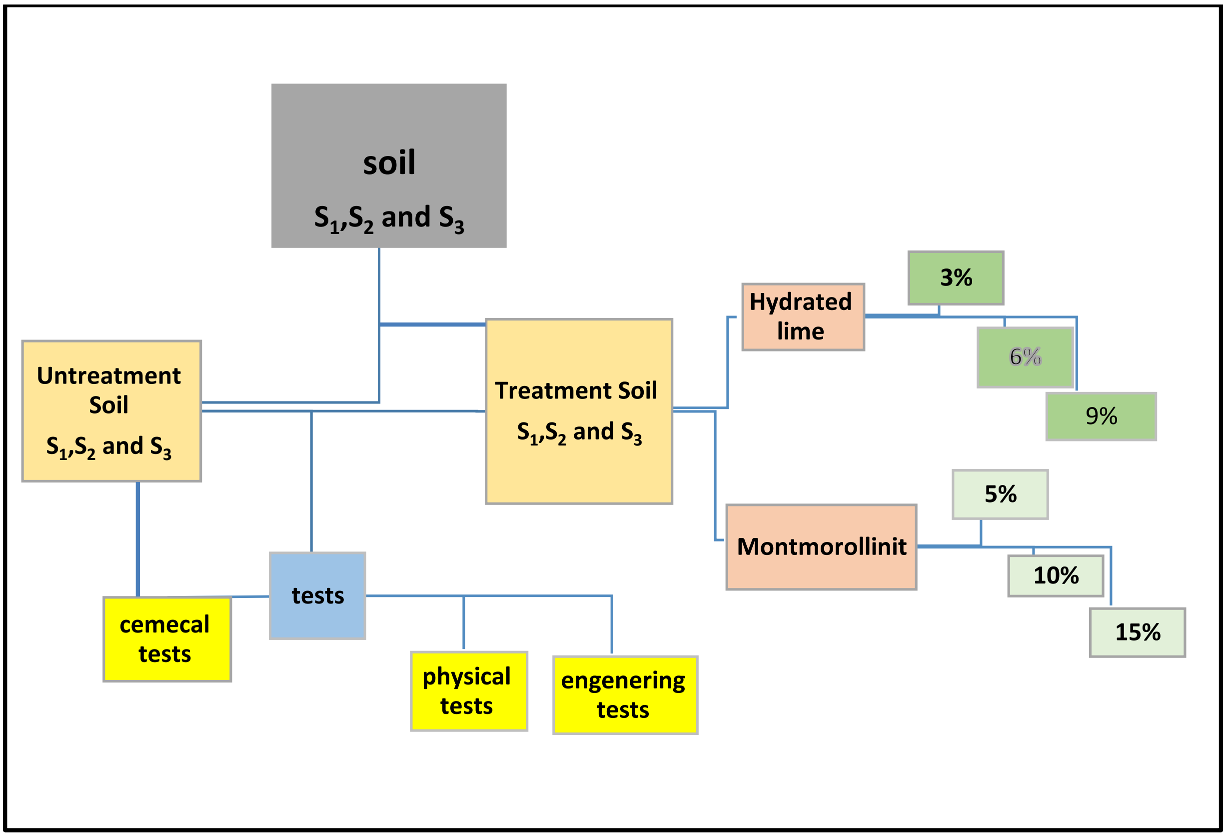


Figure (3-1): Block diagram showing the methodology that followed in the Procedures during the study.

3.2 Materials of Study

3.2.1 Soil

Disturbed soil samples are collectied, meaning the samples that have been extracted from the ground and that have been subjected to physical and mechanical disruption. Three different positions of soils (Soil1, Soil2 and Soil3) were taken from Najaf city to cover all the study area region. Najaf-Karbala plateau region which lay in Al-Najaf governorate is recognized as sandy soil attributed to Debdiba formation. The samples were obtained from depth (1.5- 2.5) m below ground surface level for using as a model experiments, Figure (1-1), Table (3-1), the soil of study area site characteristics are determined for use in laboratory model testing like physical, chemical and engineering parameters of the soil.

Table (3-1): The coordinate, color and the gypsum contents of soil sample in the study area.

Samples	Longitude	Latitude	Color	Gypsum contents
Soil 1	44°15'13.39"E	32°11'43.97"N	white – grayish	56%
Soil 2	44°15'18.10"E	32° 4'30.56"N	white- beigest	48%
Soil 3	44° 02'2.47"E	32° 07'0.88"N	Whitish	72%
Soil 4	44°24'18.11"E	31°57'19.20"N	white- beigest	16%
Soil 5	44°22'39.96"E	31°58'14.54"N	white - brownish	24%
Soil 6	44°22'28.79"E	31°58'7.02"N	white - brownish	10%
Soil 7	44°22'15.35"E	31°57'34.98"N	white – grayish	7%
Soil 8	44°20'7.56"E	31°58'10.85"N	white – grayish	13%
Soil 9	44°18'27.15"E	31°59'33.15"N	white- beigest	18%
Soil 10	44°16'48.32"E	32° 1'18.39"N	white - brownish	31%

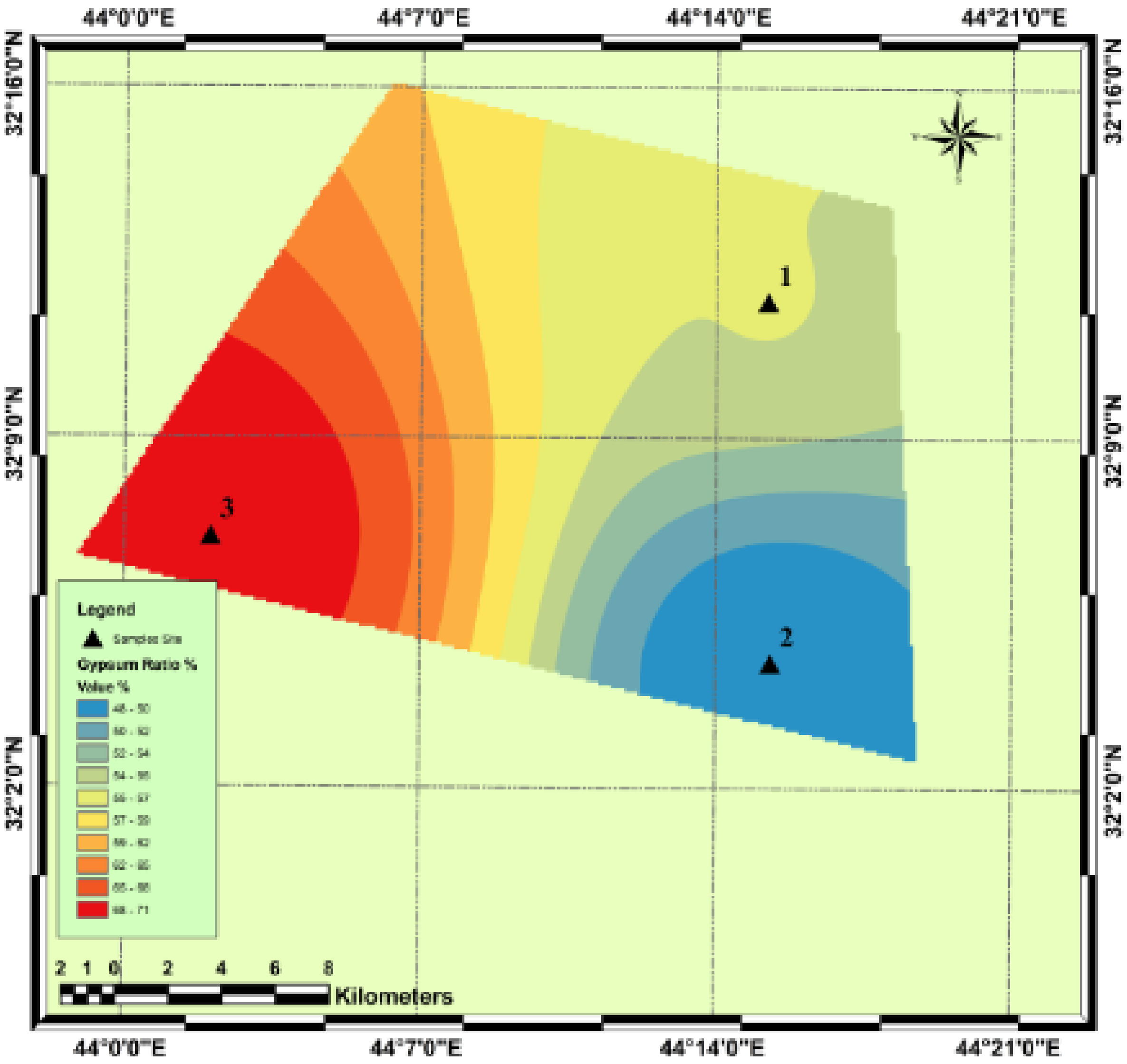


Figure (3-2): Interpolation of gepseous soil ratio for study area

3.2.2 Samples Prepare

The samples are prepared according to the American specifications for the non-treatment or treatment soil, whether they were for traditional or non-traditional stabilizers. Where add 3, 6 and 9% Hydrated lime and 5, 10 and 15% Montmrillonite for each of the three samples, as shown in the table (3-2). The amount of the additive is calculated on the basis of the dry weight of the soil as in the following equation:-

Amount of additive = Weight of dry soil × Percentage of additive / 100….. (3-1).

Table (3-2): The samples to study area prepared according to the American specifications

N	Examination name	Specification source	Number of samples
1	Moisture content	ASTM D 2216-2006	21
2	Atterberg limits	ASTM D 4318-05, 2010	21
3	Specific weight	ASTM D 854- 2010	21
4	Grain size analysis	ASTM D 422-2007	21
5	Collapse test	ASTM D5333 -2018	21
6	Compaction test	ASTM D698 , 2012	21
7	Direct shear tests	ASTM- D3080 , 2011	21

3.3 Additives

There are two types of materials were used as additives materials Montmrillonite, and Hydrated lime to the gypseous soil samples in this study and by the different ways via mixing and working of examination Samples, as well as water was added to prepare samples.

3.3.1 Hydrated Lime as an Additive

The samples are subjected to a percentage of Hydrated lime treatment (3, 6, and 9%) respectively, Hydrated lime was produced from Lime factory- Karbala (plate3-1).

Plate (3-1): Lime factory in Karbala Governorate

It is in conformity with the Iraqi standard specification No. (807)-2004 (I.B.S, 2004), which contents the percentage of lime elements that was used to conducted add of lime to sample tests. Table (3-3) the central laboratories of Al-Noura factory in Karbala governorate, contents percentages of Lime elements that are used to the samples additive for the tests.

Table (3-3): hydrated lime chemical properties contents in percentage that used in the tests of sample in study area and taken from the central laboratories of Lime factory in the Karbala governorate

NO	Oxide	Values %
1	CaO	84
2	SiO_2	2.4
3	AL_2O_3	1.3
4	Fe_2O_3	1.8
5	MgO	0.43
6	Na_2O	0.5
7	SO_3	0.33
8	$CaCo_3$	8.11

3.3.2 Montmorollinite as an Additive

The samples were treatment by Montmrillonite with a percentage 5, 10 and 15% respectively. Technically, Montmrillonite is most important clay mineral as main component of betonies. Betonies is a tetrahedral SiO_4 with deep-rooted octahedral layers of aluminum, iron and hydroxide ions. The common Montmrillonite Particle consists of approximately 1 nm thick alumina silicate layers with side sizes in series from 700 nm, which are accumulated in large stacks, (Fig. 3-2), (https://doi(10).

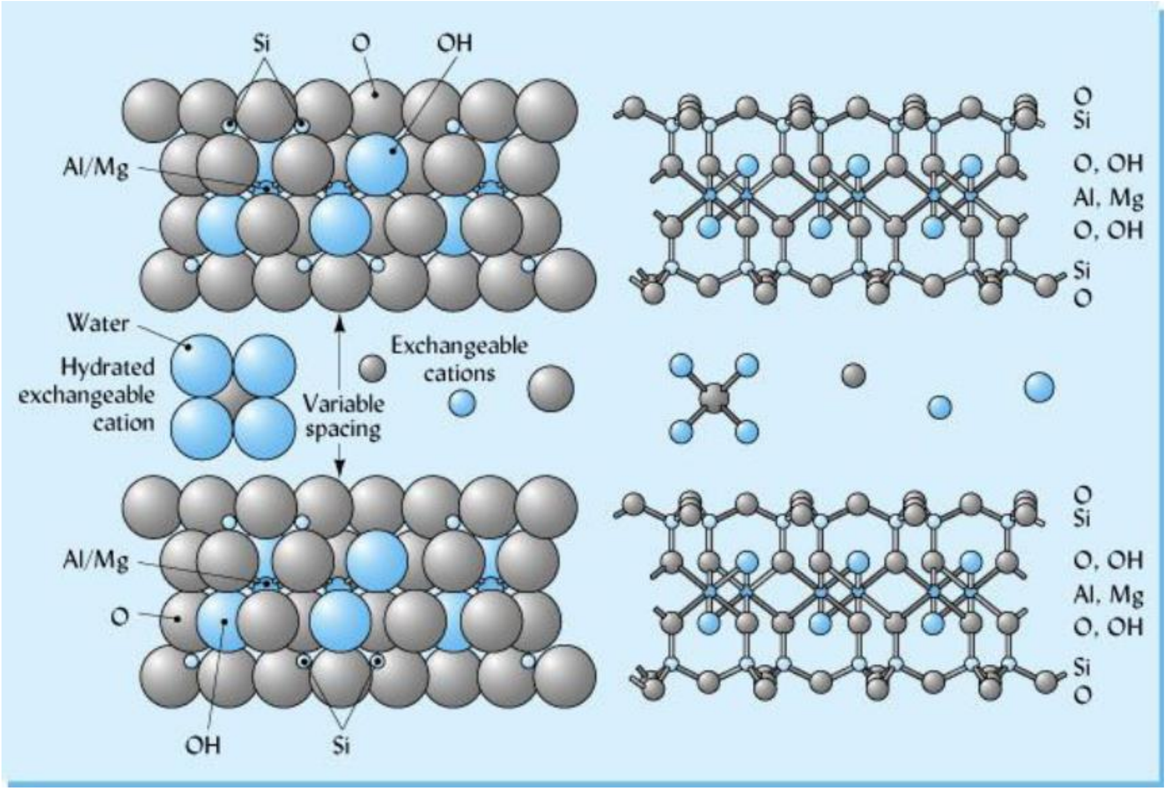


Figure (3-3): Montmorillonite particle chemical consists layers, (https://doi(10).

Montmrillonite was brought from the General Commission for Ground Water / Al-Najaf AL Ashraf Branch, where it's using as a casing for hole well to drill of groundwater wells (Plate 3-2). Montmorollinite material was used to treatment the samples for the tests.

Plate (3-2): Montmorollinite material (API 13A Section 9, 2019 specification).

Montmorollinite material is imported from global sources and according to the following specification, (*https://van-bent.com/ van-bent.com*):-

VAN-BENT MINERALS API Bentonite is used as a viscosifier and Fluid Loss reducing agent. It is most effective in the fresh water. Pre hydrated VAN-BENT MINERALS API Bentonite can be used in brackish and salt water.

Typical performance of VAN-BENT MINERALS API 13A section 9 Bentonite when tested as per API method is as follows, (Table 3-4 and Table 3-5).

Table 3-4: Specification of microgel bentonite powder, (https://doi(10).

No.	Physical Properties	Specification
1.	Viscometer Dial reading at 600 rpm	30 Min
2.	Yield point / plastic viscosity ratio	3 Max
3.	Filtrate volume (in cc)	15 Max
4.	Residue greater than 75 micron (200 mesh) wet analysis	4.0 % Max

Table (3-5): API 13A section 9 Bentonite chemical composition ratios, (https://doi(10).

	No	Oxide	Values %
Analysis quick typical	1.	SiO2	58.0 - 64.0
	2.	Al2O3	18.0 - 21.0
	3.	Fe2O3	2.5 - 2.8
	4.	MgO	2.5 - 3.2
	5.	CaO	0.1 - 1.0
	6.	Na2O	1.5 - 2.7
	7.	K2O	0.2 - 0.4

3.3.3 Water as an additive

Water additive to the samples in order to carry out examinations, where each method require a certain percentage of water. In tests that require the use of distilled water, distilled water is used. As well as the use of tap water for the tests that do not require used the distilled water. The properties of added water was calculated according to the following table (3-6) shows the properties of water tap that used in this research.

Table (3-6): Physic-chemical properties of liquefy water (Eshoo, 2004)

NO.	Parameter	Values
1	Total Hardness (mg/l)	240-260
2	Turbidity (NTU)	< 10
3	PH	7.8-8.2
4	Ca (mg/l)	60-65
5	Mg (mg/l)	15-20
6	Cl^- (mg/l)	20-25
7	So3 (mg/l)	80-100
8	Na (mg/l)	< 10
9	Alkalinity (mg/l)	140-150
10	F (mg/l)	< 10

3.4 Laboratory Tests

This include:-

3.4.1 Physical Tests

The physical properties for the soil must tracked the dry temperature for samples in all tests and it reach to $55 - 60$ ^{0}C due to presence of high gypsum in soil and to avoid the loss in crystal water, according to ASTM, D 2216 – 2006.

The physical testing that conducted on the samples as the following steps:-

3.4.1.1 Moisture Content Analysis

Test carried out by use 250 g of soil was taken for each sample and placed in an empty container, previously weighed and empty. Then we recorded the weight of the sample with the model and put it in an oven at a temperature of 110 degrees for 24 hours and then the dry weight was taken. The fallowing equation no. (3-2).

$M.C = \frac{W2-W3}{W3-W1} \times 100$……….. (3-2).

M.C: moisture content.

w_1**:** Weight of the container when it is empty.

w_2**:** Container weight with sample.

w_3**:** Container weight with dry sample.

3.4.1.2 Grain Size Analysis

Sieve analysis test is done according to (ASTM D 422-2007) specification, a wet washing method was used for all soil samples, grain size analysis of the gypseous soil is tested by using a number of sieve analysis (Plate 3-3).

Plate (3-3): Sieve analysis, the device and work methodology.

3.4.1.3 Atterberg Limits

The Atterberg limits for the gypseous soil are tested according to (ASTMD 4318 – 2010). Atterberg limits (liquid limit, plastic limit, plasticity Index) were determined according to the methods that used by the American Society for Laboratory Testing and materials, where a sample of transit soil is taken from sieve no. (40) And it was treated with water and placed in the Casagrande device and made a several attempts to fine the relationship between the number of blows and water contents (Plate 3- 4).

Plate (3-4): Casagrande device.

Atterberg limits consists of:-

a. Liquid Limit (LL)

The liquid limit (LL) is the water content at which a soil changes from plastic to liquid behavior, (Eshoo, 2004).

b .Plastic limit (PL)

The plastic limit was also calculated by making a wick with a diameter of (3.25 mm) until cracks appear in addition to taking the moisture content and after three attempts were made, the plasticity limit was extracted.

c. Plasticity Index (PI)

The plasticity index (PI) is a measure of the plasticity of soil. The PI is the difference between the liquid limit and the plastic limit, (AL-Ashoo, 1991).

The plasticity Index was calculated from the following equation no. (3-3).

PI = L.L – PL ……….. (3-3).

Where:-

LL: Liquid limit.

PL: Plastic limit.

3.4.1.4 Specific Gravity

Is the weight ratio of a solid (soil) at a certain temperature to the weight of the same volume of water at the same temperature, with the soil typically including particles of varying weights.

This test is conducted according to the procedure of the ASTM D854 -10. Kerosene is used instead of distilled water to avoid gypsum dissolution in water using pycnometer method.

3.4.2 Engineering test of gypseous Soil

3.4.2.1 Collapse Testes

Collapse potential can be fined by using Oedometer device (plate 3-5). The test is carried out according to the American Standard ASTM D5333 -2018, and the method that used is derived by depended on (Knight1963 ،) method. This amount of dried soil was combined with a calculated amount of water to achieve the predetermined initial water content (ωo), and the combination is kneaded by hand to achieve a more homogeneous result. The wet soil was compacted, a pressure wedge was used on the specimen's surface and was inserted into the Oedometer's ring. Then, the sample is statically pressed to fit the ring exactly. The size of the consolidation ring was determined by weighing an amount of dried soil (diameter 76 mm, height 20 mm).

Plate (3-5): Oedometer device.

In this test, the samples are carried out according of the same manner as standard accession test in case of a dry state (no water is added). After applying a stress of (200 kilopascals) and waiting for a period of (24) hours, water is added to the cell and leave the sample for a period of 24 hour, the changes in the height of the samples (Δh) are recorded and the examination is continues as like standard accession examination. The collapse test is used on untreated gypsum soil samples and the treated samples that are treatments with a different amounts of Montmrillonite and Hydrated lime by measuring the changes in the sample thickness in the cell disc of the sample during the seven-day period of immersion the sample. The Equation (3-4) was used to account of collapse potential.

$C.P = (\Delta h/H) \times 100\%$ ……………….. (3-4).

Where:-

C.P: Collapse potential.

Δh: Change in thickness of sample.

H: The original thickness of the sample.

The relationship of the probability of collapse to the severity of the foundation problems is illustrated through Table 3-7), which represents the criterion used to classify gypsum soil on the basis of the probability of collapse. As it is that the increase in CP increases with the increase of wetting of gypseous soil

Table (3-7): Severity of collapse based on CP values (Hayal and other, 2020)

Collapse Potential CP (%)	Severity
0-1	No problem
1-5	Moderate problem
5-10	Problem
10-20	Severe problem
>20	Very severe problem

3.4.2.2 Compaction Test

This test is carried out in accordance with ASTM D 698 -2012, specifications ,When soil is saturated with water (all the gaps are filled with water), the ratio of the weight of dry soil to the entire volume of the soil mass is known as the saturated density, (Al- Zubaydi, 2006).

The effect of adding different percentages of hydrated lime and Nano- clay on the properties of compaction (maximum dry density and optimum moisture content) using the modified compaction method.

Natural soil models are prepared with a density equal to the field density and natural moisture, where the models were prepared by preparing an appropriate amount of dry soil and then weighing it and adding an amount of water in order to make the moisture content equal to what it is in the field (natural moisture percentage).

And then the model is stacked using the tools of the standard stacking method (where the modified stacking hammer and the modified stacking cylinder were used), where the number of strokes for each layer is changed, ranging from (20-25) strokes (plate 3-6), in order to obtain a prepared model according to a density approaching the field density

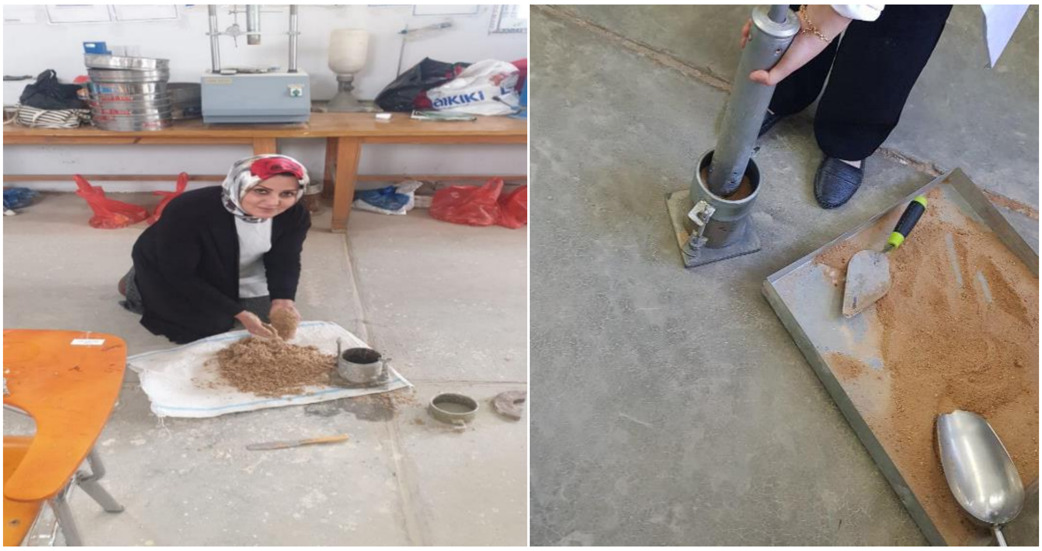


Plate (3-6): Compaction test methodology for the sample

3.4.2.3 Direct Shear Test

This test is used to calculate the maximum resistance the soil has to pressure and stress. All samples are tested in a shear box test under normal loads of (3.5, 7 and 14 kg/m^2) Plate (3-7) in accordance with the ASTM- D 3080, 2011 specification. The following soil characteristics are calculated by this test (Angle of internal friction and cohesion) and it's calculated by the equation no (3-5).

$\tau = C + \sigma_n \tan Ø$ ……. (3-5).

Where:

τ: Shear strength.

C: Cohesion.

σ_n: Applied vertical stress at failure.

Ø: internal friction angle

Plate (3-7): Shear box device

3.4.3 Chemical Tests

According to British Standard (BS 1377:1975), soil chemical tests are performed to find the chemical characteristics (Plate (3-8). Table (3-8) demonstrates the chemical tests for the natural soil utilized.

Plate (3-8): Chemical tests for sample of study area

Table 3-8: Chemical testes for the natural soils sample of study area.

No	Examination name	Test numbers
1.	Sulphate (SO3%)	3
2.	Calcium Carbonates (CaCO3%)	3
3.	Chloride(CL)	3
4.	Gypsum (CaSO4. 2H2O %)	3
5.	pH	3
6.	Total dissolved solids, T.D.S	3
7.	Conductivity	3
8	Organic material	3

Chapter Four

Results and Discussion

4.1 Prefers

This chapter includes laboratory tests for treated and untreated soils that are taken from three locations within city of Al-Najaf Al-Ashraff. Such of engineering problems are happens due to the soil have high proportion of gypsum such which leads to dissolving and Collapse. The samples are taken from depth (1.5 – 2.5) m, and the groundwater level is far ranges of (4m to 27m), (GCGW). However, the sample locations are shown in figure (1-1).

4.2 General Description of Natural Soils

4.2.1 Location no.1

Gypseos soil taken from a site near shrine (Safi Al-Safa) and describe it as white-gray course to medium grains Sandy with little gravel, containing a gypsum percentage of 56.6% and a field density 1.98 gm/cm^3.

4.2.2 Location no.2

Gypseos soil taken from a site (the residential complex / Al-Rahma neighborhood) and describe it as white- beige coarse to medium grains Sandy with little gravel, containing a gypsum percentage of 48.6% and a field density 1.99 gm/cm^3.

4.2.3 Location no.3

Gypseos soil taken from a site (The Popular Mobilization Headquarters / 20 km northwest of Bahr al-Najaf) and describe it as white coarse to medium grains Sandy with little gravel, containing a gypsum percentage of 72.8% and a field density 1.85 gm/cm^3.

4.3 Laboratory tests for natural soils

Laboratory tests for untreated natural soils were carried out, including physical, engineering and chemical tests, according to (Table 4-1).

Table (4-1) Physical, Engineering and Geotechnical properties for natural soils in study area.

No	SOIL PROPRTES		L0CATION		
			1	2	3
			Safi Al-Safa	Al- Rahma neighborhood	The Popular Mobilization Headquarters
1.	Moisture content %		4.5	4	5
2.	Specific Gravity		2.34	2.46	2.21
3.	Atterberg Limits	L.L%	27	21	20
4.		P.L%	NP	NP	NP
5.		P.I%	NP	NP	NP
6.	Max Dry Density($\gamma_{d.max}$)gm/cm3		2.084	2.032	2.022
7.	Classification System(USCS)		S.P	S.P	S.P
8.	Optimum Moisture Content %		4.02	3.21	4.47
9.	Sulphate %		26.34	22.63	33.85
10.	Gypsum %		56.6	48.6	72.8
11.	Chloride %		0.497	0.355	0.994
12.	Carbonate %		12	11.6	5.6
13.	Total Soluble Salts (ppm)		1550	1650	1930
14.	PH		7.83	6.07	7.9
15.	E.C (ms)		3.08	3.31	3.84
16.	Direct shear coefficients	Cohesion (C) KN/m2	0	0	0
17.		Internal Friction angle(Ø)Degree	40	27	36.5

The laboratory results of the chemical tests for the natural soil no. (1) Showed that the percentage of Gypsum is (56.6%), the percentage of Sulphate (26.3%), the percentage of chloride (0.49%), the percentage of carbonate (12%) the percentage of Total dissolved salts (1550 ppm), electrical conductivity (3.08 ms) and finally the percentage of organic materials was (4.02%) and the PH was (7.8) and it is within the permissible geotechnical limits.

As for the natural soil no. (2) Shows that the percentage of Gypsum is (48.6%), the percentage of Sulphate (22.6%), the percentage of chloride (0.35%), the percentage of carbonate (11.6%) the percentage of Total dissolved salts (1650 ppm), electrical conductivity (3.31 ms) and finally the percentage of organic materials was (3.21%) and the PH was (6.07) and it is within the permissible geotechnical limits. Finally the laboratory results of the chemical tests for the natural soil no.(3) Showed that the percentage of Gypsum is (72.8%), the percentage of Sulphate (33.8%), the percentage of chloride (0.99%), the percentage of carbonate (5.6%) the percentage of Total dissolved salts (1930 ppm), electrical conductivity (3.84 ms) and finally the percentage of organic materials was (4.47%) and the PH was (7.9) and it is within the permissible geotechnical limits.

4.4 Laboratory Tests for Treated Soil

The effect of additives Hydrated lime and Montmrillonite on treated soils in changing the results of laboratory tests.

4.4.1 Atterberg Limits for Treatment Soil

When treated for the three gypseous soils (1, 2 and 3) by a different Percentage from hydrated lime and Montmrillonite, Atterbeg limits was affected more than that's what was observed (Table 4-2).

Table (4-2): Physical, Engineering and Geotechnical properties for treatment soils in hydrated lime & Montmorollinite add.

			SOIL PROPRTES							
	Add type	Percent	Moisture content%	Atterberg Limits			Max Dry Density $\gamma d.max$	Classification System (USCS)	Direct shear	
				L.L%	P.L%	P.I%			(C)	(Ø)
Soil – 1	Hydrated lime Add	3%	14.53	30	NP	NP	2.065	SP	55	38
		6%	13.2	33	NP	NP	2.044	SP	72	32
		9%	5.2	40	NP	NP	2.019	SP	0	35
	Mot. Add	5%	18.1	31	NP	NP	2.059	SP	12	38
		10%	15.47	35	NP	NP	2.034	SP	25	35
		15%	15.53	41	26	15	2.012	SC	12	27.5
Soil -2	Hydrated lime Add	3%	11.6	22	NP	NP	2.025	SP	35	38
		6%	10.75	27	NP	NP	2.008	SP	8	40
		9%	12.3	35	NP	NP	1.993	SP	30	45
	Mot .add	5%	14.7	22.5	NP	NP	2.013	SP	13	53
		10%	15.6	28	NP	NP	1.985	SP	45	23
		15%	17.32	36	22	14	1.978	SC	0	35
Soil -3	Hydrated lime .add	3%	14.98	23.5	NP	NP	2.003	SP	8	38
		6%	16.64	28	NP	NP	1.985	SP	55	35
		9%	9.07	33	NP	NP	1.944	SP	8	35
	Mot .add	5%	5.62	27	NP	NP	2.013	SP	13	35
		10%	9.34	32	NP	NP	1.985	SP	50	28
		15%	15.41	36	23	13	1.962	SC	0	23

a. Hydrated Lime Additive

When Hydrated lime additive to the three gypseous soils (1, 2 and 3) by a different Percentage (3, 6 and 9%), Atterbeg limits was affected more than that's what was observed (Table 4-2). Figure (4-1 a), (4-1 b) and (4-1 c) shows the results of a liquid limits are changed and the soil becomes more liquidity limit when it's treated.

The reason for this, hydrated lime increases liquid limits significantly and it becomes clear that the limit of liquidity and the plasticity index of the treated soils are devoid of plastic.

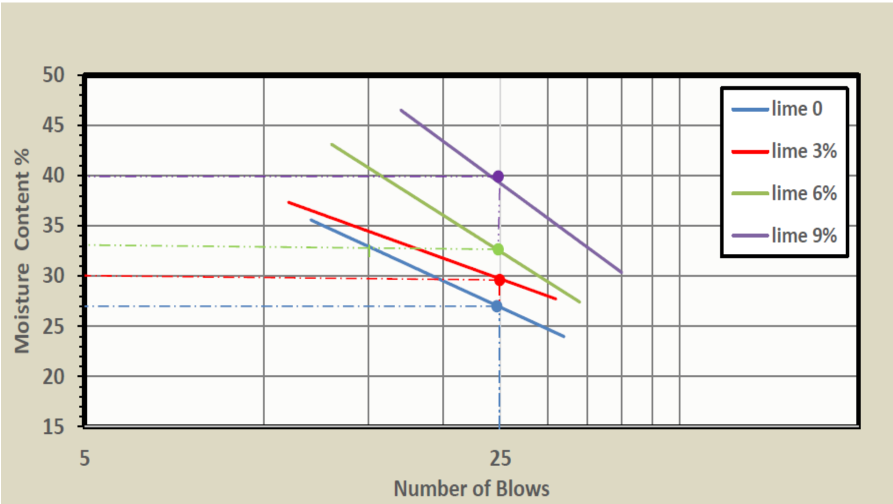


Figure (4-1 a): Liquid limits when adding hydrated lime with percentages (0, 3, 6 and 9 %) for soil 1 in study area.

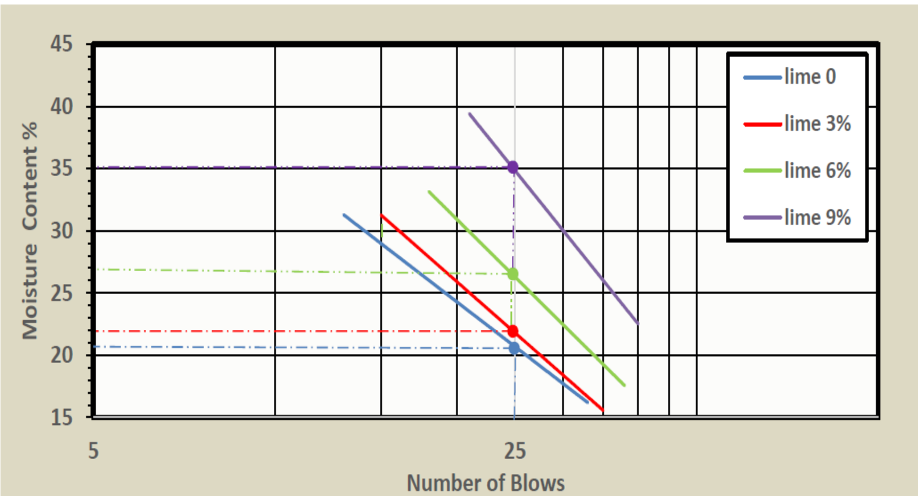


Figure (4-1 b): Liquid limits when adding hydrated lime with percentages (0, 3, 6, and 9 %) soil 2 in study area

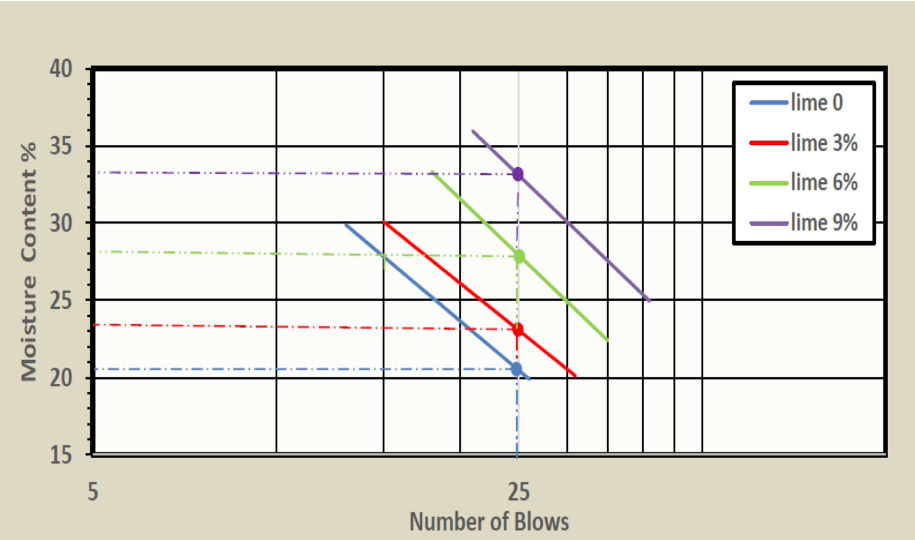


Figure (4-1c): Liquid limits when adding hydrated lime with percentages (0, 3, 6, and 9 %) soil 3 in study area.

b. Montmorollinite Additive

When Nano – Clay (Montmrillonite) was added to the three gypseous soils (1, 2 and 3) with a different ratio (5%, 10% and 15%), Atterbeg limits were affected more than what that was observed (Table 4-2).

Figures (4-2 a), (4-2 b) and (4-2 c) show the results of Atterbeg limits are changed and the soil becomes more liquidity limit when it's treated. The reason for this is that Montmrillonite increases liquid limits significantly and it becomes clear that the limit of liquidity and the plasticity index of the treated soils are Non-plastic. And some samples showed little plasticity Index when 15% Montmrillonite was added.

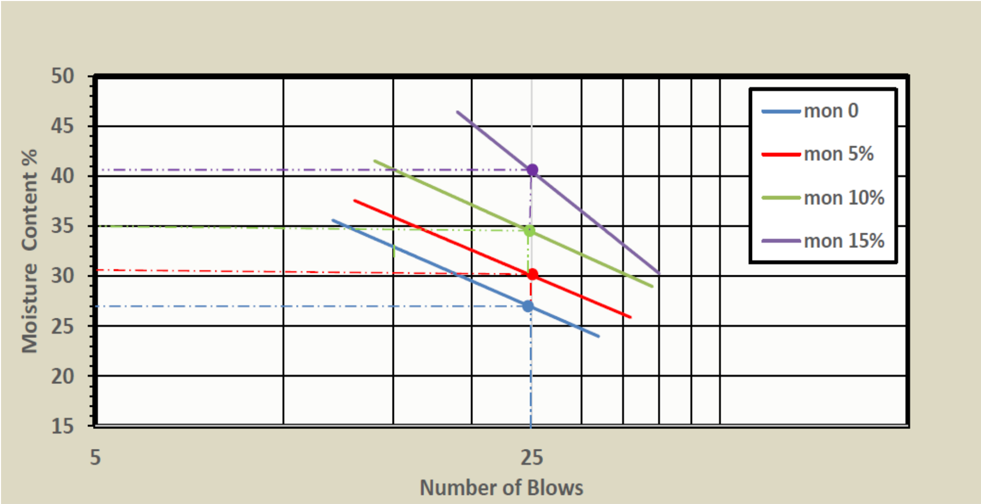


Figure (4-2 a): Liquid limits when adding Montmrillonite with percentages (0, 5, 10, and 15%) for soil 1 in study area.

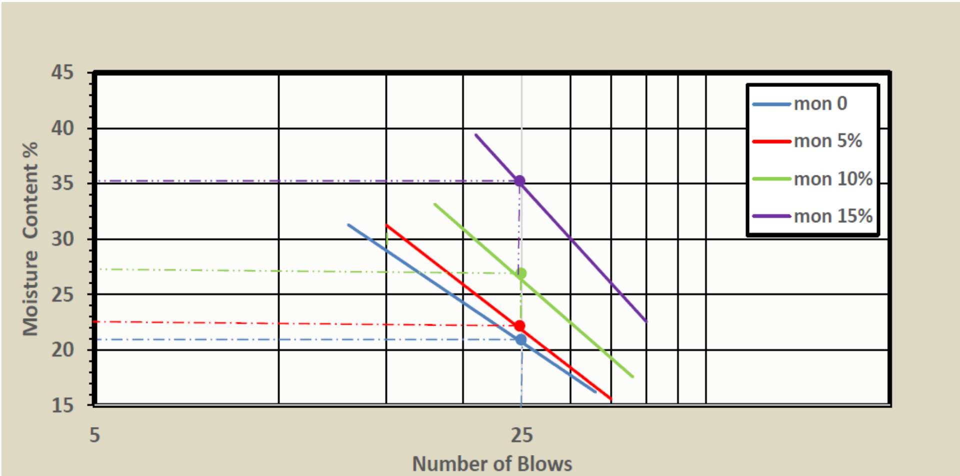


Figure (4-2b): Liquid limits when adding Montmrillonite with percentages (0, 5, 10, and 15 %) for soil 2 in study area.

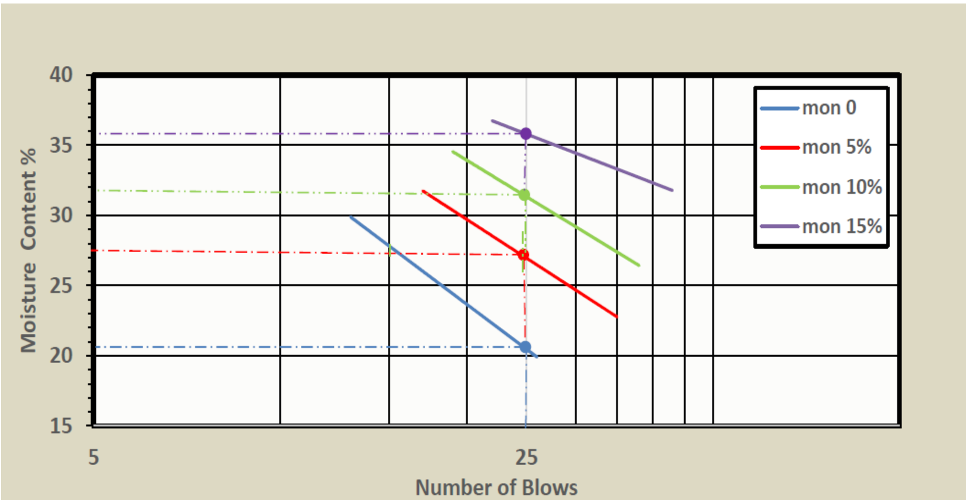


Figure (4-2c): Liquid limits when adding Montmrillonite with percentages (0, 5, 10, and 15%) for soil 3 in study area.

4.4.2 Sieving Analysis

a. Hydrated Lime Additive

Show the results of sieving analyses are no changed and the soil is classified as SP (poorly graded sand) according to the unified soil classification system in for natural soils when it's treated in hydrated lime (3, 6 and 9%), as figures (4-3 a) , (4-3 b) and (4-3 c). And tables (4-3), (4-4) and (4-5) for the three soils, respectively

Table (4-3): Shows Grain size analysis when adding hydrated lime with percentages (0, 3, 6 and 9 %) for soil 1 in study area.

Sieve No	Sieve Opening	Percent ∑Rn			
		Soil treated with hydrated lime			
		0%	3%	6%	9%
3/8	9.5	79	88	87	87
4	4.75	78.1	80.4	82.6	84
10	2	66.7	61.5	66	69
20	0.85	39.5	44.2	48.4	54
40	0.42	19.6	24.4	32	39
100	0.15	2.3	5.4	10.2	14
200	0.075	1.6	2.8	3.4	4

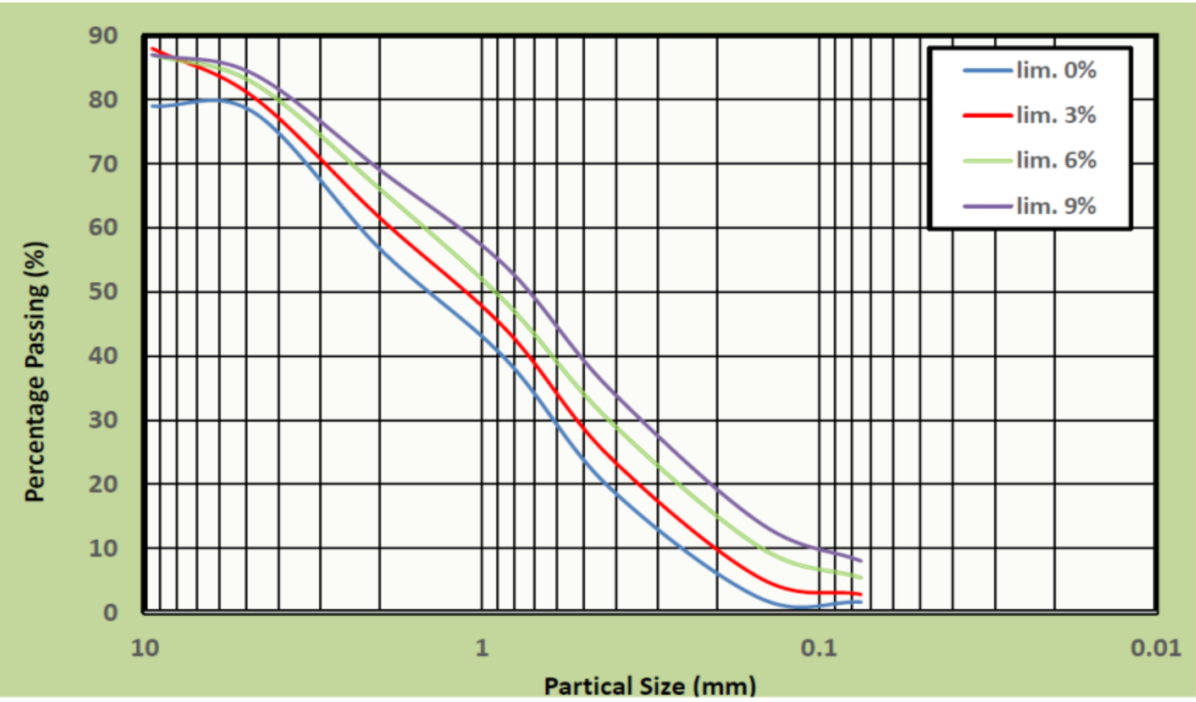


Figure (4-3 a): Grain size analysis when adding hydrated lime with percentages (0, 3, 6 and 9 %) for soil 1 in study area.

Table (4-4): Shows Grain size analysis when adding hydrated lime with percentages (0, 3, 6 and 9 %) for soil 2 in study area.

Sieve No	Sieve Opening (mm)	Percent ∑Rn			
		Soil treated with hydrated lime			
		0%	3%	6%	9%
3/8	9.5	96	97.6	97.4	97.4
4	4.75	89.8	91.6	91	91
10	2	75.6	80.2	82	82
20	0.85	65	69.8	74.5	69.3
40	0.42	38.8	44.8	49.4	53.4
100	0.15	6.6	10.2	16	16
200	0.075	2.2	2.6	3.2	4.4

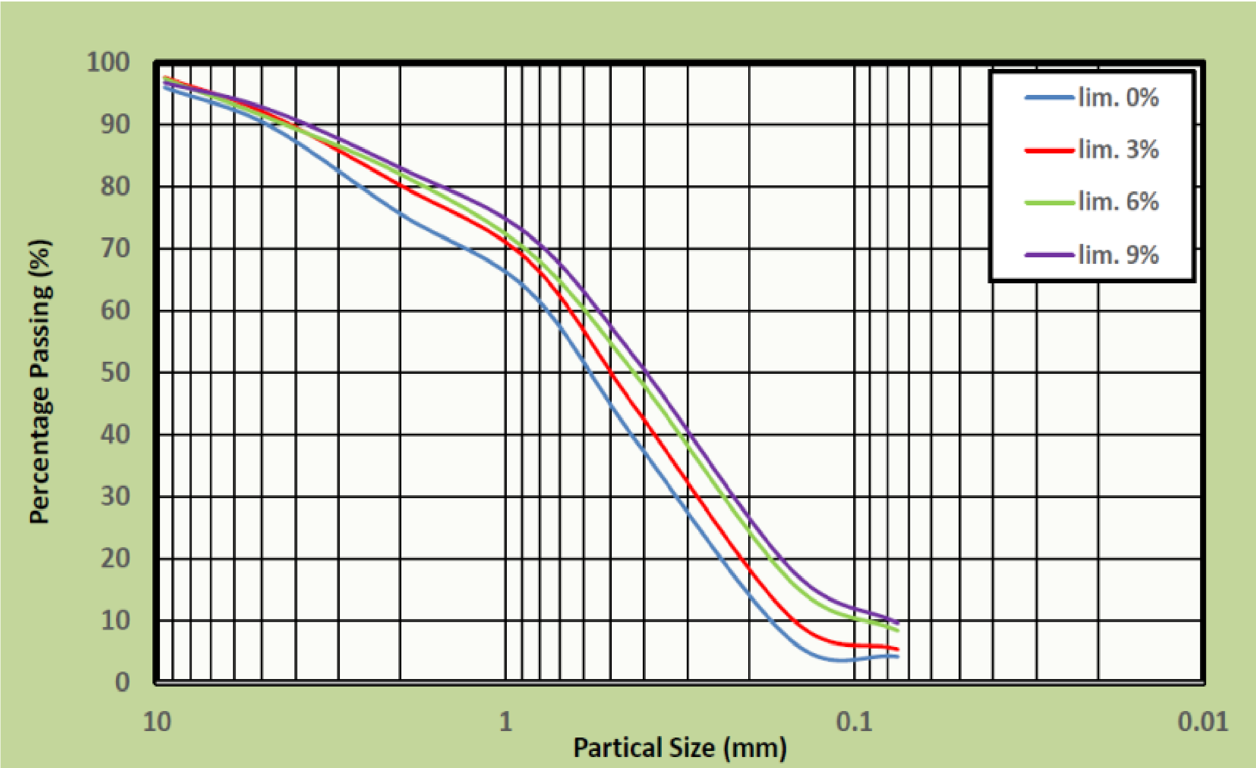


Figure (4-3b): Grain size analysis when adding hydrated lime with percentages (0, 3, 6 and 9 %) for soil 2 in study area.

Table (4-5): Shows Grain size analysis when adding hydrated lime with percentages (0, 3, 6 and 9 %) for soil 3 in study area.

Sieve No	Sieve Opening (mm)	Percent ∑Rn			
		Soil treated with hydrated lime			
		0%	3%	6%	9%
3/8	9.5	96.2	97	97.8	98.2
4	4.75	88.2	89.2	89.8	90.8
10	2	74.8	76.8	78	79.6
20	0.85	58.6	61.7	65.4	69.2
40	0.42	29.8	33.9	38.7	41.8
100	0.15	4.2	7.6	11.2	14.2
200	0.075	2.2	2.8	3.3	4.2

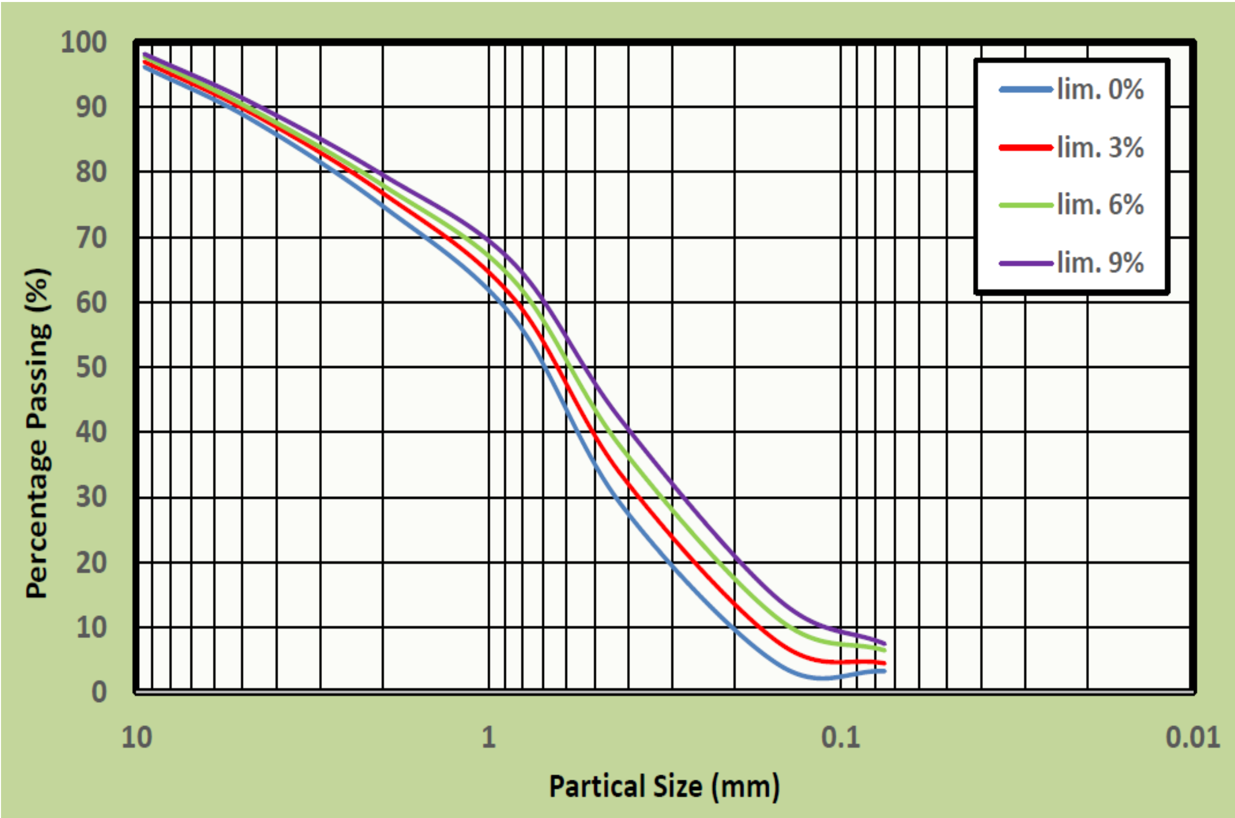


Figure (4-3c): Grain size analysis when adding hydrated lime with percentages (0, 3, 6 and 9 %) for soil 3 in study area.

b. Montmorollinite additive

show the results of a Sieving analyses are not changed and the soil is classified as SP (poorly graded sand) according to the unified soil classification system in for natural soils and when it's treated in present (5,10 and 15%) Montmrillonite it changed to SC (sand clay) due to the increase in the percentage of soil passing through the sieve 200 by more than 5% according to the unified classification system (SUCS), as Figure (4-4 a), (4-4 b) and (4-4 c). And tables (4-6), (4-7) and (4-8) for the three soils, respectively

Table (4-6): Shows Grain size analysis when adding Montmrillonite with percentages (0, 5, 10 and 15 %) for soil 1 in study area.

Sieve No	sieve Opening	Percent ∑Rn			
		Soil treated with Montmrillonite			
		0%	5%	10%	15%
3/8	9.5	79	82	81	81
4	4.75	78.1	81	79	80
10	2	56.7	62.4	76.6	71
20	0.85	39.5	44.6	52	54
40	0.42	19.6	24	27.6	30.3
100	0.15	2.3	8.5	15.5	18
200	0.075	1.61	6.8	11.3	16.7

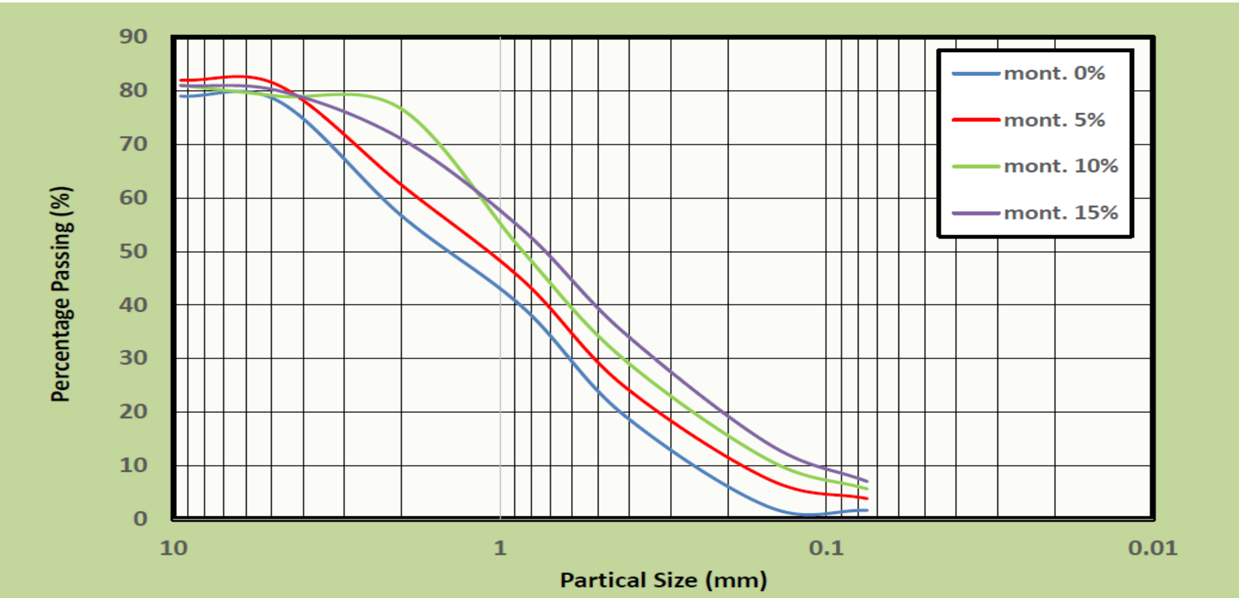


Figure (4-4 a): Grain size analysis when adding Montmrillonite with percentages (0, 5, 10 and 15 %) for soil 1 in study area.

Table (4-7): Shows Grain size analysis when adding Montmrillonite with percentages (0, 5, 10 and 15 %) for soil 2 in study area.

Sieve No	sieve Opening (mm)	Percent ∑Rn Soil treated with Montmrillonite			
		0%	5%	10%	15%
3/8	9.5	96	96.2	93	91
4	4.75	89.8	89.2	90	89.6
10	2	75.6	75.8	77	78.4
20	0.85	61.5	63.8	64.4	66
40	0.42	26.8	29.8	34.6	36.8
100	0.15	6.6	12	14.8	19.4
200	0.075	4.2	9.6	11.6	17.8

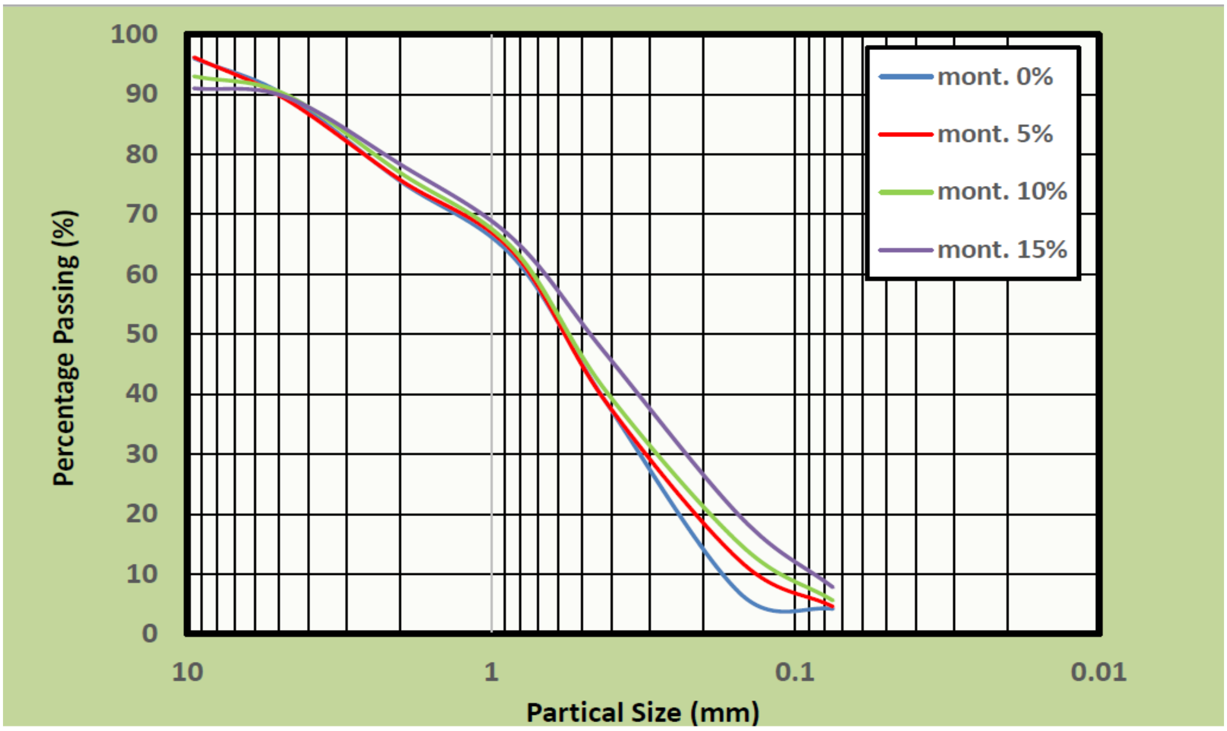


Figure (4-4 b): Grain size analysis when adding Montmrillonite with percentages (0, 5, 10 and 15 %) for soil 2 in study area.

Table (4-8): Shows Grain size analysis when adding Montmrillonite with percentages (0, 5, 10 and 15 %) for soil 3 in study area.

Sieve No	sieve Opening (mm)	Percent ∑Rn Soil treated with Montmrillonite			
		0%	5%	10%	15%
3/8	9.5	96.2	97	97.2	91
4	4.75	88.2	87	87.8	89.6
10	2	74.8	74.8	76.8	78.4
20	0.85	51.6	56.2	62	66
40	0.42	22.8	25.4	26.8	36.8
100	0.15	4.2	10.6	16.2	19.4
200	0.075	3.2	8.4	11.4	17.6

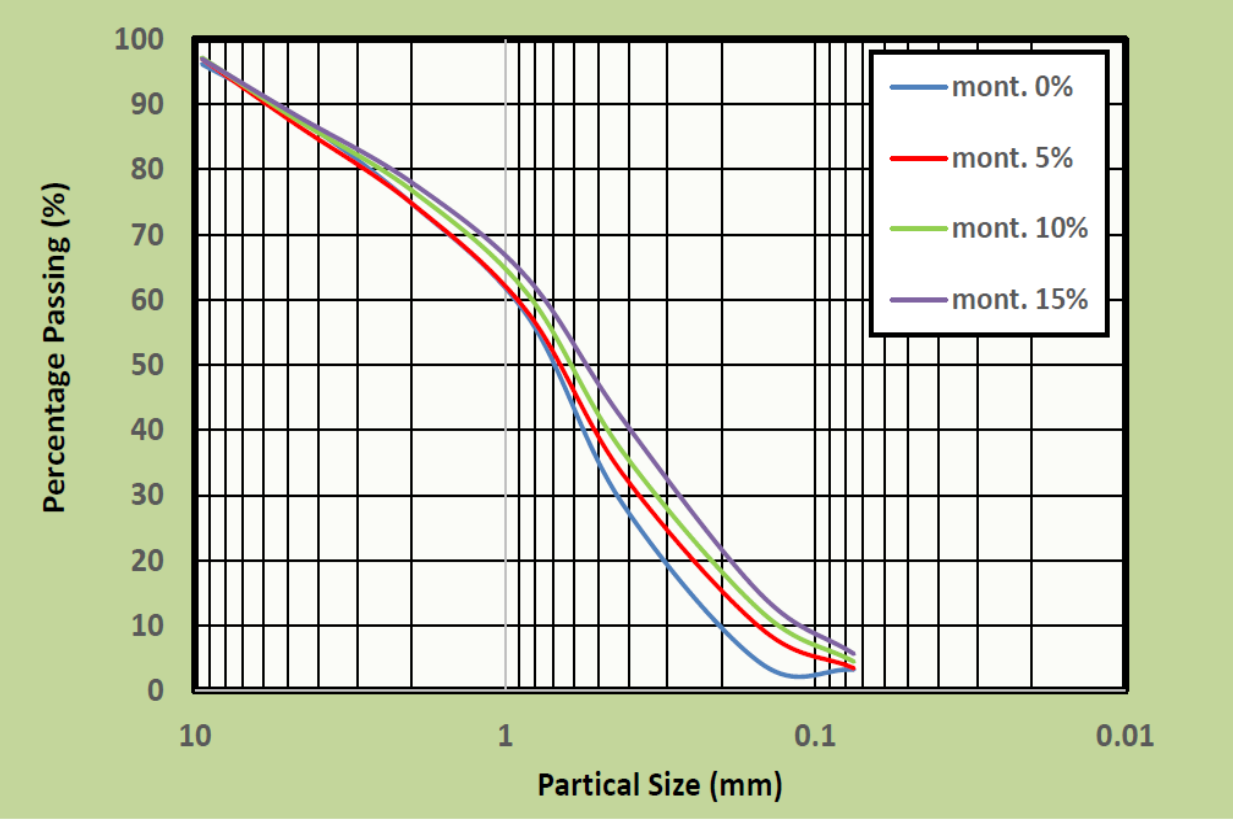


Figure (4-4c): Grain size analysis when adding Montmrillonite with percentages (0, 5, 10 and 15 %) for soil 3 in study area.

4.4.3 Specific Gravity

Values for specific gravity of the soil solids are determined according to ASTM D-854. Kerosene is used instead of water to avoid dissolution of gypsum. The result shows that the specific gravity value for the untreated gypseous soil is (2.34, 2.46 and 2.21) for soil 1, soil 2 and soil 3 respectively.

Specific gravity of the soil treated with of the hydrated lime and Montmrillonite, it will be less than the specific weight of the natural soil. Thus, this leads to a decrease in the specific weight of the treated soil.

4.4.4 Maximum Dry Density and Optimum Moisture Content

The effect of adding different percentages of hydrated lime and Montmrillonite on the values of moisture content as well as maximum dry density.

a . Hydrated Lime Additive

The effect of adding different percentages of lime on the properties of compaction (maximum dry density and optimum moisture content) using the modified compaction method. Three percentages of Hydrated lime were added to the natural soil, which are (3, 6 and 9%), as in the table (4-9).

Figures (4 - 5 a), (4-5 b) and (4-5 c) show the results of the Compaction tests were found that the higher percentage of Hydrated lime which was added led to a decrease in the maximum dry density and an increase in the optimal moisture content, While increase in the optimal moisture content for treated soil with Hydrated lime result from the tendency of the hydrated lime to combine with water. The decrease in the maximum dry density is due to the flocculation phenomena (Eshoo, 2004).

Table (4-9) shows the results of the Compaction test for Natural soil and the three treated soils when adding Hydrated lime with percentages (0 ,3,6, and 9 %) in study area.

Soil 1	Natural soil	Optimum M.C%	14
		Ɣd.max gm/cm^3	2.084
	3%	Optimum M.C%	15
		Ɣd.max gm/cm^3	2.065
	6%	Optimum M.C%	16
		Ɣd.max gm/cm^3	2.044
	9%	Optimum M.C%	17
		Ɣd.max gm/cm^3	2.019
Soil 2	Natural soil	Optimum M.C%	13
		Ɣd.max gm/cm^3	2.032
	3%	Optimum M.C%	14
		Ɣd.max gm/cm^3	2.025
	6%	Optimum M.C%	14
		Ɣd.max gm/cm^3	2.008
	9%	Optimum M.C%	15
		Ɣd.max gm/cm^3	1.993
Soil 3	Natural soil	Optimum M.C%	14
		Ɣd.max gm/cm^3	2.022
	3%	Optimum M.C%	15
		Ɣd.max gm/cm^3	2.003
	6%	Optimum M.C%	16
		Ɣd.max gm/cm^3	1.985
	9%	Optimum M.C%	17
		Ɣd.max gm/cm^3	1.944

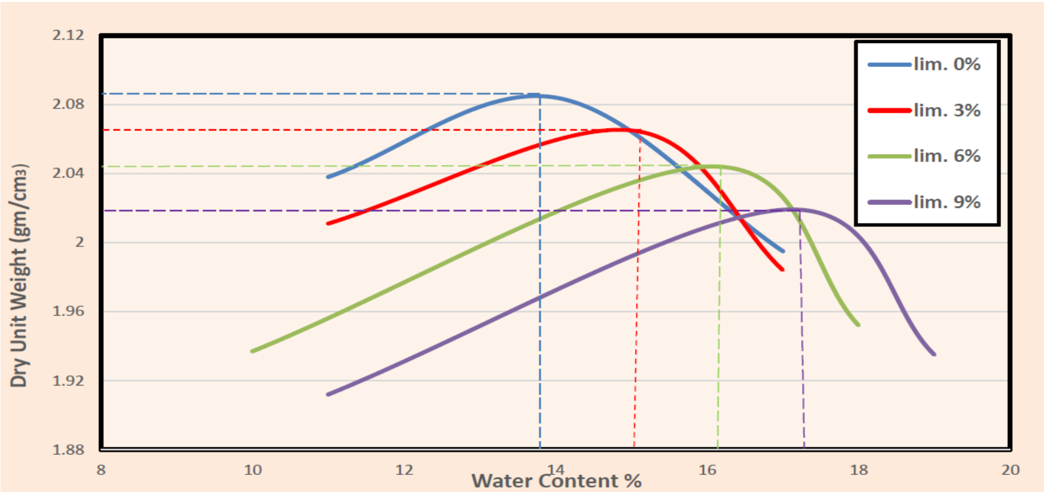


Figure (4-5a): Shows (Ɣd.max) and Optimum Moisture Content when adding Hydrated lime with percentages (0 ,3,6, and 9 %) for soil 1 in study area.

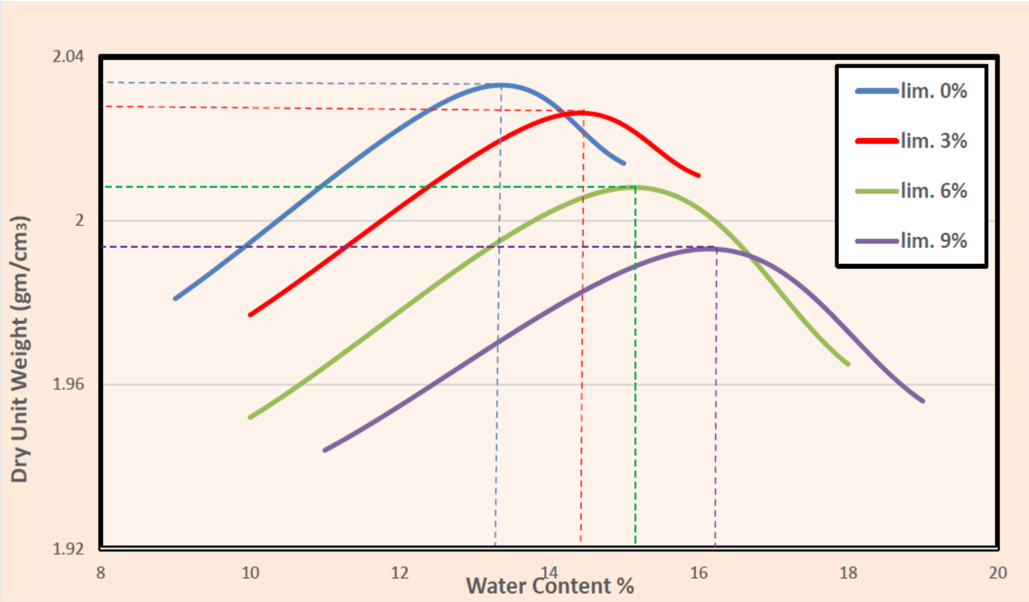


Figure (4-5b): Shows (Ɣd.max) and Optimum Moisture Content when adding Hydrated lime with percentages (0 ,3,6, and 9 %) for soil 2 in study area.

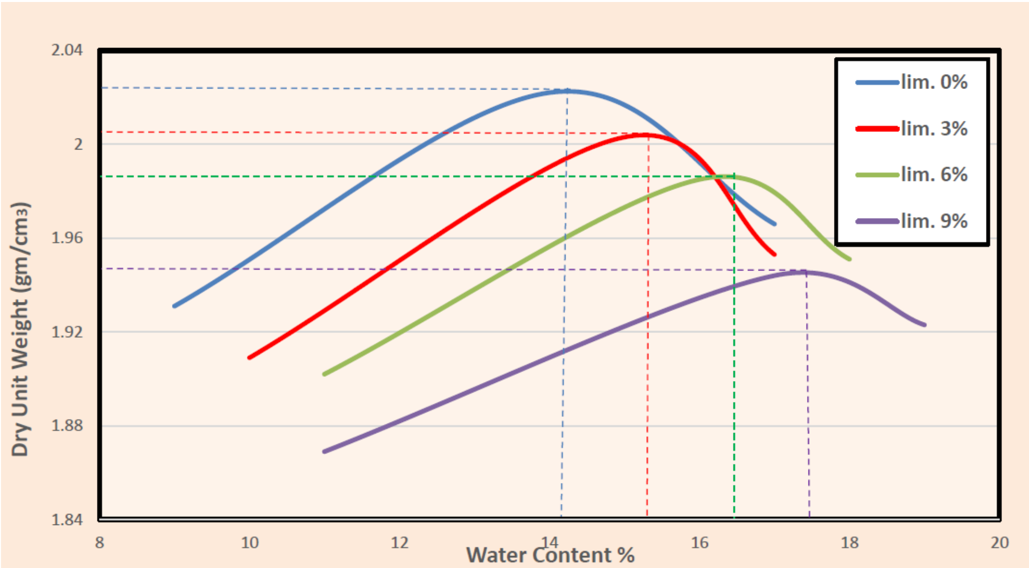


Figure (4-5 c): Shows (Ɣd.max) and Optimum Moisture Content when adding hydrated lime with percentages (0, 3, 6 and 9 %) for soil 3 in study area.

b . Montmorollinite Additive

The effect of adding different proportions of Montmrillonite on the properties of compaction tests (maximum dry density and optimum moisture content) using the modified pressing method. Three Nano-clay ratios are added to the natural soil (5, 10, 15%), as in the table (4-10).

Figures (4-6 a), (4-6 b) and (4-6 c) show the results of stress tests and it was found that the higher the percentage of Montmrillonite added, the lower the maximum dry density and the higher the optimum moisture content. The decrease in maximum dry density is due to the phenomenon of flocculation, and other researchers have come to the same conclusion.

Table (4-10) shows the results of the Compaction test for Natural soil and the three treated soils when adding Montmorollinite with percentages (0, 5, 10 and 15 %) in study area.

S0il 1	Natural soil	Optimum M.C%	14
		Ɣd.max gm/cm³	2.084
	5%	Optimum M.C%	14
		Ɣd.max gm/cm³	2.059
	10%	Optimum M.C%	13
		Ɣd.max gm/cm³	2.034
	15%	Optimum M.C%	14
		Ɣd.max gm/cm³	2.012
Soil 2	Natural soil	Optimum M.C%	13
		Ɣd.max gm/cm³	2.032
	5%	Optimum M.C%	14
		Ɣd.max gm/cm³	2.013
	10%	Optimum M.C%	13
		Ɣd.max gm/cm³	1.985
	15%	Optimum M.C%	14
		Ɣd.max gm/cm³	1.978
Soil 3	Natural soil	Optimum M.C%	14
		Ɣd.max gm/cm³	2022
	5%	Optimum M.C%	15
		Ɣd.max gm/cm³	2.013
	10%	Optimum M.C%	16
		Ɣd.max gm/cm³	1.985
	15%	Optimum M.C%	17
		Ɣd.max gm/cm³	1.962

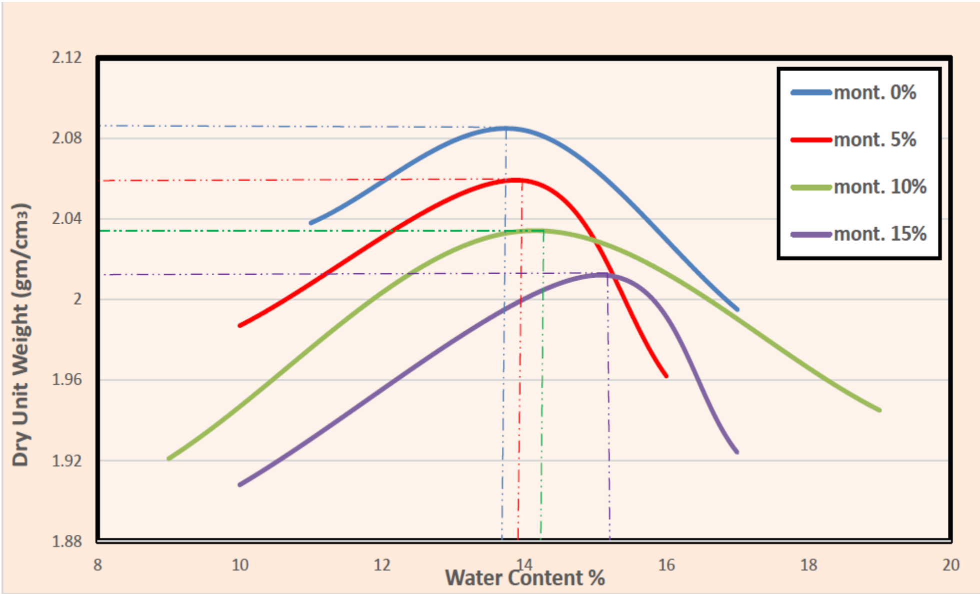


Figure (4-6 a): Shows (Ɣd.max) and Optimum Moisture Content when adding Montmrillonite with percentages (0 ,5,10, and 15 %) for soil 1 in study area.

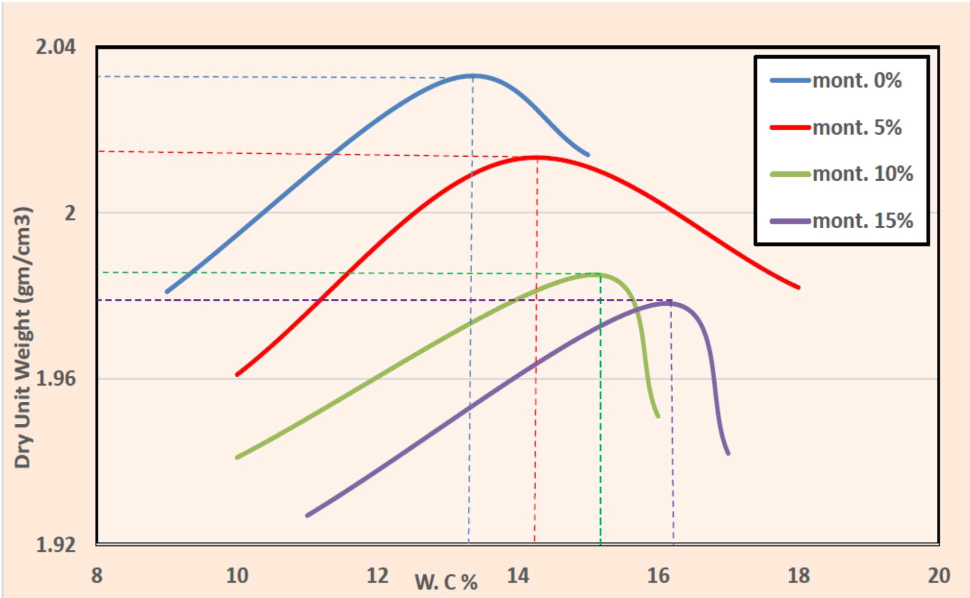


Figure (4-6b): Shows (Ɣd.max) and Optimum Moisture Content when adding Montmrillonite with percentages (0, 5, 10 and 15 %) for soil 2 in study area.

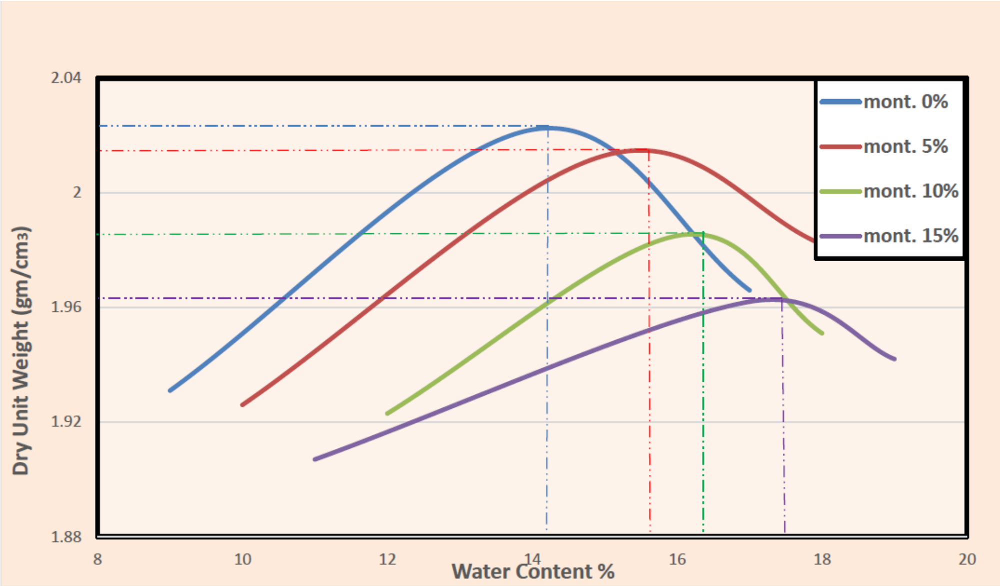


Figure (4-6 c): Shows (Ɣd.max) and Optimum Moisture Content when adding Montmrillonite with percentages (0, 5, 10 and 15 %) for soil 3 in study area.

4.4.5 Direct Shear Test

Its include :-

a. Hydrated Lime Additive

The values of shear strength modulus (c) and (Ø) for the soil treated with different percentage of slaked lime (0, 3, 6 and 9%) were shown in Figures (4-7a), (4-7b) and (4-7c), they show an increase in cohesion (c), with an increase in the proportion of hydrated lime from 3% to 6%, While observed a decrease in cohesion when adding a percentage 9% of hydrated lime. The reason for this is that the lime increases the cohesion strength between molecules to the limit of adding 6%, Then the cohesion decreases when 9% of is added Hydrated lime. where the hydrated lime molecules work to separate the molecules from each other, and the cohesion force decreases. It is also noted that the internal friction angle (Ø) decreases with the increase in the percentage of lime.

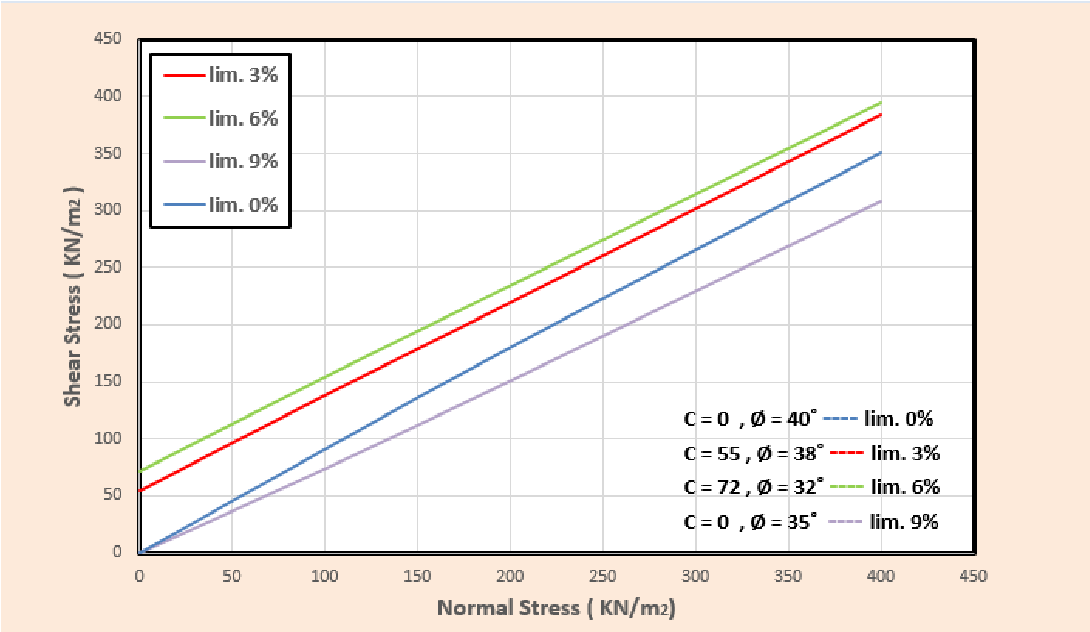


Figure (4-7 a): Shows (Ø) and (C) when adding hydrated lime with percentages (0, 3, 6, and 9 %) for soil 1 in study area.

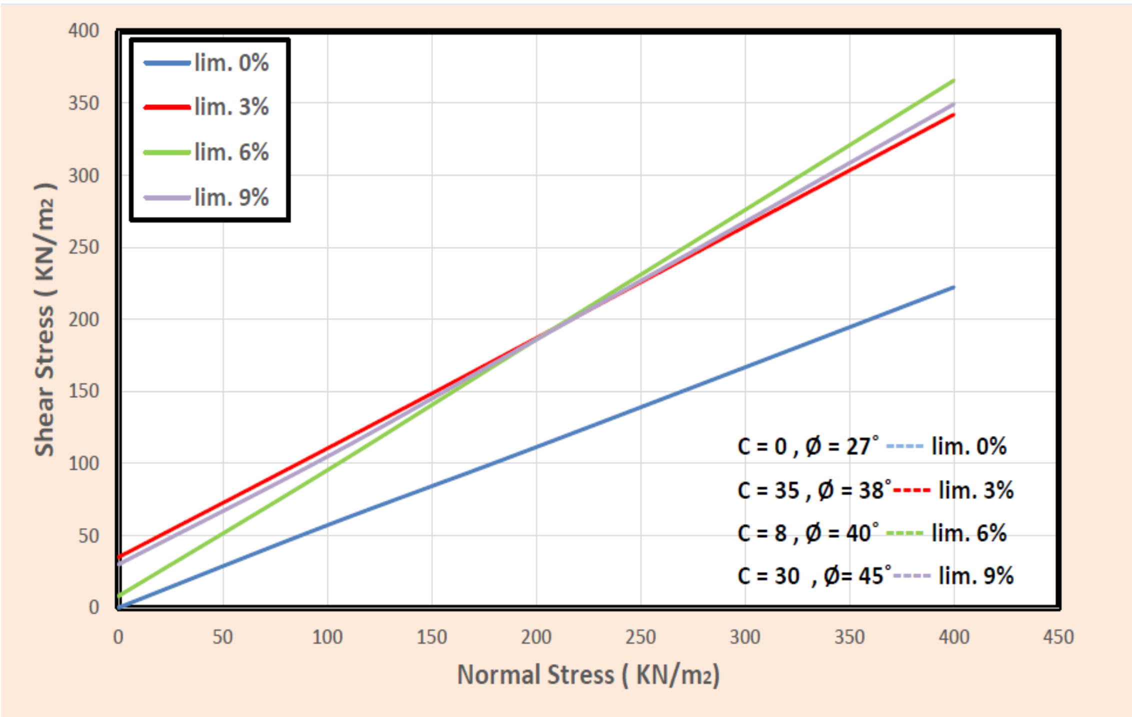


Figure (4-7b): Shows (Ø) and (C) when adding hydrated lime with percentages (0 , 3 , 6 and 9 %) for soil 2 in study area.

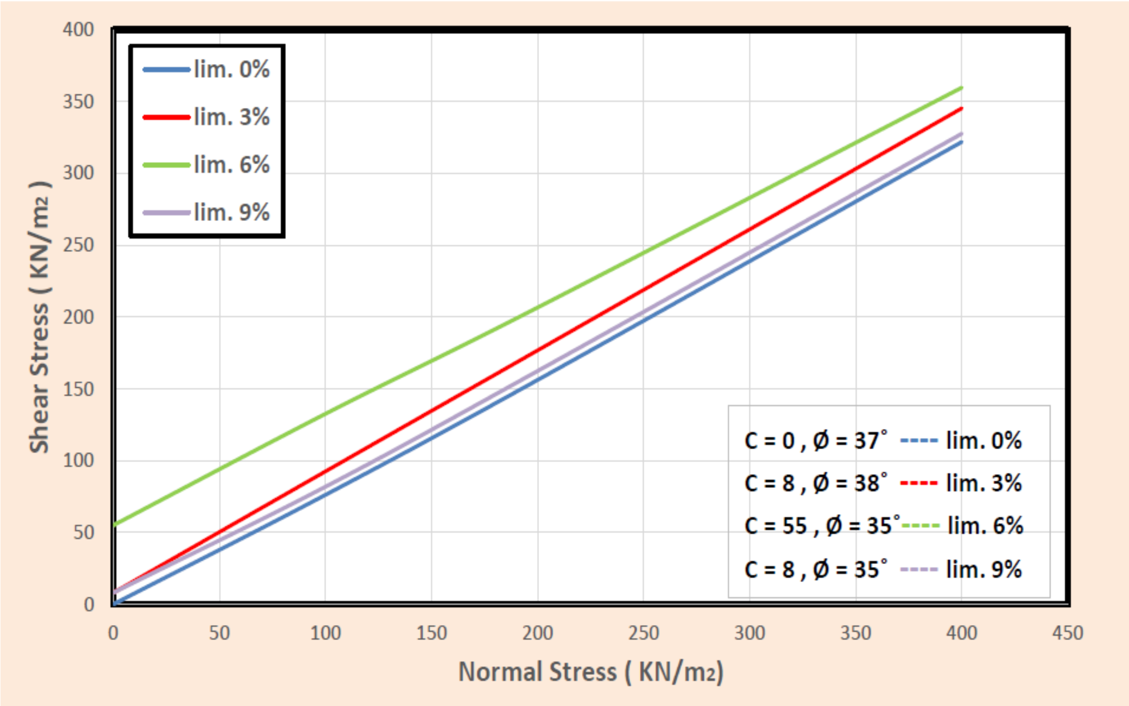


Figure (4-7c): Shows (Ø) and (C) when adding hydrated lime with percentages (0, 3, 6 and 9%) for soil 3 in study area.

b. Montmorollinite Additive

exhibit values shear Strength parameter (c) and (Ø) for the soil that was treated by a different ratio of Montmrillonite (0,5, 10 and 15%). in Figures (4-8 a), (4-8 b) and (4-8 c).

The figures show an increase in the cohesion (c), which increases with the increase in the percentage of lime from 5% to 10%, after which cohesion decreases as the percentage of addition from Montmrillonite at ratio 15% increases. And also noted that the internal friction angle (Ø) decreases with the increase in the percentage of Montmrillonite.

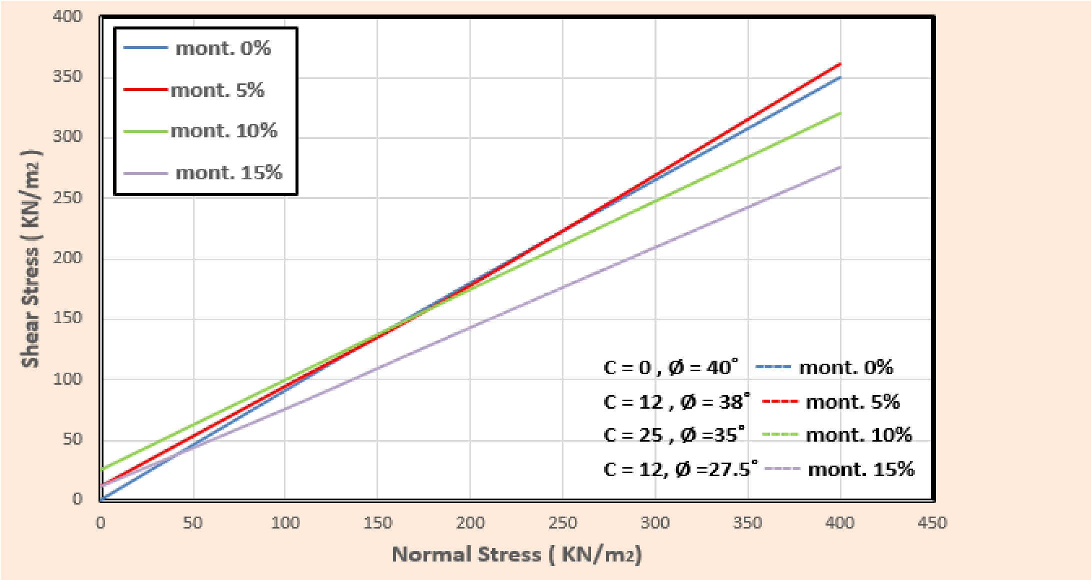


Figure (4-8a): Shows (Ø) and (C) when adding Montmrillonite with percentages (0, 5, 10, and 15 %) for soil 1 in study area.

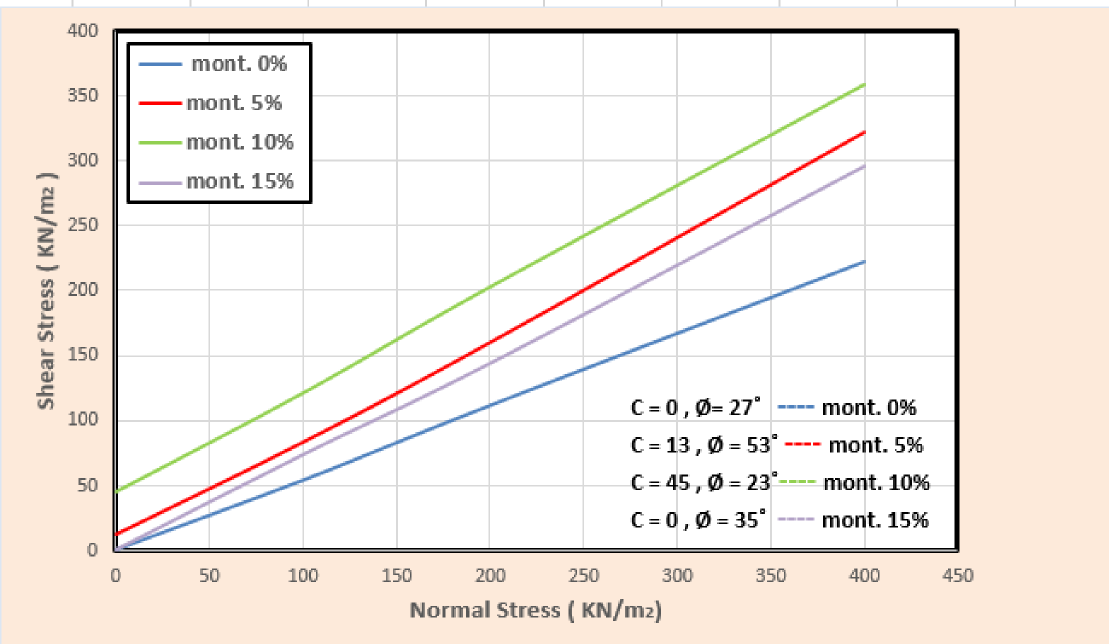


Figure (4-8b): Shows (Ø) and (C) when adding Montmrillonite with percentages (0, 5, 10, and 15 %) for soil 2 in study area.

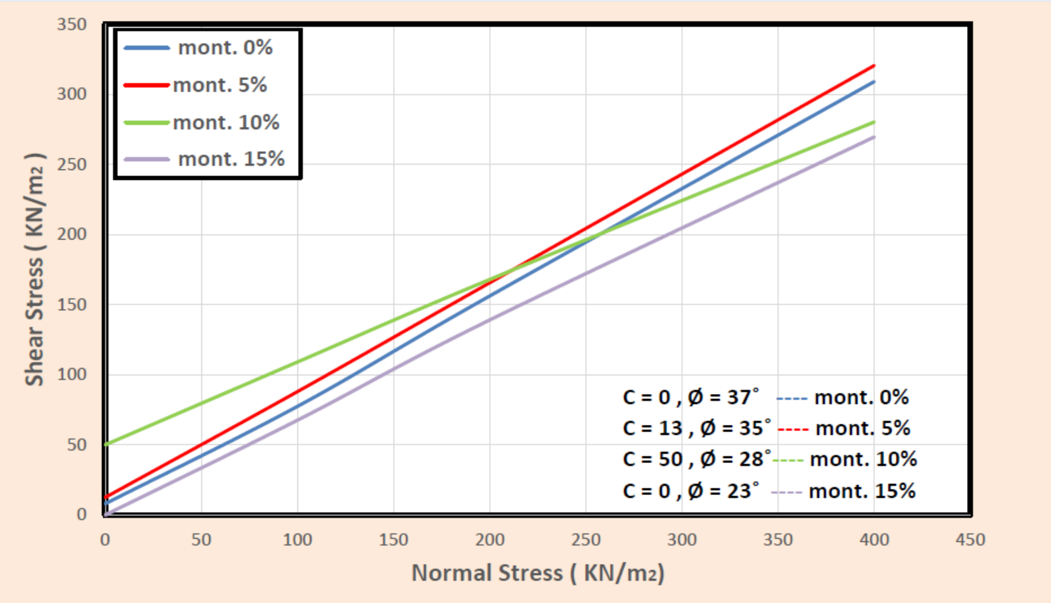


Figure (4-8c): Shows (Ø) and (C) when adding Montmrillonite with percentages (0, 5, 10, and 15 %) for soil 3 in study area.

4.4.6 Collapse Test

Such testing is performed through utilizing Oedometer device. A single Oedometer test had been conducted to decide the collapsing potential (CP) for the soils (Table 4-11). At that point, the testing proceeds by extra load and emptying as in the customary consolidating testing. (Table 3-7) presents the criterion used to classify gypseous soils based on collapse potential. It is evident that the increase in CP refers to increase of the problem of gypseous soil collapse upon wetting. The collapse stress in the soil models is directly proportional to the gypsum content. The change in thickness was calculated according to the equation (3- 4).

$C.P = (\Delta h/H) \times 100$…. (3-4)

Soil collapse is categorized by Collapse potential (CP) is a measure of vertical strain that is divided to by the total thickness of a certain material in practice (Hayal et al, 2020), (Table 3-7)

The initial collapse of metastable soil texture owing to gypsum breakdown when the soil is wet, causing the linkages between grains to break down, can be termed as the collapse process. Molecular forces are the weakest forces between particles, and they weaken as water saturation rises. The ionic-electrostatic force and the capillary force have similar magnitudes. Electrostatic forces are unstable in the presence of water, and capillary forces only develop at saturation. The strongest cementation bridges can be created using chemical agents such as irons present in Nano-materials. Furthermore, the distortion and size of the inter-aggregate and intra-aggregate pores affect the collapsibility of stabilized gypseous soils.

a. Hydrated Lime Additive

The Hydrated lime is added to the soil in percentages of (0, 3, 6 and 9%) and the findings revealed the following improvements.

- **Soil 1**

The results of a single collapse test performed on gypsum saturated soil (sample 1) on the natural soil at 200 KN, pressure. The vertical strain increased, whereas the collapse probability dropped to (12 %) Figure (4-9 a) shows.

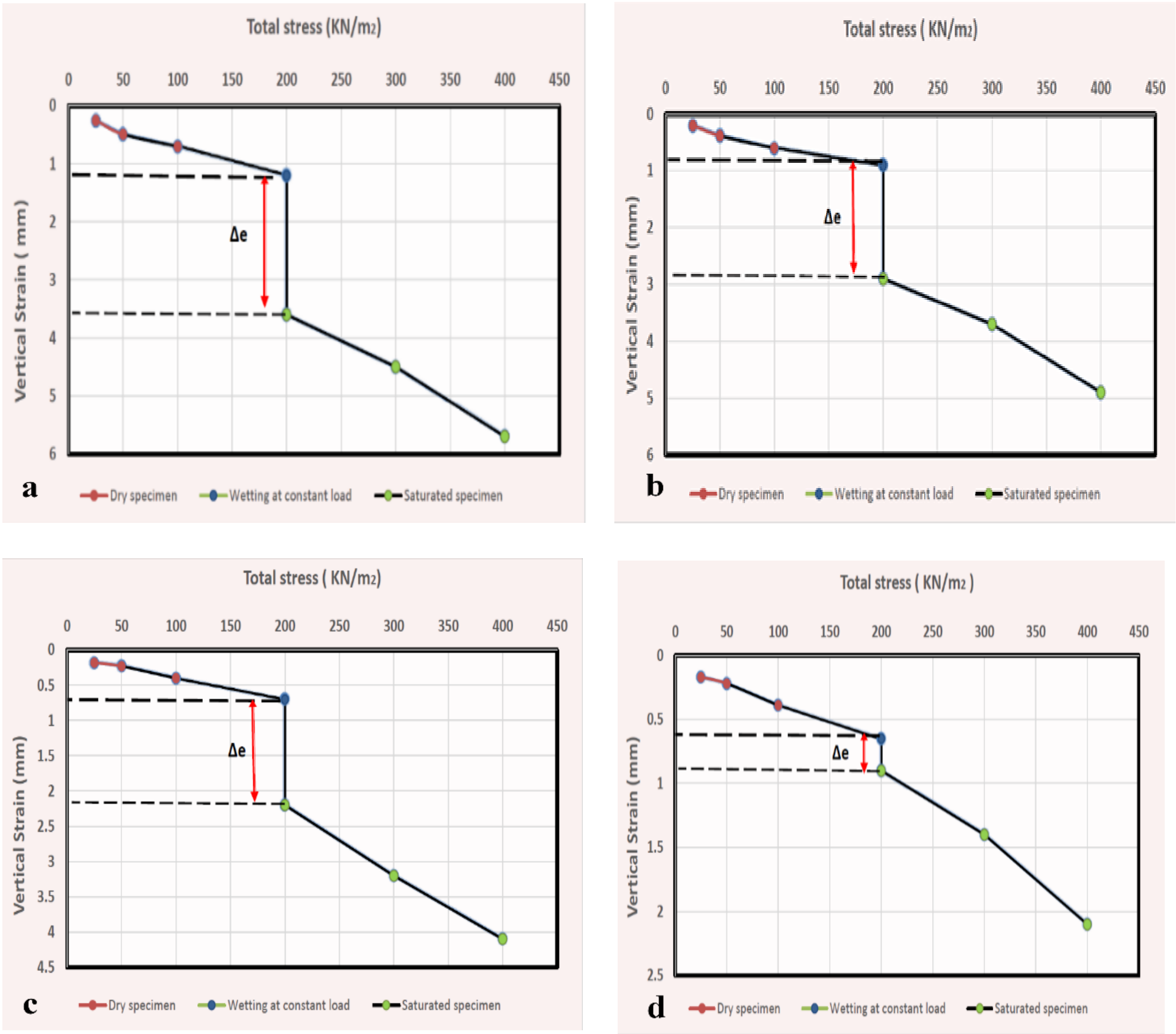


Figure (4 – 9): Shows Collapse test results on the gypseous soil no.1 that treated with hydrated lime (0,3,6 and 9%) for figures (a,b,c and d) respectively in the study area.

The results of a single collapse test performed on gypsum saturated soil (sample 1) treated with hydrated lime at ratio (3, 6 and 9) % respectively, The vertical stress displacement at a pressure equal to 200 kN, which leads to the recording of a collapse probability (10, 7.5 and 1.25) %, for treatment soil respectively. As show in Figures (4-9 b), (4-9 c) and (4-9 d).

This means that the added hydrated lime at ratio (9%) modifies the soil 1 from a severe problem case to a moderately problem case.

- **Soil 2**

The results of a single collapse test performed on gypsum saturated soil (sample 2) on the natural soil at 200 KN, pressure. The vertical strain increased, whereas the collapse probability dropped to (11.5 %) Figure (4-10 a) shows.

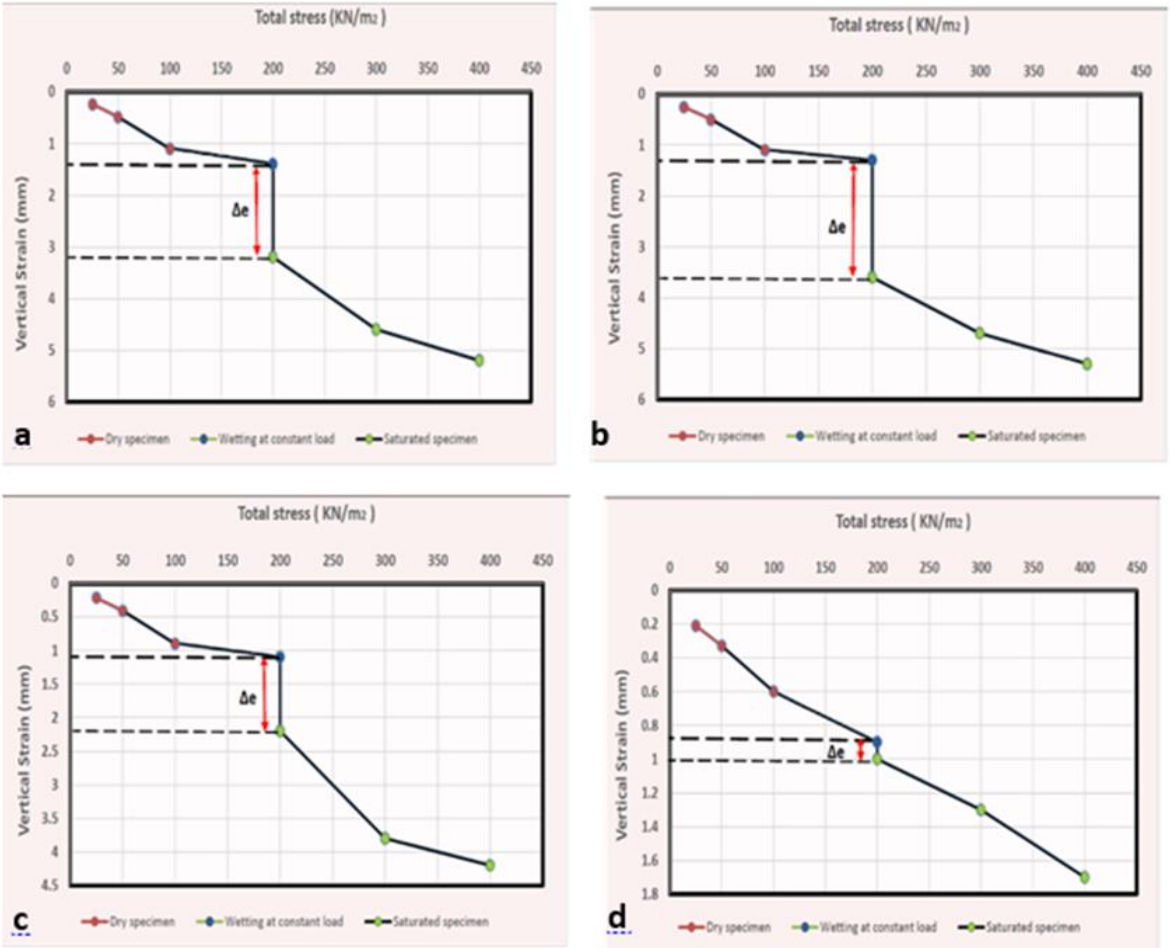


Figure (4 – 10) Shows Collapse test results on the gypseous soil no.2 that treated with hydrated lime (0,3,6 and 9%) for figures (a,b,c and d) respectively in the study area .

Figures (4-10 b), (4-10 c) and (4-10 d) show the results of a single collapse test performed on gypsum saturated soil (sample 1) treated with hydrated lime at ratio (3, 6 and 9) % respectively, The vertical stress displacement at a pressure equal to 200 kN, which leads to the recording of a collapse probability (9, 5.5 and 0.5) %, for treatment soil respectively.

This means that the added hydrated lime at ratio (9%) modifies the soil 1 from a severe problem case to no problem case.

- **Soil 3**

The results of a single collapse test performed on gypsum saturated soil (sample 3) on the natural soil at 200 KN, pressure. The vertical strain increased, whereas the collapse probability dropped to (13.5 %) Figure (4-11 a) shows.

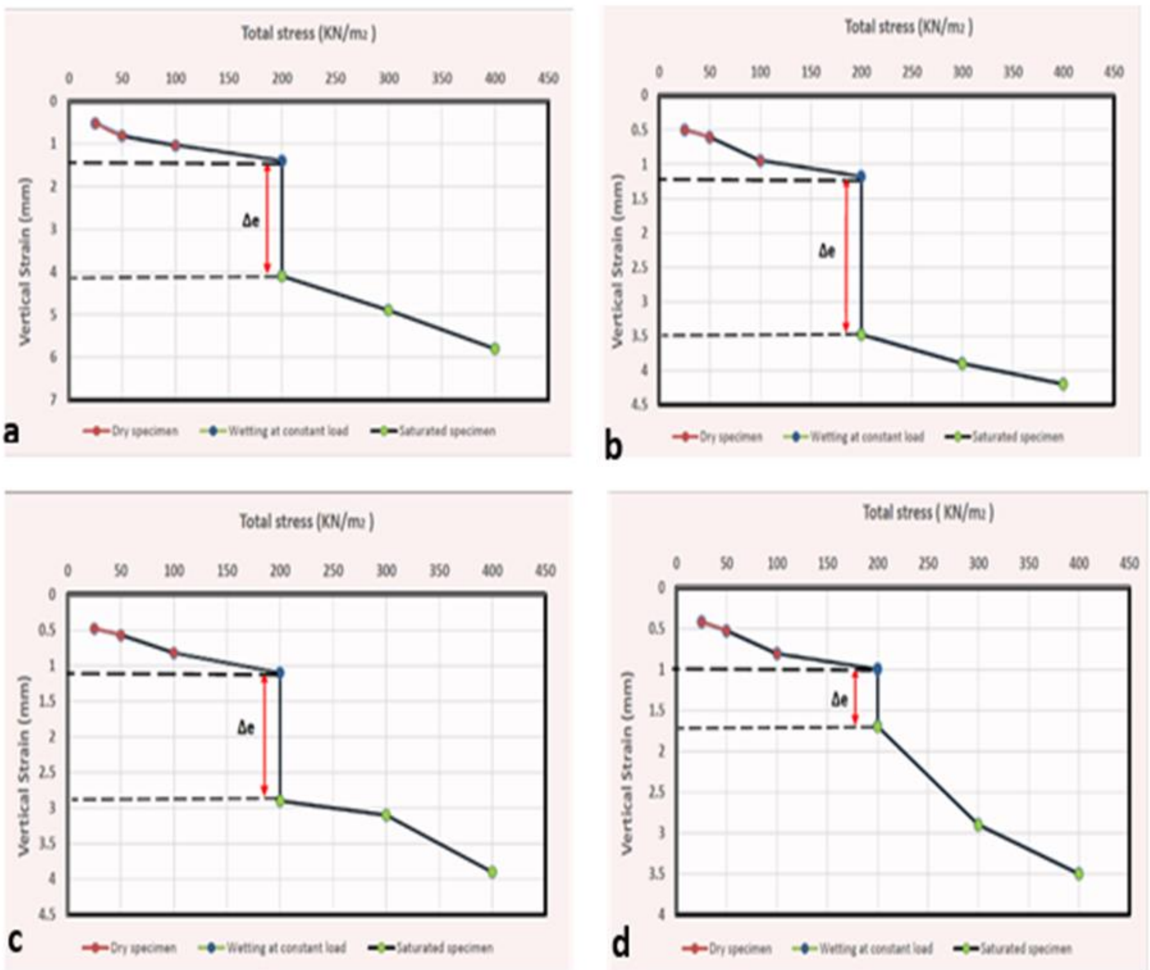


Figure (4 – 11): Shows Collapse test results on the gypseous soil no.3 that treated with hydrated lime (0, 3 , 6 and 9%) for figures (a ,b ,c and d) respectively in the study area.

Figures (4-11 b), (4-11 c) and (4-11 d) show the results of a single collapse test performed on gypsum saturated soil (sample 1) treated with hydrated lime at ratio (3, 6 and 9) % respectively, The vertical stress displacement at a pressure equal to

200 kN, which leads to the recording of a collapse probability (11.5, 9 and 3.5) %, for treatment soil respectively.

This means that the added hydrated lime at ratio (9%) modifies the soil 1 from a severe problem case to moderate problem case.

b. Montmorollinite additive

This variety is known as Montmrillonite, and it is not considered a hazardous substance. The Nano-clay was added to the soil in percentages of (5, 10, and 15%) and the findings revealed the following improvements.

- **Soil 1**

The results of a single collapse test performed on gypsum saturated soil (sample 1) on the natural soil at 200 KN, pressure. The vertical strain increased, whereas the collapse probability dropped to (12 %) Figure (4-12 a) shows.

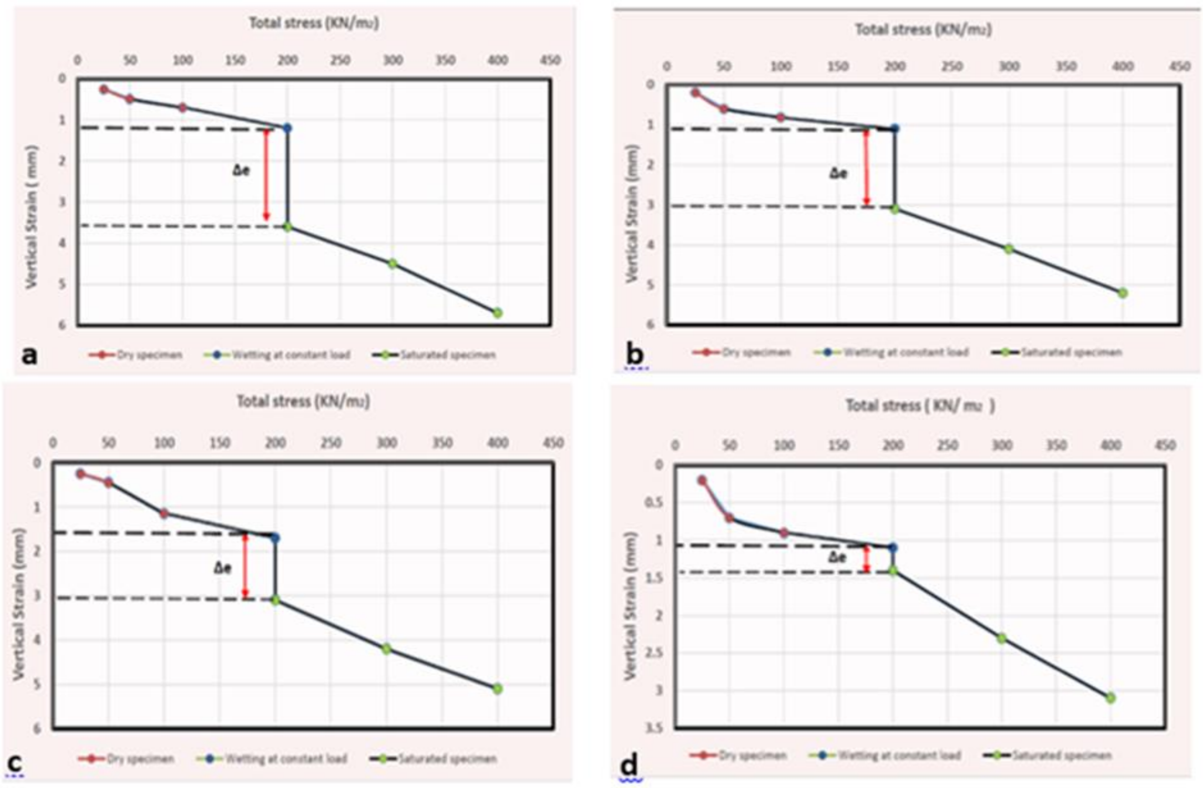


Figure (4 – 12)Shows Collapse test results on the gypseous soil no.1 that treated with Montmorollinite (0,5,10 and 15%) for figures (a, b, c and d) respectively in the study area.

Figures (4-12 b), (4-12 c) and (4-12 d) show the results of a single collapse test performed on gypsum saturated soil (sample 1) treated with Montmrillonite at ratio (5, 10 and 15) % respectively, The vertical stress displacement at a pressure equal to 200 kN, which leads to the recording of a collapse probability (10,7 and 1.5) %, for treatment soil respectively.

This means that the added Montmrillonite at ratio (15%) modifies the soil 1 from a severe problem case to Moderate problem case.

- **Soil 2**

The results of a single collapse test performed on gypsum saturated soil (sample 2) on the natural soil at 200 KN, pressure. The vertical strain increased, whereas the collapse probability dropped to (11.5 %) Figure (4-13 a) shows.

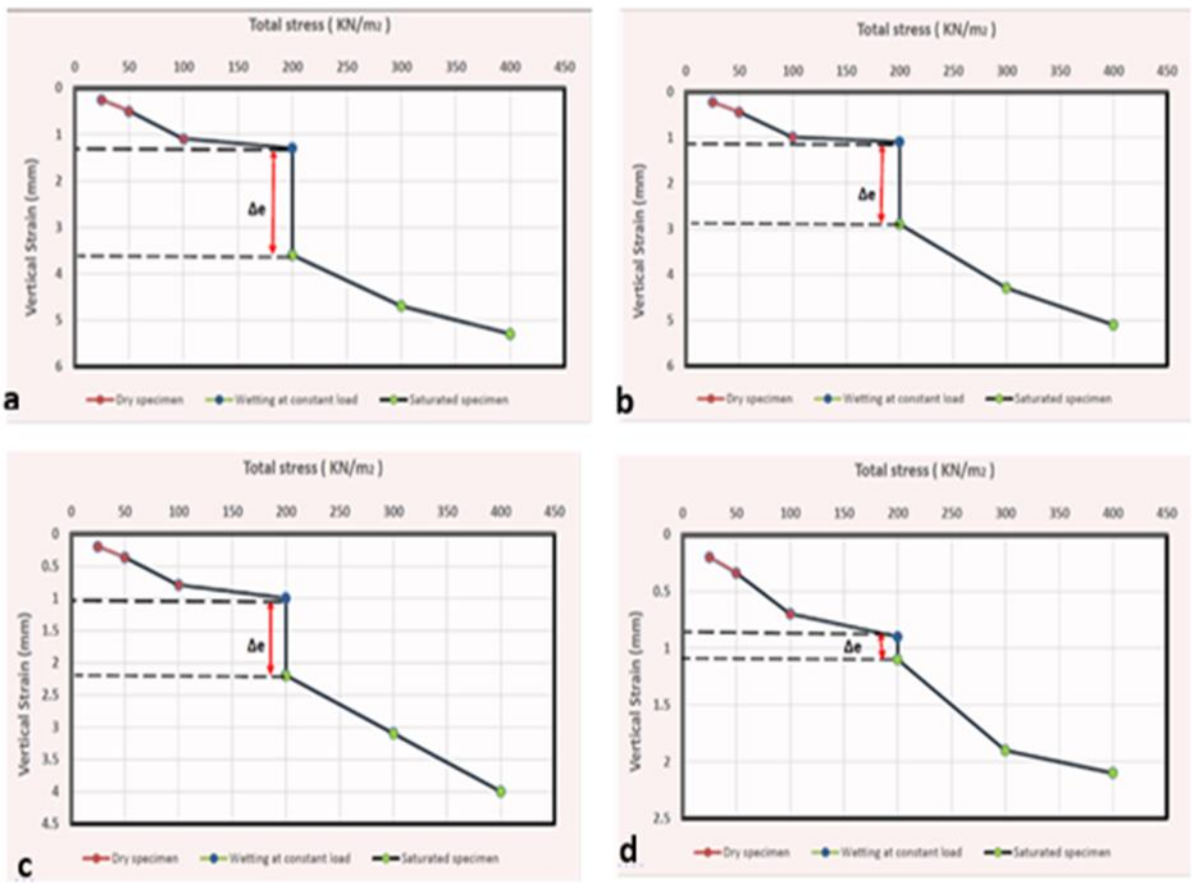


Figure (4 – 13) Shows Collapse test results on the gypseous soil no.2 that treated with Montmorollinite (0,5,10 and 15%) for figures (a,b,c and d) respectively in the study area.

Figures (4-13 b), (4-13 c) and (4-13 d) show the results of a single collapse test performed on gypsum saturated soil (sample 1) treated with Montmrillonite at ratio (5, 10 and 15) % respectively, The vertical stress displacement at a pressure equal to 200 kN, which leads to the recording of a collapse probability (9 ,6 and 1) %, for treatment soil respectively.

This means that the added Montmrillonite at ratio (15%) modifies the soil 1 from a severe problem case to no problem case.

- **Soil 3**

The results of a single collapse test performed on gypsum saturated soil (sample 3) on the natural soil at 200 KN, pressure. The vertical strain increased, whereas the collapse probability dropped to (13.5 %) Figure (4-14 a) shows.

Figures (4-14 b), (4-14 c) and (4-14 d) show the results of a single collapse test performed on gypsum saturated soil (sample 1) treated with Montmrillonite at ratio (5, 10 and 15) % respectively, The vertical stress displacement at a pressure equal to 200 kN, which leads to the recording of a collapse probability (11 ,8 and 4) %, for treatment soil respectively.

This means that the added Montmrillonite at ratio (15%) modifies the soil 1 from a severe problem case to Moderate problem case.

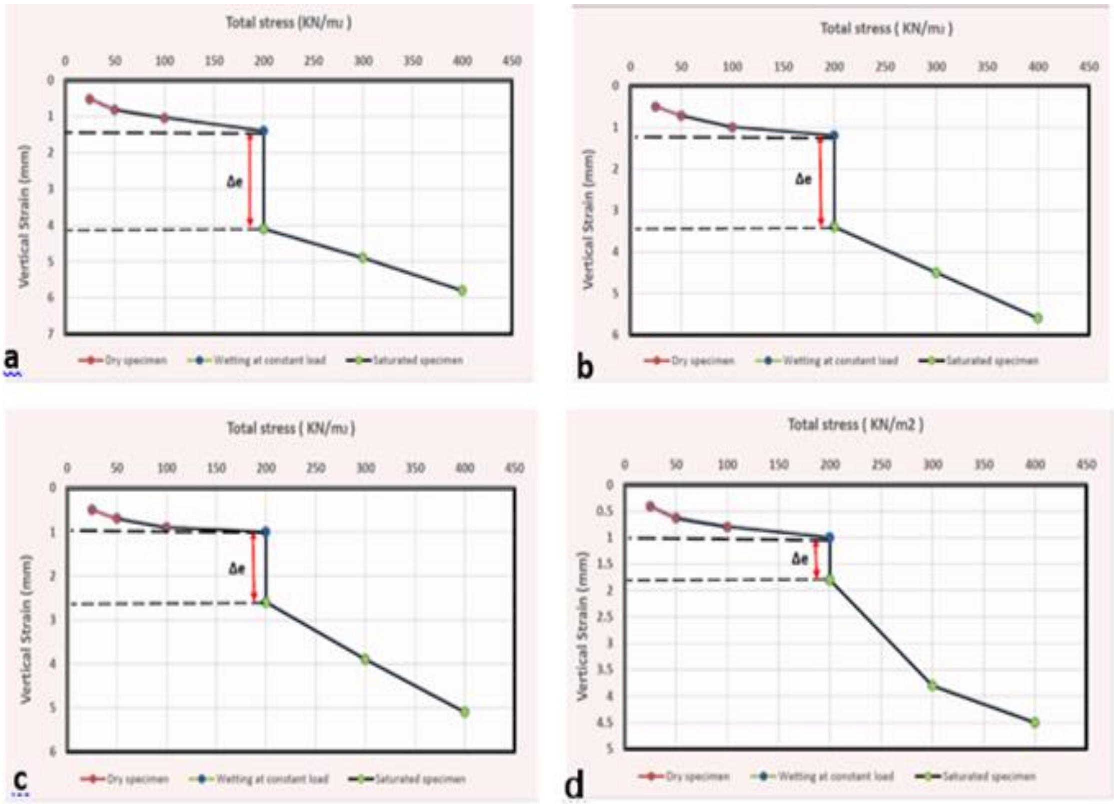


Figure (4 – 14): Shows Collapse test results on the gypseous soil no.3 that treated with Montmorollinite (0,5,10 and 15%) for figures (a,b,c and d) respectively in the study area.

Table (4 -11) Results of single collapse test Non- treatment and Treated with Hydrated Lime and Montmorollinite for the sample in the study area

No	Type of Additives	Present	Collapse potential test					
			Sample 1 56.6%		Sample 2 48.6%		Sample 3 72.8%	
			Δh In (mm)	C.P = (Δh/H) × 100%	Δh In (mm)	C.P = (Δh/H) × 100%	Δh In (mm)	C.P = (Δh/H) × 100%
1.	Add	0 %	2.4	12	2.3	11.5	2.7	13.5
2.	Hydrated lime. Add	3 %	2	10	1.8	9	2.3	11.5
3.		6 %	1.5	7.5	1.1	5.5	1.8	9
4.		9 %	0.25	1.25	0.1	0.5	0.7	3.5
5.	Montmrillonite Add	5 %	2	10	1.8	9	2.2	11
6.		10 %	1.4	7	1.2	6	1.6	8
7.		15 %	0.3	1.5	0.2	1	0.8	4

4.5 Evaluation Collapse Potential Results Using GIS Technology

A map of the distribution of collapse values for natural soils and soils treated in different proportions for the study area was drawn using the program GIS. And through the profiles, the following is shown.

4.5.1 Evaluation Collapse Potential for Natural Soils Using GIS

Figure no (4-15) shows the distribution of collapse values in the study area of natural Soil, Where it is noted that the collapse in the western and northwest direction is due to the increase in the proportion of gypsum in the soil.

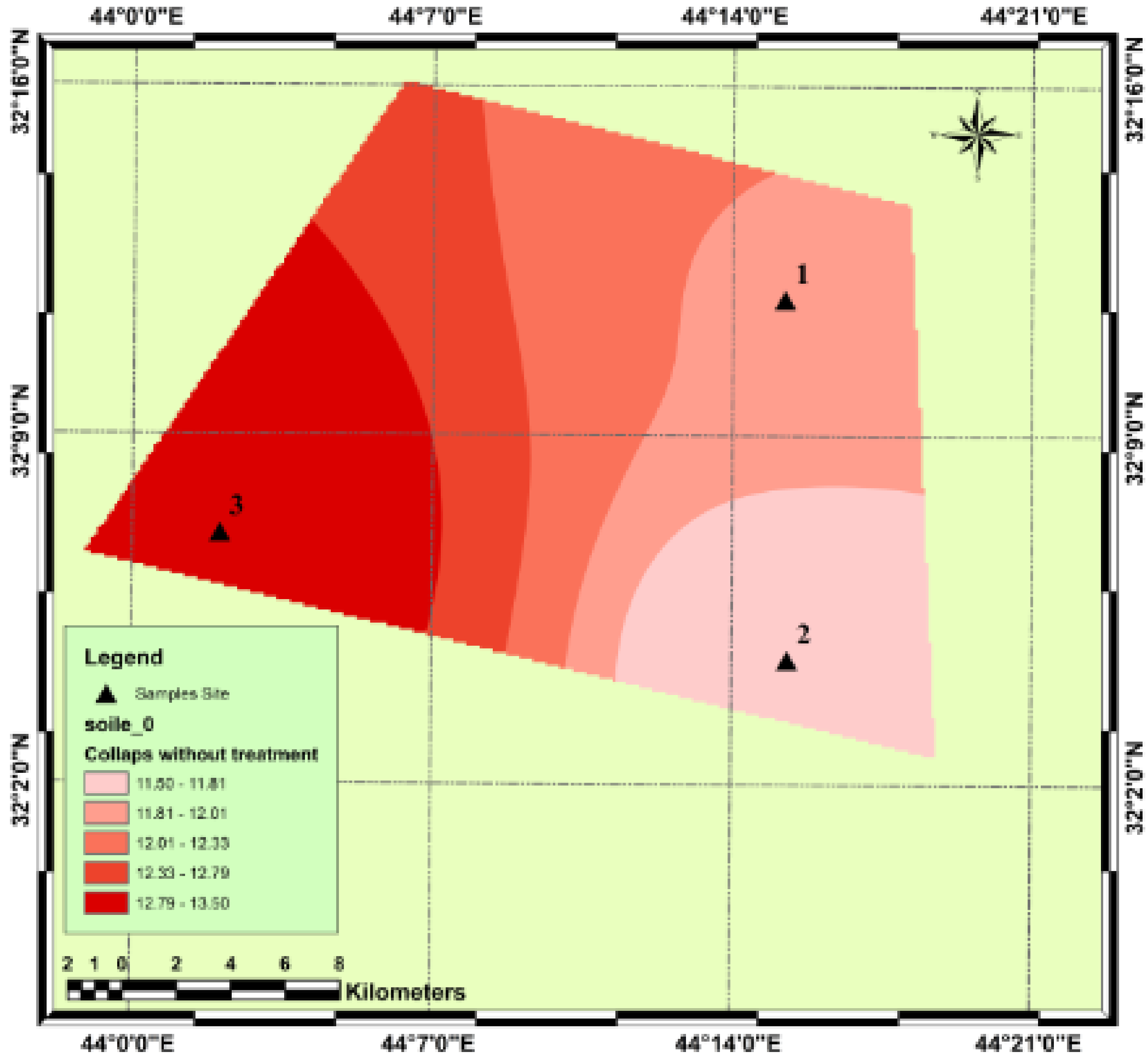


Figure (4 - 15): Collapse distribution values in the study area for natural soil.

4.5.2 Evaluation Collapse Potential for Treated Soils with Hydrated lime Using GIS

Figure (4-16) shows the distribution of the collapse values in the study area when the soil is treated with Hydrated lime ratio of 3%, A slight improvement in the collapse values rate is observed.

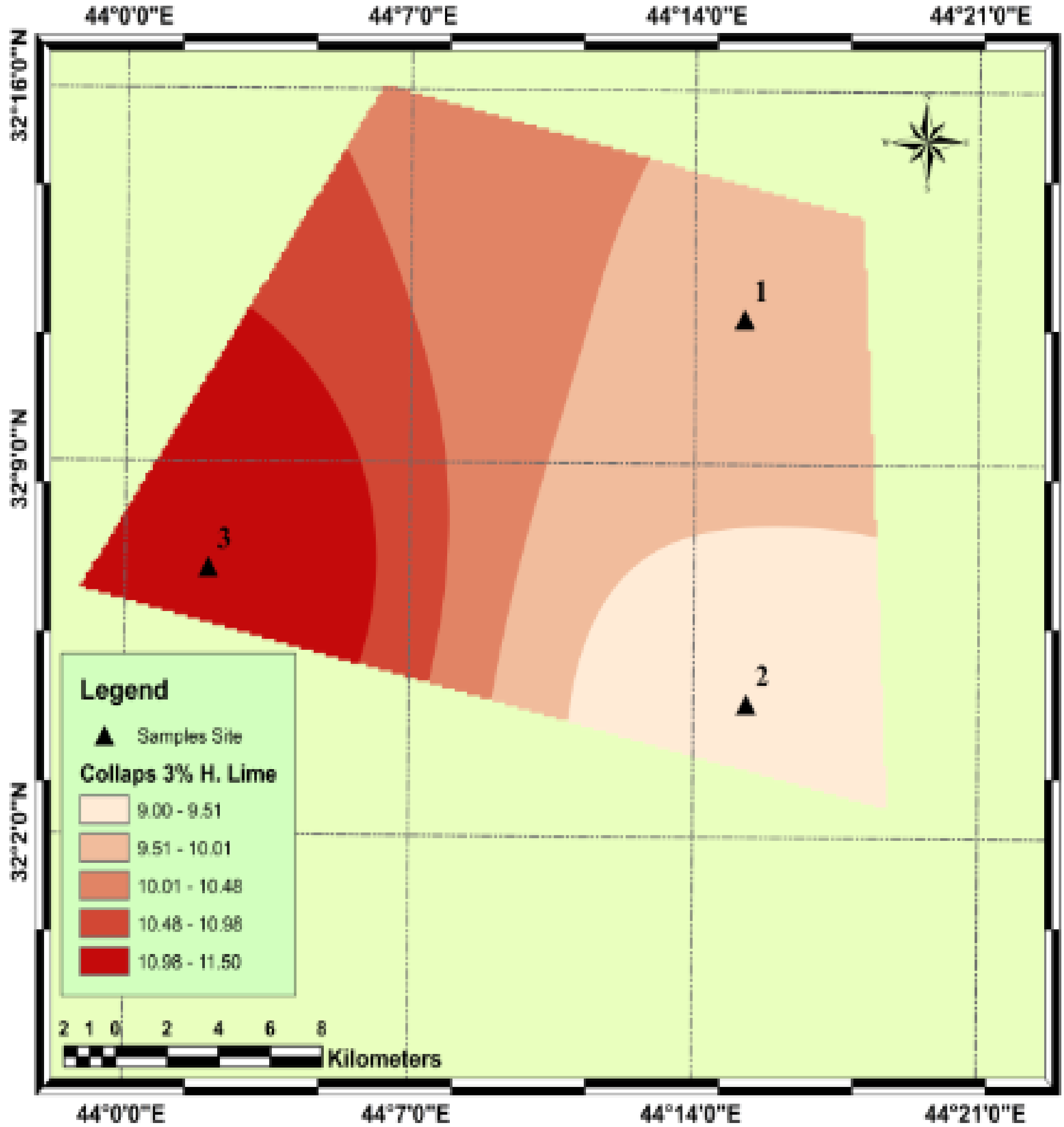


Figure (4-16): Collapse distribution values in the study area when the soil is treated with hydrated lime ratio of 3%.

Figure (4-17) shows the distribution of the collapse values in the study area when the soil is treated with Hydrated lime ratio of 6%, A slight improvement in the collapse values rate is observed.

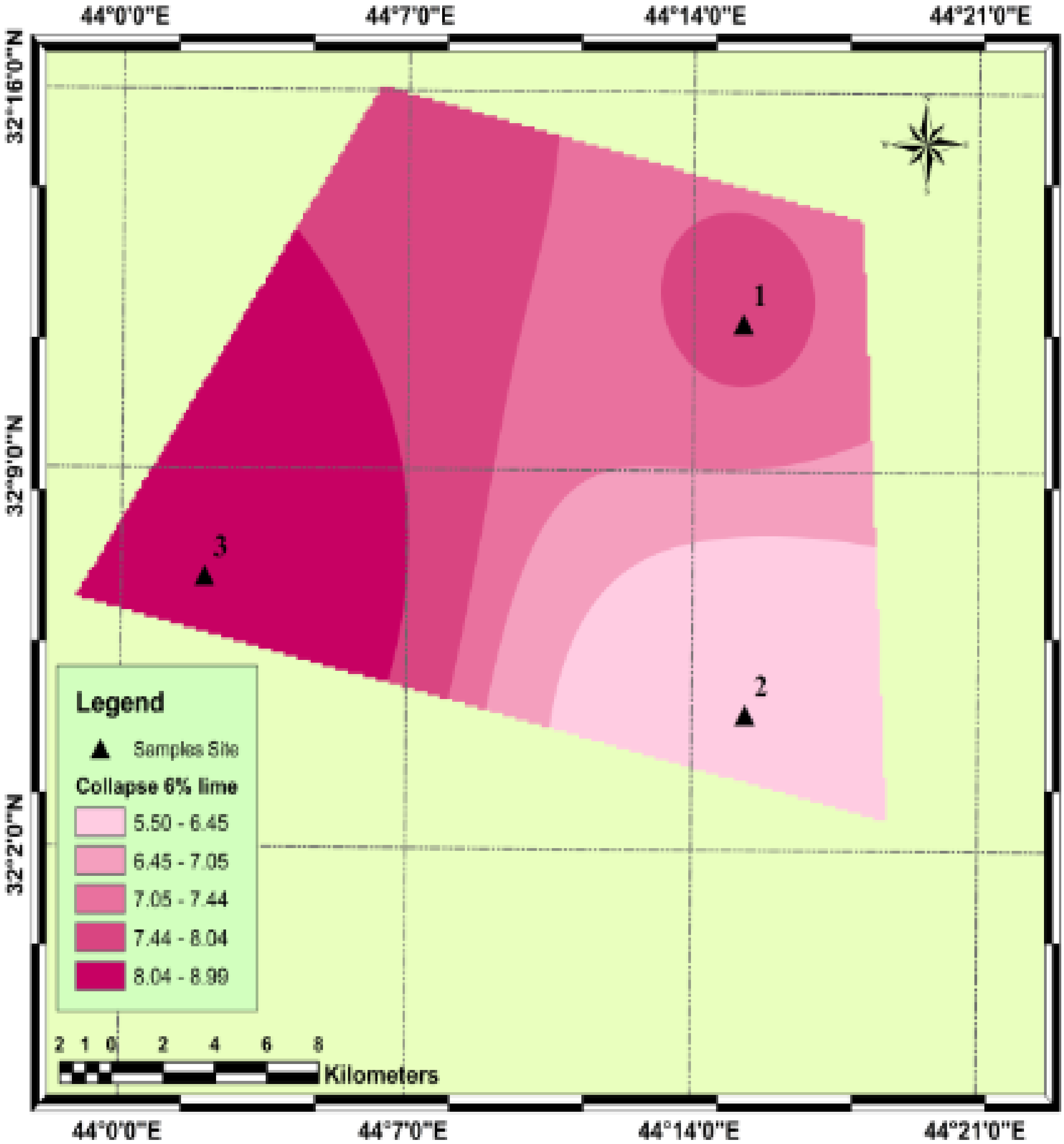


Figure (4 - 17): Collapse distribution values of the study area when the soil is treated with hydrated lime ratio of 6%

Figure n (4-18) shows the distribution of the collapse values in the study area when the soil is treated with Hydrated lime ratio of 9% , It is noted that the collapse of the soil improved well This means that the additive modifies the soil from a “Severe problem” state to a “moderate problem” or “no problem” state.

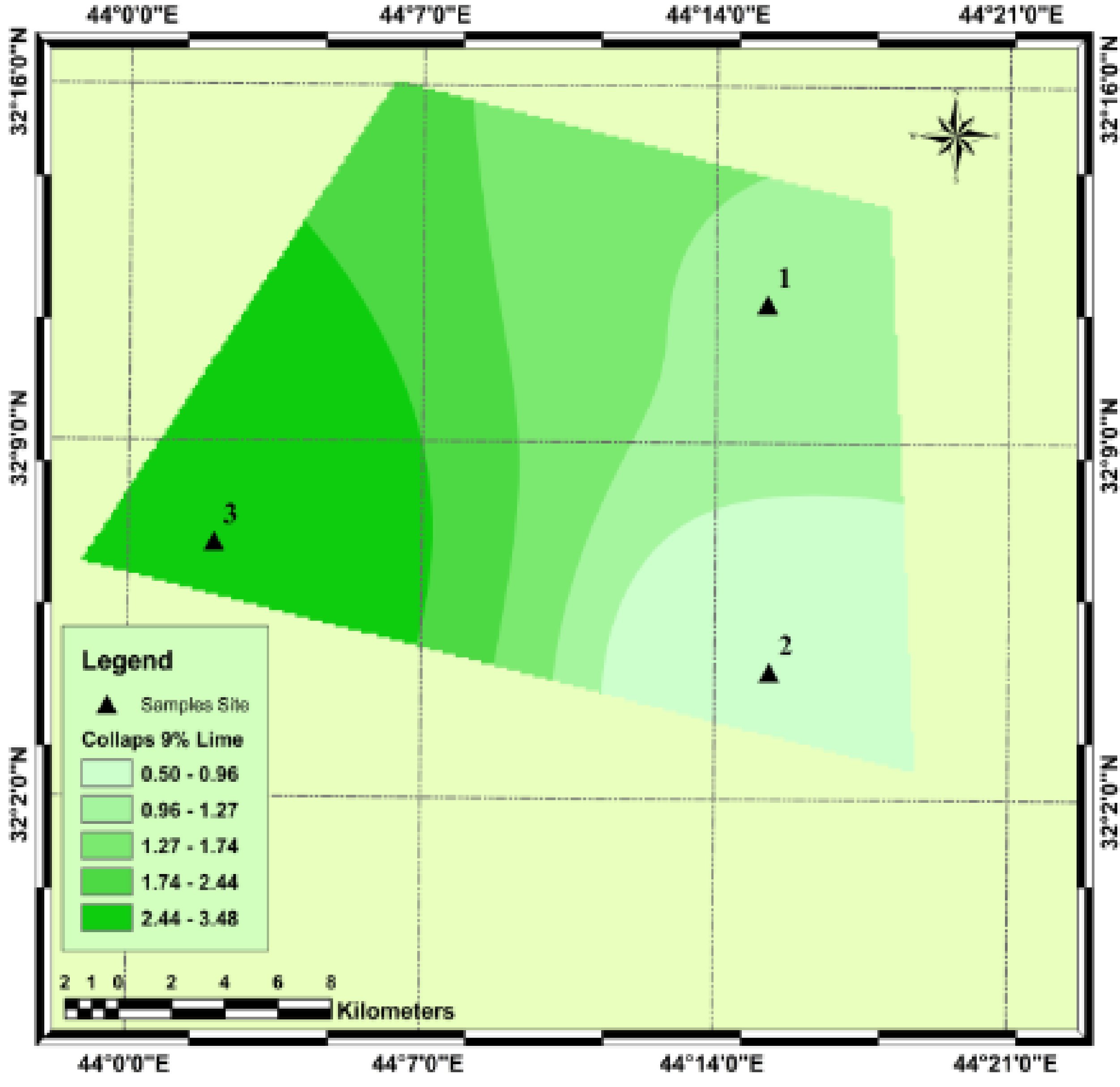


Figure (4-18): Collapse distribution of the values of the study area when the soil is treated with hydrated lime ratio of 9%.

4.5.3 Evaluation Collapse Potential for Treated Soils with Montmrillonite Using GIS

Figure (4-19) shows the distribution of the collapse values in the study area when the soil is treated with Montmrillonite ratio of 5% , A slight improvement in the collapse values rate is observed.

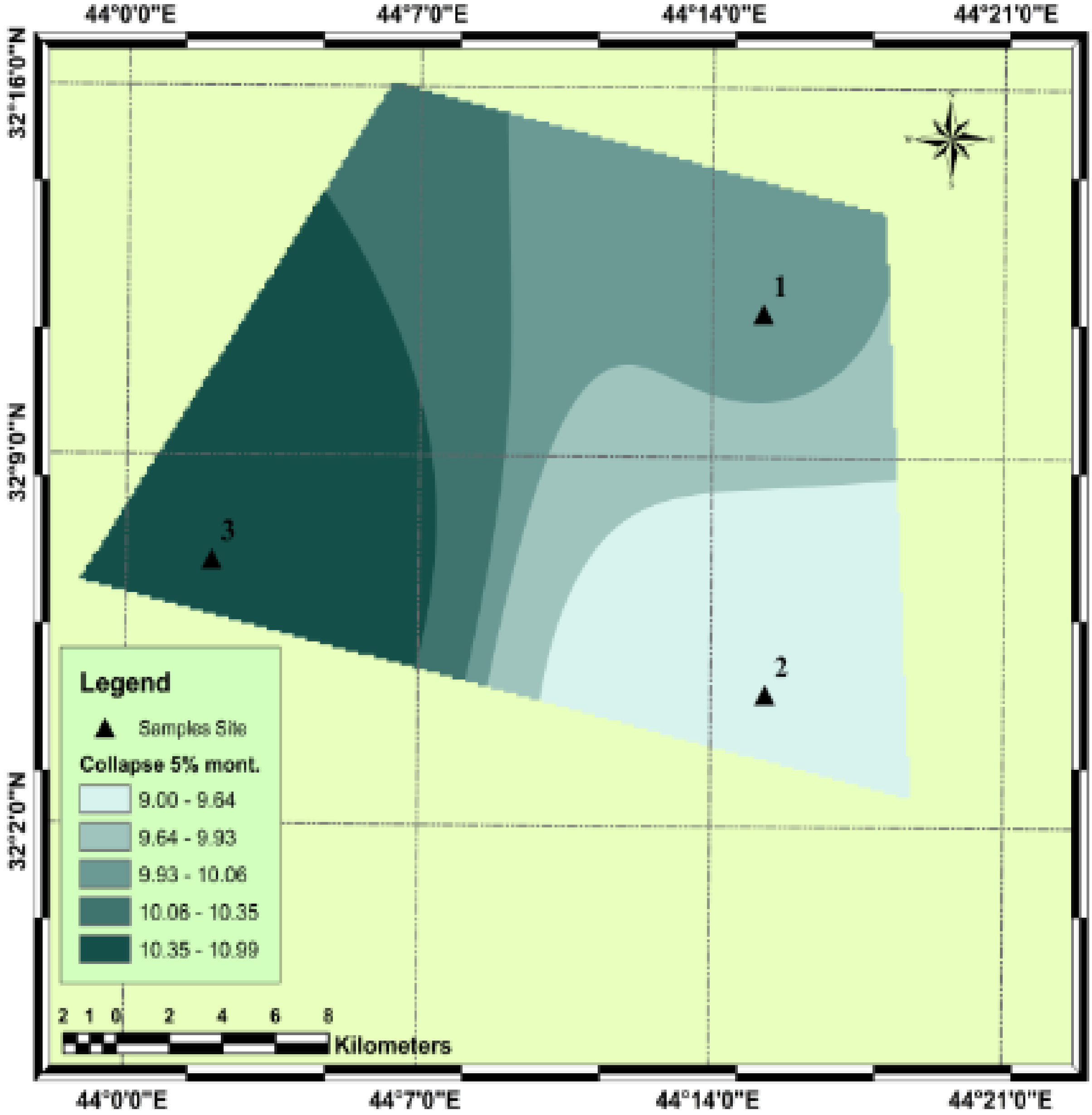


Figure (4 -19): Collapse distribution values of the study area when the soil is treated with montmorollinite ratio of 5%.

Figure (4-20) shows the distribution of the collapse values in the study area when the soil is treated with Montmrillonite ratio of 10% , The collapse values has clearly improved.

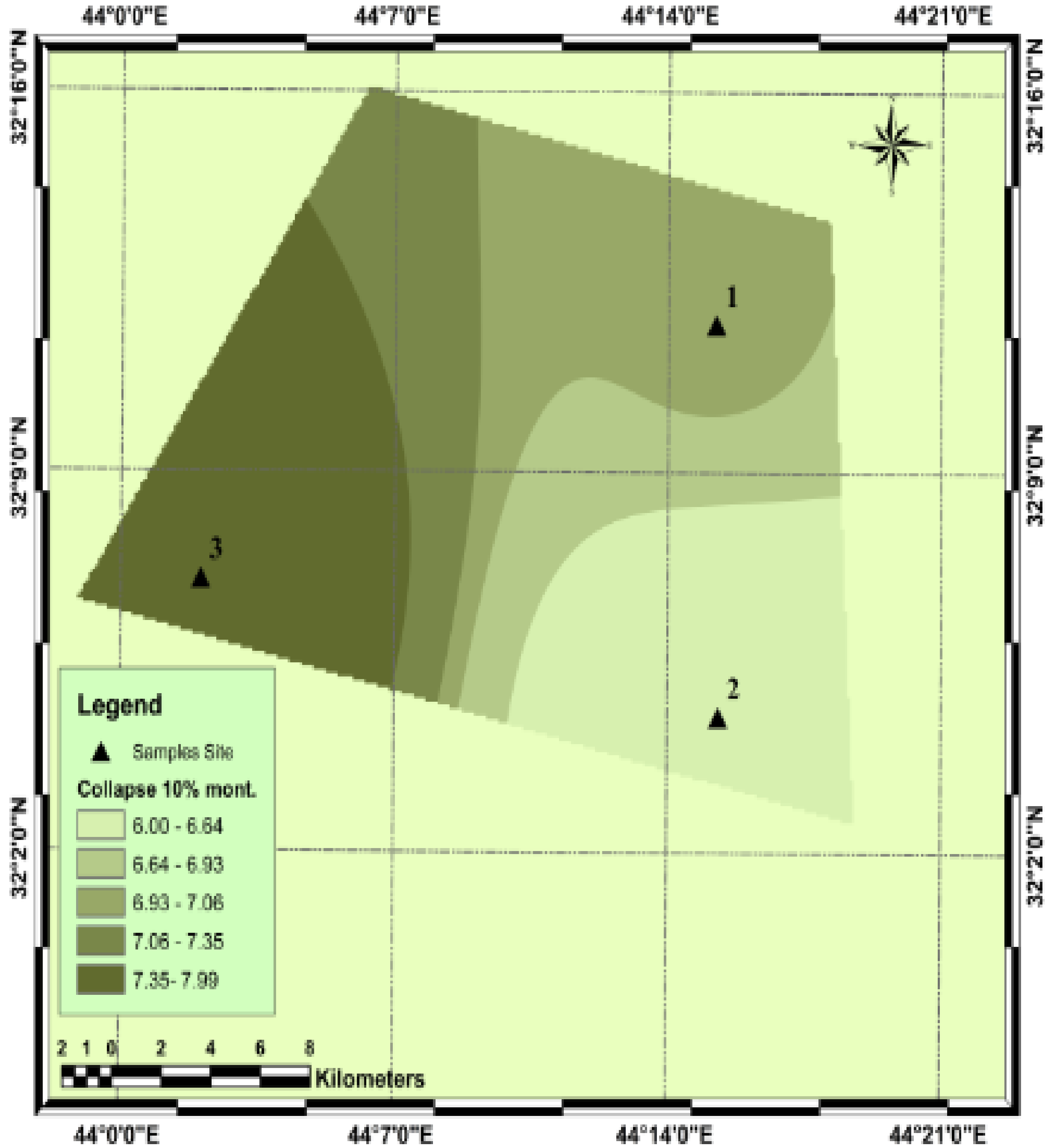


Figure (4 - 20): Collapse distribution values of the study area when the soil is treated with montmorollinite ratio of 10%.

Figure (4-21) shows the distribution of the collapse values in the study area when the soil is treated with Montmrillonite ratio of 15% , It is noted that the collapse of the soil improved well This means that the additive modifies the soil from a “Severe problem” state to a “moderate problem” or “no problem” state.

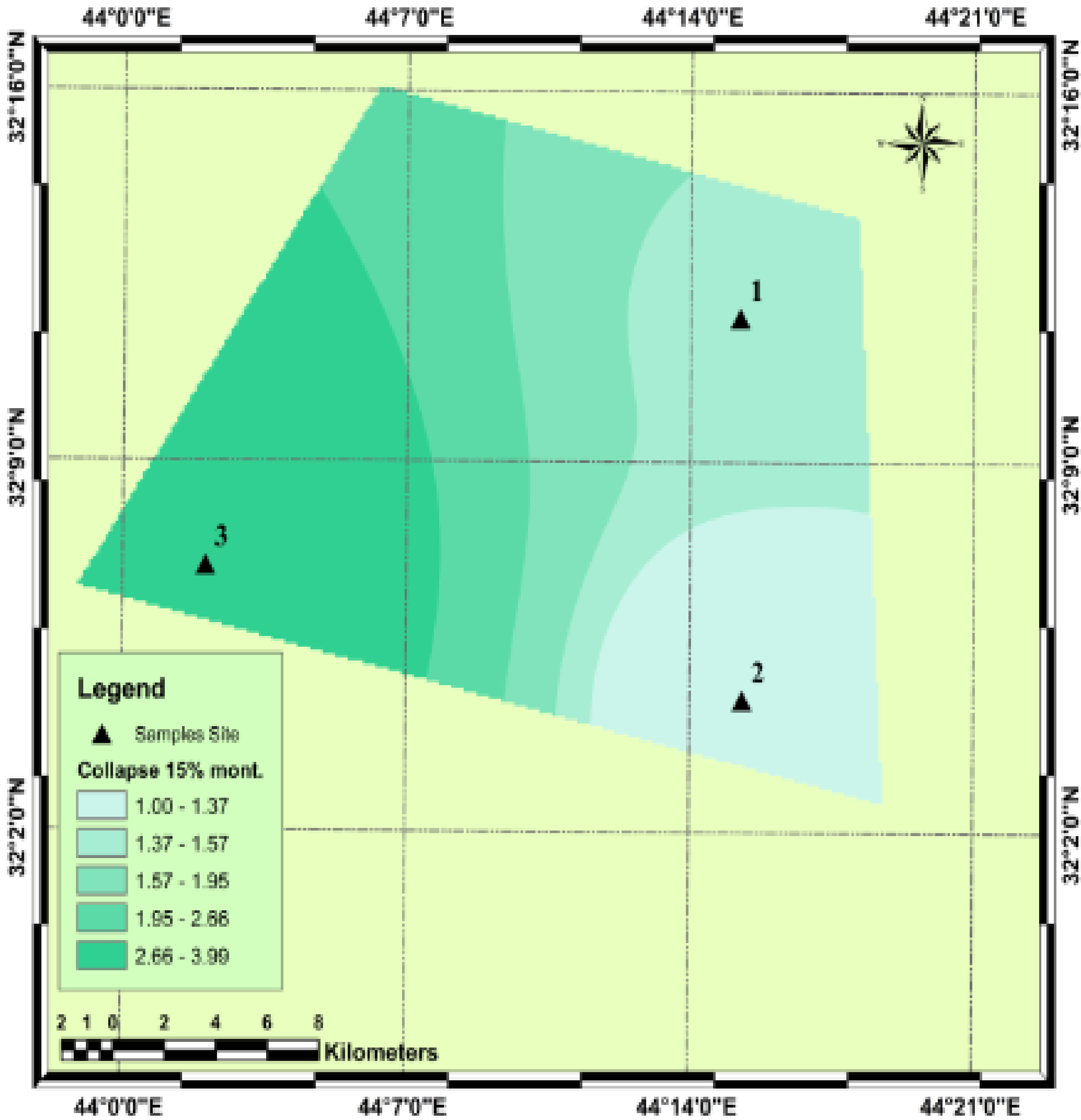


Figure (4 - 21): Collapse distribution values of the study area when the soil is treated with montmorollinite ratio of 15%.

4.6 The Economic Feasibility of the Study

The economic feasibility of soil treatment can be calculated by knowing the amount of material used to stabilize gypsum soils with the optimal rate of treatment by applying equation no (4-1) ,(Mohammad,2020) .

$x = \frac{L \times W \times H \times D}{100} \times P \div (P + 100)$ ………… (4-1).

Where: -

x: Quantity of material used for installation in tons

L: Length

W: Width

H: Height

D: Density

P: The perfect fit ratio

a. Hydrated Lime Additive

By applying the equation no. (4-1), the amount of hydrated lime can be known used to improve gypsum soils with the optimum addition rate that was reached in the research, which is 9% per cubic meter.

It turns out that the use of Hydrated lime Inexpensive economically and very suitable for use for improvement purposes, as the cost of Hydrated lime (110) thousand dinars per ton.

b. Montmorollinite Additive

By applying the equation no. (4-1), the amount of Montmrillonite can be known used to improve gypsum soils with the optimum addition rate that was reached in the research, which is 15% per cubic meter. It turns out that the use of Montmrillonite Inexpensive economically and very suitable for use for improvement purposes, as the cost of Montmrillonite (450) thousand, dinars per ton.

Chapter Five

Conclusions And Recommendations

5. 1 Conclusions

1 -Increasing the proportion of gypsum in the soil in the northwest direction in the study area.

2- Through the use of the Unified Soil Classification System (USCS), it was found that all soil samples in the study area are (SP) poorly gradient sand for natural soils and treated soils. Except for soil treated with 15%, it will (SC) sandy clay

3- The results of a liquid limits are changed and the soil becomes more liquidity limit when it's treated due to that Hydrated lime and Montmrillonite, increases the liquid limits significantly.

4- Decrease the optimum dry density and increase the optimum moisture content by increasing the percentage of additives from hydrated lime and Nano-clay.

5- Increasing the cohesion (c) by increasing the percentage of added hydrate lime up to a percentage 6% , after that the percentage begins to decrease when a percentage is added 9% , Also, noting the decrease in the shear angle (Ø) , This means that the ideal percentage of addition to improve the engineering specifications of the soil is 6%.

6- Increasing the cohesion (c) by increasing the percentage of added Montmrillonite up to a percentage 10%, after that the percentage begins to decrease when a percentage is added 15% , Also, noting the decrease in the shear angle (Ø),This means that the ideal percentage of addition to improve the engineering specifications of the soil is 10%.

7- The probability of collapse was reduced in the treated soil site no.1 and soil no.3, this means that the additive modifies the soil from a “severe problem” status to a “medium problem” state.

8- The probability of collapse at the treated soil site no.2 has been reduced, this means that the additive modifies the soil from a “Severe problem” status to a “no problem” state.

9- In the distribution map using the program GIS of the collapsing value for natural soils, it was shown that soil no. 3 gave the highest value of the collapse value 13.5%. The reason is due to the high proportion of gypsum.

10- Improvement of all geotechnical properties for soils treated with additives Hydrated lime and Montmrillonite In all percentage.

11-From the results, it was found that the change in collapse potential was close to the additives used in the study area.

5.2 Recommendation

Based on the foregoing conclusions, some of the following recommendations may be taken into consideration when conducting future studies:

1-Studying the effect of adding some non-traditional stabilizers (such as polymers, glass fibber, magnesium chloride and others) in the soil of the study area.

2-From the previous results and conclusions, we can recommend the use of Montmorlinite as an additive in injection and grouting operations for cavities under some engineering facilities.

Reverence

- Abood. M. K. (1993).treatment of Gypseous soils with sodium silicate. Unpublished M.Sc. Thesis, building & construction dept., university of technology, Baghdad
- Al-Abdullah, s.f.i. (1996): the upper limits of Gypseous salts in the clay core of Al-Adhaim dam, Ph.D. Thesis, civil engineering dpt., College of Engineering, University of Baghdad
- AL-Alaei S.J.Abd-Alhusain. (2017): Gypseous Soil Engineering Properties In The Middle Euphrates Area (Analysis and Evaluation), M.Sc. Thesis, Babylon Unversity, Applied Geology Department. (P-96).
- Al-Ashoo ,m.a.,(1991), soil mechanic, Al-Musial University /Iraq.
- Al-Barazanji a.f. (1973). Gypsiferous soils in Iraq. Ph.D. Dissertation. Ghent University. Belgium.
- Al – Dabbas *et. al.,* (2010) studied the comparison of Gypsiferous soils in Samarra and Karbala areas, Iraq.
- Al-Dilaimy, F.k.(1989): Effect of Gypsum Content on Strength and Deformation of a Remolded Clayey Soil, M.Sc. Thesis, Engineering College ,University of Salah-Alden, Erbil.(In Arabic).
- Al-Ebydy, majstyr, (1992) "tthbyt aljyr lltrbt aljbsy", majstyr. Atrwht, qsm alhndst almdnyt, jamet almwsl.
- Al-Ghanimy, M.A. 2018. Assessment of Hydrogeological Condition in Karbala –Najaf Plateau, Iraq. Ph.D. Thesis, (unpublished), University of Baghdad, 208p.
- Al-Enzy, a.w., (2019). Hydrochemical, hydrogeological and isotopic investigation of groundwater in Dammam aquifer at southern desert, west of Najaf governorate, Ph.D. Thesis submitted to the College of Science University of Bashar, 177p.

- Al-Heeti, a. A. (1990). The engineering properties of compacted Gypsified soil. Unpublished m. Sc. Thesis, civil engineering dept., University of Baghdad.
- Al-Jiburi, h.j., 2002; hydro geological and hydrochemical study of karbala quadrangle (n1-3s-14). Scale 1:250 000, geosurv. Int. Rep. No. 2825.
- Al-Khafaji, a. N. 1990: "some chemical properties of south jazira irrigation project", soil report submitted to Dijla irrigation center. Mosul.
- Al-Khafaji, I.R. (2009). Effects of dust storms on some Iraqi territories, PhD thesis, Baghdad University.
- Al-Mohammedi, n.m; Nashat, i. H. & bako,g. Y.(1987). Compressibility and collapse of Gypseous soils. 6th Asian conf. Of soil mechanics, Tokyo.
- Al-Mufty, a. A., (1997), “effect of gypsum dissolution on the mechanical behavior of Gypseous soils” Ph.D. Thesis, department of civil engineering, Baghdad University.
- Al-Neami, m. M., 2010: "improvement of Gypseous soil by clinker additives", engineering and technology journal, vol.28, no.19.
- Al-Nouri, i., and Saleam, s. “compressibility characteristics of Gypseous sandy soils.” ***Geotechnical testing journal***, vol. 17, no. 4, (1994), 465-474.
- Al-Qaissy, fif, 1989, effect of gypsum content and its migration on compressibility and shear strength of the soil, m.s.c. thesis, building and construction dep., university. of Technology. P 213.
- Al-Shemmari, a., n., (2012). Establishing relations between hydraulic parameters and geoelectrical properties for fractured rock aquifer In Dammam formation at Bahr al-Najaf basin, unpub. A thesis submitted to the college of science university of Baghdad, 176p.
- Al-Sakini, J. (1986). Neotectonic activity in Basrah vicinity and the dryness of western canals of Shatt Al-Arab. In Proceedings of the first symposium

on Khor Al-Zubair, Marine Science Center, Basrah University (pp. 415-416).

- ASTM- D 3080, 2011. "Designation: standard test method for direct shear test of soils under consolidated drained conditions." annual book of standards, volume 04.08, soil and rock; dimension stone; Geosynthetics, American society for testing material (ASTM).
- ASTM- D 2487-11. Standard practice for classification of soils for engineering purposes (unified soil classification system). American society for testing materials, west Conshohocken, Pennsylvania, pa19428, usa, 2011.
- ASTM- D 422, 2007: “standard test methods for particle-size analysis of soils”. Annual book of ASTM standards, ASTM international, west Conshohocken, pa.
- ASTM- D 4318-10. Standard test methods for liquid limit, plastic limit, and plasticity index of soils. American society for testing materials, west Conshohocken, Pennsylvania, pa 19428, use, 2010.
- ASTM- D 5333 (2018), “standard test method for measurement of collapse potential of soils”. Annual book of ASTM standards, vol.04.08, Philadelphia, pa, ASTM, use. Copyright, ASTM international, 100 barr harbor drive, p &o box c700, west Conshohocken, p &a 19428-2959, United States.
- ASTM- D 698 (2012), "standard test methods for laboratory compaction characteristics of soil using standard effort (600knm/m3)", reprinted from the annual book of ASTM standards. Copyright ASTM, vol.4, no.8.
- ASTM- D 854 (2010), “standard test methods for specific gravity of soil solids by water pycnometer”. Annual book of ASTM standards, vol.04.08, Philadelphia, p & a, ASTM, use. Copyright, ASTM international, 10&0 barr harbor drive, PO Box c700, west Conshohocken.

- ASTM- D 2216 standard test methods for laboratory determination of water (moisture) content of soil and rock by mass. West Conshohocken: American society for testing & materials, 2005.
- Azam s., Abduljawad s., al-Shayea n. & al-Amoudi o., (1998). Expansive characteristics of gypsiferous / anhydrtic soil formations. Engineering geology 51: 89-107.
- Al - Zory ،e.a. (1993) "Tathyr alnd ela altrbt aljbsyt Aljyryt Almstqr", Majstyr. Atrwht, Jamet Almwsl.
- Al- Zubaydi, j. H. A., (2006). Geotechnical study for selcted soil between Hilla and Kut cites (middle of Iraq), PhD thesis, Baghdad university/Iraq.171 p (in Arabic).
- Barzanji (1973) concluded that geological formation with the evaporation of the inland seas are the origin of moat gypsiferous soils in Iraq.
- Buringh, P. 1960. Soil and Soil Condition of Iarq. Ministry of Agriculture. Dierectorate General of Aricultural and Project، Baghdad, 332 P.
- Barwari, a.m. and Slewa, n.a., (1995). Geological map of Karbala quadrangle, scale 1:250 000, sheet ni-38-14. Geosurv, Baghdad.
- Bello, N.J., Amori A. A. and Adejuwon, 2011, “Introduction to climatology and biogeography”, Technical Seminar, Department of Water Resources Management and Agro meteorology, College of Environmental Resources Management, 21 P.
- Bowles, j.,e, 1988, foundation analysis and design, 4th .ed., megraw-hill book co., Singapore, 1004p.
- Bs 1377 – 2: 1990 (British standard institution), "method of test for soils for civil engineering purposes" British standard institution, London, UK. , 1990.
- Buday, t., and Jassim, s. Z., (1987): the regional geology of Iraq (tectonics, magmatic, and metamorphism), volum2, 325p.

- Buringh, p. 1960: soil and soil condition of Iraq. Ministry of agriculture. Directorate general of Aricultural and project, Baghdad, 332 p.
- Chiligar. (1983). Methods for Dating Very Old Groundwater: Government publishing Service.
- Dontsova, Taylor, S., Park, E., & Bullion, K., (2015). Dissolution of three insensitive munitions formulations. Chemosphere, 119, 342-348
- Eshoo, b. G. (2004), “stabilization of gypseous soils by lime and emulsified asphalt”, M.sc. Thesis, college of engineering, university of Mosul, (p-77).
- Fair bridge, r. W, (1972). The encyclopedia of geochemistry & environmental sciences. Dowden Hutchinson & Ross Inc., Stroudsburg, Pennsylvania, 1321p.
- Fao; food and agriculture organization of the United Nations. Management of gypsiferous soils. www.fao.org/docrep/to323e/to323e0 7.htm (1990).
- Gcgw (general commission of groundwater).2018. Advanced survey of hydrogeological resources in Iraq, phase ii (ashri-2). Ministry of water resources of Iraq, Bagdad, Iraq.
- Gcgw: general commission for groundwater. Ministry of water resource, Iraq.
- Goudie, a. & viles h, Salt weathering hazards. Wiley, England, (1997).
- Hussain, M.S., 2005. Mineralogical, hydrochemical and geochemical study of gypsiferous soils in Al-Najaf –Karbala and Falluja areas. Unpub. M.Sc. Thesis, University of Baghdad، 160pp.
- https://doi.org/10.1520/gtj10307j
- Https://van-bent.com.
- https://van-bent.com/api-13a-section-9/
- I.b.s, 2004: (Iraqi building specification) 600 "technical specifications", ministry of construction and housing public municipalities, republic of Iraq.

- Jafarzadah, a.a. and zinck, j.a., 2000: "worldwide distribution and substational management of soils with gypsum". Isd Ana sayfasi, Netherlands.
- Jassim, s. Z. And Goff, j. C., (2006).geology of Iraq. Dolin, Prague and Moravian museum, Brno, Czech republic.314 p.
- Khaled a. A. Al-Haddad, (2008): collapsing of gypsum soils in the Samarra region; department of applied earth sciences, college of science, Tikrit University, Tikrit, Iraq.
- Knight, 1963, the origin and ocurrence of collapsing soils‹proceedings 3rd regional of Africa on soil mechanics and foundation engineering,vol.1, pp. 127-130.
- Kovda (1954) state that gypsum accumulation occurs in two ways by the Evaporation of mineralized ground water and by the precipitation within Ground water itself.
- Lamb, t. W. And Whitman, r. V. 1964, soil mechanics, john Wiley and sons. Inc. New York.
- Larsen g. And Chilingar g.1983 : diagnosis in sediments and sedimentary rocks .Elsevier scientific publishing Company, Amsterdam.
- Mahdi, B.O (2004). Some engineering aspects of gypseous soils, ph.d. Thesis, civil Engineering d. Pt., College of Engineering, University of Baghdad.p.175.
- Mahmood, (2007) studied the effect of gypsum percentage on geotechnical properties of gypsiferous soil at Basra governorate (western side).
- Maitham a. K. Al-Ghanimy, (2018). Assessment of hydrogeological condition in Karbala – Najaf plateau, Iraq, thesis submitted to the College of Science University of Baghdad, 208p.
- Majeed, N.N., Geotechnical study of Gypseous Soil Chosen from Places in Kirkuk City (2004). PhD thesis, Baghdad university/Iraq.303 P (in Arabic).
- Mohammad,(2020) https://youtu.be/VAv_yWp0ZPQ

- Nashat, l.H., 1990, engineering characteristics of some Gypseous soils in Iraq, ph.D. Thesis, Civil, Engineering. Dep. Univ. of Baghdad.
- O.e.c (37 / d / 10), (1992): Kifl 3d survey, pre-planning report, geophysical study dept., o.e.c. document, 88 p.
- Petrukhin, v.p. and Arakelyan, e.a., 1985, strength of gypsumclay and its variation during the leaching, soil mechanics and foundation engineering. vol.21, no.6. Pp 23-25.
- Pettijohn, e. J. sedimentary rocks, (1975): harper international edition, Singapore, 628p.
- Razouki, s. S. And el-Janabi, o. A., (1999). "Decrease in the cbr of gypsiferous soil due to long-term soaking", quarterly journal of engineering geology.
- Rogers, C.D.F. and Glendinning, S. (1993). Modification of clay soils using lime. In C. a. Rogers (Ed.), Proceeding of the Seminar held at Oughborough University on Lime Stabilization (pp. 99-114). London: Thomas Telford.
- Saeed, S.A., 1994 Specifications of Gypsiferous Soils. Symposium on gypsiferous soils and their influence onconstructions, NCCL, 4/7/1994, Baghdad (Abstract).
- Saleam, S.N.M., 1988, Geotechnical characteristics of a Gypseaeous Sandy Soil Including the Effect of Contamination with some oil products, M.SC Thesis Bulding and Construction Dep،.university. of Technology .
- Selley, r. C. Applied sedimentology. Academic press, u.s.a, (2000).
- Sherwood, p. (1993). Soil stabilization with cement and lime. State of the Art Review. London: Transport Research Laboratory, HMSO.
- Singh, R.B. and al-Layla, M.T., 1979, Engineering Behavior and Micro Structure of a Collapsible Mosul clay under physico – chemical reversal of Leacheng, Proceeding of thr 6th South East Asia Conference on soil Engineening, Tailei.

- Sissakian, v.k., 2000: geological map of Iraq, 3rd edition, scale 1:1000 000, geosurv, Bagdad, Iraq.
- Sissakian and Ibrahim, (2005) were compiled the Geological Hazards Map, scale 1: 1000 000, GEOSURV, Bagdad, Iraq.
- Smart j. V. Gypsum. Mineral information leaflet no. 26, Australia (1999).
- Stipho, a. S., (1985): on the engineering properties of saline soil. Quarterly Journal of Engineering Geology, 18:129-137.
- Subhi, H.M., 1987, the properties of salt contaminated soils and their influence on the performance of reads in Iraq, ph.d. Thesis ،Queen Marry College, University of London.
- Trenberth, K., Meehl, J., Masters, J., Somerville, R., Cutting, H., Chung, S. and Hassol, S., 2011, “Current extreme weather and climate change”, Climate Communication Organization, 28 P.
- Van Alphen, J.O.y. and Romero, F.D.R., 1971, Gypsiferous Soils, Notes on their Chaeracterstics and Management, nt. Inst. For Land Reclamation and Improvement, Bulletin 12, Wagening ،
- Yassin, M.J., 2006. Study of geotechnical, mineralogical and geochemical properties of gypsiferous soils for selected samples from Samara, Najaf and Karbala areas, Central Iraq. Unpub. Ph.D.Thesis, University of Baghdad, 185pp.
- Zakaria, W.A, 1995, Permeability of Gypseous Soil, M.SC. Thesis،Buiding and Construcation Dep.unir. Of Technology Baghdad.P220.

المستخلص

تضمنت هذه الدراسة تحسين الترب الجبسية لثلاث مواقع مختارة في محافظة النجف الاشرف و ذلك بأضافة النورة المطفأة بنسبة (3، 6 و 9%) و الطيــن النانـــوي (المونتموريلونايت) بنسبة (5، 10 و15%) على الخواص الهندسية للتربة الجبسية المأخوذة من جزء من هضبة النجف- كربلاء و كانت نسبة الجبس في التربة الطبيعية للنماذج المأخوذه هي (52 ، 48 و 72%) للمواقع رقم (1 ، 2 و 3) على التوالي حيث أظهرت هذه الدراسة زيادة نسبة الجبس في التربة في الاتجاه الشمالي الغربي لمنطقة الدراسة.

تضمنت هذه الدراسة دراسة تأثير استخدام المواد النانوية و النورة المطفأة في تحسين وتثبيت التربة الجبسية و باستخدام العمل المخبري . و جمعت هذه الترب الجبسية من مواقع مختارة في مدينة النجف وخلطت مع الطين النانوي (المونتموريلونايت) و النورة المظفأة ، حيث أضيفت بكميات قليلة كنسبة مئوية من الوزن الجاف للتربة. اجريت الاختبارات لتحديد العديد من الخصائص مثل تحليل الغربال ، والوزن النوعي ، وأقصى كثافة جافة ، ومحتوى الرطوبة الأمثل ، وإمكانية الانهيار.

أظهرت نتائج العمل التجريبي حصول تعديل في الخواص الجيوتكنيكية لعينات التربة وان أقصى كثافة جافة هي (2.065 ، 2.025 و 2.003) غرام / سم3 عند المحتوى الرطوبة المثالي (15٪ ، 14٪ ، 15٪) على التوالي للعينات الثلاث في حالة اضافة النورة المطفأة . بينما وجدت أقصى كثافة جافة هي (2.059 ، 2.013 و 2.013) عند المحتوى الرطوبي المثالي (14٪ ، 14٪ ، 15٪) على التوالي للعينات الثلاث في حالة اضافة الطين النانوي . تنخفض الكثافة الجافة القصوى بينما يزيد المحتوى الرطوبي الأمثل مع زيادة نسبة المضاف من النورة المطفأة و الطين النانوي .

كذلك بينت النتائج تغيير حدود السيولة وتصبح التربة أكثر سيولة عند معالجتها بسبب ان النورة المطفأة و الطين النانوي يزيدان من حدود السيولة بشكل كبير. ان قوة التماسك (C) تزداد بزيادة نسبة النورة المطفأة من 3٪ إلى 6٪ ، وبعد ذلك تنخفض لتصل إلى الصفر عند الإضافة 9٪ والسبب في ذلك أن النورة المضافة تزيد من قوة التماسك بين الجزيئات إلى حد إضافة 6٪ ، ثم ينخفض التماسك إلى الصفر عند إضافة 9٪ من النورة ، حيث تعمل جزيئات النورة على فصل جزيئات التربة عن بعضها البعض بسبب حصول ظاهرة التلبد مما يؤدي الى قلة قوة التماسك. ويلاحظ أيضًا أن زاوية الاحتكاك الداخلي (Ø) تتناقص مع زيادة نسبة المواد المضافة من النورة المطفأة و الطين النانوي .

و من خلال العمل المختبري توصلنا الى نقصان احتمالية الانهيار بمجرد زيادة نسبة الاضافة من الملاط النانوي و النورة المطفأة . وبالتالي ، فإن إضافة المونتموريلونيت و النورة المطفأة حتى بنسب منخفضة يمكن أن يحسن الخصائص الجيوتكنيكية للترب الجبسية. حيث ادى تأثير أضافة الطين النانوي إلى تغيير

احتمالية الانهيار من (12 ، 11.5 و 13.5٪) إلى (1.5 ، 1 و 4٪) للعينات S1 و S2 و S3 على التوالي نتيجة معالجة التربة . و كذلك ادى تأثير اضافة النورة المطفأة إلى تغيير احتمالية الانهيار من (12 ، 11.5 و 13.5٪) إلى (1.25 ، 0.5 ، 3.5٪) للعينات S1 و S2 و S3 على التوالي نتيجة معالجة التربة ، وهذا يعني أن المادة المضافة تعدل التربة من حالة "مشكلة خطيرة" إلى حالة "مشكلة متوسطة" أو حالة "عدم وجود مشكلة". هذا و قد تم استعراض نتائج جهد الانهيار بأستخدام تقنية ال GIS .

جمهورية العراق

وزارة التعليم العالي والبحث العلمي

جامعة بابل كلية العلوم

قسم علم الا رض التطبيقي

تحسين التربة الجبسية
بأستخدام النورة المطفأة و المونتموريلونايت
لمواقع مختارة في مدينة النجف الاشرف ، وسط العراق

رسالة مقدمة الى قسم علم الارض التطبيقي كلية العلوم

جامعة بابل

كجزء من متطلبات نيل درجة

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