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Swelling Potential and Mineralogy of Al-Hartha City Soil in Basrah-Southern Iraq

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Abstract

Mineralogical and geotechnical properties used to analyse the swelling potentials of Al-Hartha City. According to mineralogy, montmorillonite is a dominated clay mineral (33.61%) followed by montmorillonite-chlorite (33.34%), kaolinite (9.18%) and illite (5.38%). While calcite, Quartz, Feldspar, and dolomite are non-clay minerals that are also present. According to geotechnical analysis, the percent of clay range between 9-42% with an average of 25.5%, silt 55-80% with an average of 67.5% and sand 0-17% with an average of 8.5%. While liquid limits and plasticity index are, respectively, 10–25% with an average of 17.5% and 35%–51% with an average of 43%. According to the unified soil classification system (USCS), these soils are mainly low plasticity lean clay soils (CL) and 10% classified as medium stiff elastic silt (MH). According to activity values, soils are primarily inactive-(70%), normally active-(20%), active-(10%), and their consistency is plastic. according to an assessment of soil expansivity based on index properties and activity, a significant amount of the soil is expansive. Additionally, there is an agreement between the results of the mineralogical tests performed on these soils and the results of the measures of soil expansivity obtained from the evaluation of the swelling of the soil based on assessments of its index properties.

Keywords: Swelling potential, Clay minerals, Al-Hartha, Expansive soil, Liquid limit.

جهد انتفاخ ومعدنية تربة مدينة الهارثة في البصرة، جنوب العراق

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الخلاصة

تم استخدام الخواص المعدنية والجيوتكنيكية لتحليل جهد الانتفاخ في مدينة الهارثة. من الناحية المعدنية، فإن المونتموريلونايت هو المعدن الطيني الغالب (33.61% يليه المونتموريلونايت-كلورايت (33.41%)، الكاولينات9.18%) و الألايت (5.38%). بينما الكالسيت والكوارتز والفلدسبار والدولوميت هي المعادن غير الطينية المتواجدة. وفقاً للتحاليل الجيوتكنيكية، فإن نسبة الطين ما بين 9-40% بمعدل 25.5%، الغرين 55-80% بمعدل 67.5% والرمل 0-17% بمعدل 8.5%. بينما حدود السيولة (LL) ودليل اللدونة (PI) هي، على التوالي 10-25% بمعدل17.5% و35 -51 %بمعدل 43%. وفقا لنظام تصنيف التربة الموحد (USCS)، فإن هذه التربة هي أساسا تربة طينية قليلة اللدونة (CL) و10٪ مصنفة على أنها غرين مرن متوسط

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الصلابة .(MH) وفقا لقيم الفعالية، تصنف التربة على انها – (70%) ترب غير فعالة، (20%) – ترب متوسطة الفعالية، (10%) – ترب فعالة، وقوامها لدن. وفقا لتحاليل انتفاخ التربة بالاعتماد على الخواص الدالة والفعالية، فإن نسب كبيرة من التربة تصنف على انها ترب منتفخة. بالإضافة إلى ذلك، هناك توافق بين نتائج التحليل المعدني التي أجريت على هذه التربة ونتائج قيم تمدد التربة المحددة من تقييم جهد انتفاخ التربة بناء على الخصائص الدالة.

1. Introduction

Expanding soil can swell or shrink in volume when wet or dry due to natural variations in the weather and other environmental factors. As a result, they severely reduce the stability of slopes, subsurface structures, building foundations, and highways, and also result in cracks and collapses. The soil's kind and amount of clay, especially montmorillonite and illite, which is the most significant controlling element in many geotechnical qualities like swelling and shrinkage, affects these volumetric changes. Understanding the empirical test is made possible by knowledge of the composition of clay minerals, which will make geotechnical issues easier and maybe prevent construction failure. In this study, the soil in the study region was examined for its capacity to swell using data from its physical properties and mineral analysis results.

1.1 Location of the study area

The area of study is situated in Al-Hartha city, in the governorate of Basra's northeastern region Figure1. The investigated region is a section of the lower Mesopotamia zone within the Zubair subzone, which is a part of Iraq's unstable shelf, from a tectonic view [1]. The sites are buried behind recent alluvial sediments on the right bank of the Shatt Al-Arab. The floodplain is covered with silt and clay sediments from this river's depositional processes [2].

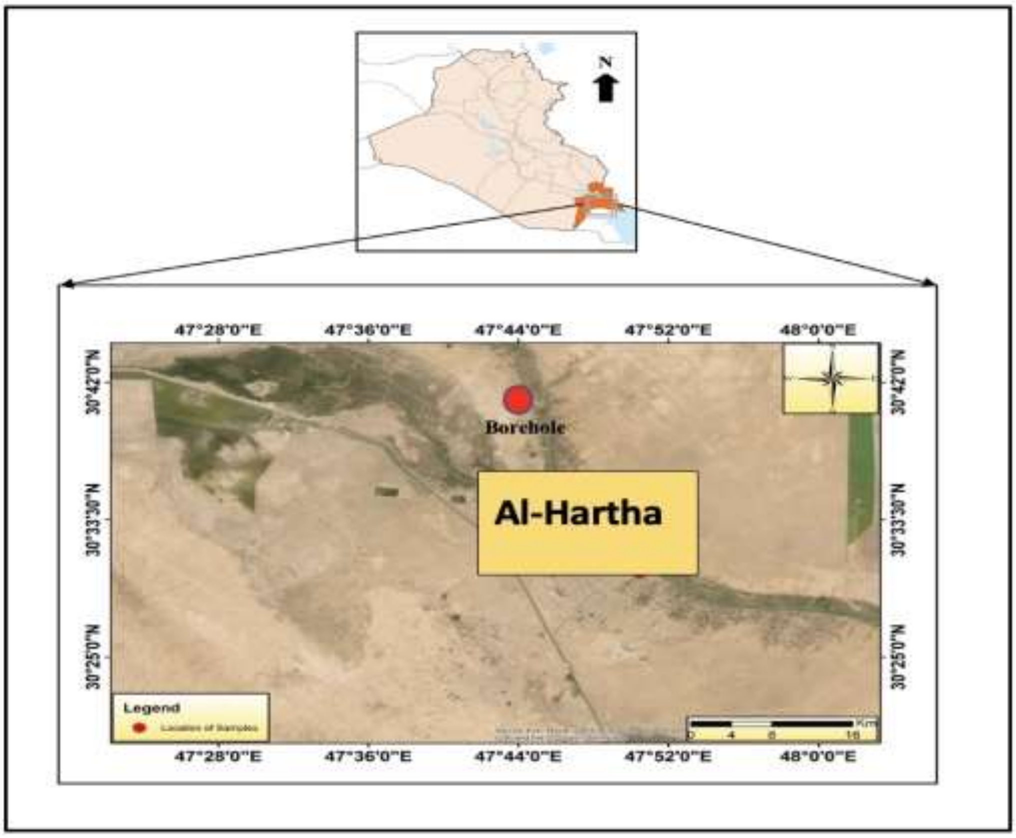

Figure 1: The location of the study area.

1.2 Materials and Methods

Ten soil samples were taken at the location in December 2021 after a borehole was dug down to a depth of 10 meter. Based on (BS1377; 1975) and American Society for Testing and Materials (ASTM) [3] [4]. Mechanical sieve analysis and hydrometer analysis were employed to evaluate the natural water content (mc), liquid limit (LL), plastic limit (PL), and plasticity index (PI). For the samples, mineral analysis (clay and non-clay minerals) was identified using analytical Xpert PRO MDP XRD at University of Basrah/ physics department.

2. Previous Study

[5] investigated the mineralogy and swelling potential of the soil at Thi-Qar University and identified the clay and non-clay minerals and found that the soil's liquid limits and plasticity index, respectively, vary from 38% to 61% and from 13% to 30% and based on the index characteristics and activity, the evaluation of soil expansivity shows a large percentage of the expansive soil.

[6] studied swelling properties for surface soils in selected areas of Al-Faw city-Basra governorate, southern Iraq. The results show that the soils of the study area consist of silty clay and clayey silt. The swelling potential ranges about medium-very high, which is causing negatively affects the stability of the engineering constructions in the city of Al-Faw and causes great damage due to cracks in the walls, roads, and others, which requires treatment before construction

3. Engineering behaviour of Clayey Soils

One of the soil types that have an impact on the development of construction projects is clayey soil. Due to the high plasticity and wide grain surface area of clay soils, which characterize them, these soils require a lot of water to form [7]. Fine-grained materials like silt and clay behave quite differently from cohesionless or non-cohesive soil. Because of the change in water content, which causes change in volume, the presence of clay matter in soil causes changes in its physical and chemical properties, such as consistency and plasticity. Which in turn causes an increase in water pore pressure (expressed by swelling and shrinking) [8].

4. Results

4.1 Mineral Analysis Results

Clay and non-clay minerals are diagnosed by using the X-Ray diffraction method (XRD) to evaluate the sample site. Figure2 depict typical XRD patterns for an Al-Hartha site sample. Table1 show the average of clay mineral content for the third meter in depth of the study site soil.

Table 1: The average of clay mineral content for the third meter in depth of the study site soil.

Treated soil	Percentage of valid clay minerals			
Al-Hartha	Montmorillonite	Montmorillonite-chlorite	Illite	Kaolinite
	33.61%	33.34%	5.38%	9.18%

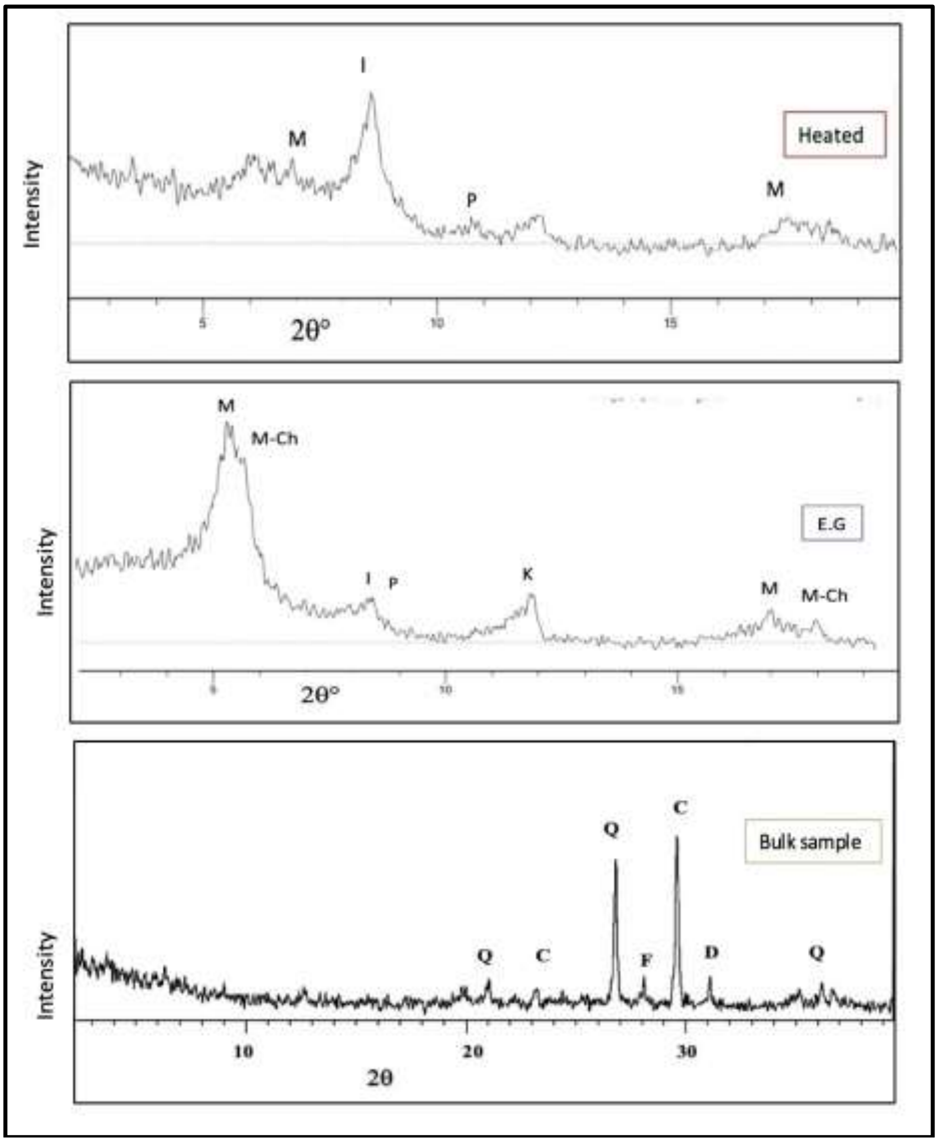

Figure 2: X-ray diffraction for the third meter at Al-Hartha.

4.2 The physical Characteristics of Soil

(Table 2) provides an overview of the study area's grain size analysis. The silt fraction composed between 55-80% of the total, on average 67.5%, followed by clay 9-42%, on average 25.5%, and sand 1-17%, on average 9%. The sample particle size distribution revealed a high percentage of fine soil and a small proportion of other particle types, including sand. Hence, these findings demonstrated that 90% of the samples at the study location are lean clay (CL), and 10% are elastic silt (MH) as shown in Table 2.

The liquid limits (LL) of the soil range between 33-44%, with an average value of 38.5% (Table 3). The proportion of various clay minerals may have an impact on whether the liquid limit and plasticity index are high or low [9]. According to [10] computation of consistency index (Ic) values for soil area, these values ranged from (31-49.4) to 40.2, on average, at the research location [10] (Table 3).

Table 2: Ratios of the soil elements for various samples were taken from the study location.

Site	Depth (m)	Partiale Size Distribution (%)		
		Clay	Silt	Sand
Al-Hartha	1	37	56	7
	2	42	55	3
	3	41	57	2
	4	37	62	1
	5	38	61	1
	6	35	65	0
	7	9	74	17
	8	14	80	6
	9	35	65	0
	10	33	66	1

Table 3. Characterization of the soils at Al-Hartha according to USCS.

Site	Depth (m)	Atterberg Limits %			M.C	Consistency index I_c =(LL-mc/PI)	Soil class	Soil description
		LL	PL	PI				
Al-Hartha	1	38	27	11	23	35.90	CL	Stiff lean clay
	2	51	35	16	25	49.4	MH	Medium stiff brown elastic silt
	3	44	30	14	26	31	CL	Medium stiff brown lean clay
	4	33	20	13	27	42.1	CL	Soft gray lean clay
	5	40	26	14	27	38.2	CL	Soft gray lean clay
	6	37	26	11	25	34.7	CL	Soft gray lean clay
	7	36	18	18	26	34.5	CL	Soft gray lean clay with sand

The plastic limit (PL) values at the study location range from 13% to 35%, with an average of 24%. The soil's plasticity index (PI) values range from 10% to 26%, with an average of 18%. Table3. According to [11] classification the soil in the research area was divided into classes based on its average 42% liquid limit Table 4.

Table 4: Classification of the fine-grained soils in the study area depended on [11].

Site	Depth (m)	Liquid limits		Plasticity index	
		Percent	Description	Percent	Description
Al-Hartha	1	38	Intermediate liquid	11	Low plastic
	2	51	High liquid	16	Moderately plastic
	3	44	Intermediate liquid	14	Moderately plastic
	4	33	Low liquid	13	Low plastic
	5	40	Intermediate liquid	14	Moderately plastic
	6	37	Low liquid	11	Moderately plastic
	7	36	Low liquid	18	Moderately plastic
	8	35	Low liquid	11	Low plastic
	9	38	Low liquid	25	Plastic
	10	42	Intermediate liquid	10	Low plastic

This means that 10% of samples have high liquid limits, 40% have intermediate liquid limits, and 50% have low liquid limits. On the other hand, the research area's soils were categorized based on the plasticity index [11] classification. Therefore, there are no plastic samples at the study site. While 10% of samples include plastic, 40% and 50% of the samples have moderately plastic (Table 4).

The soil type in Al-Hartha is primarily lean clay with low plasticity of CL-group 90% and high plasticity silt of MH-group 10%, as shown in (Table 3). Figure 3 provides a good overview of the plasticity properties of the study area.

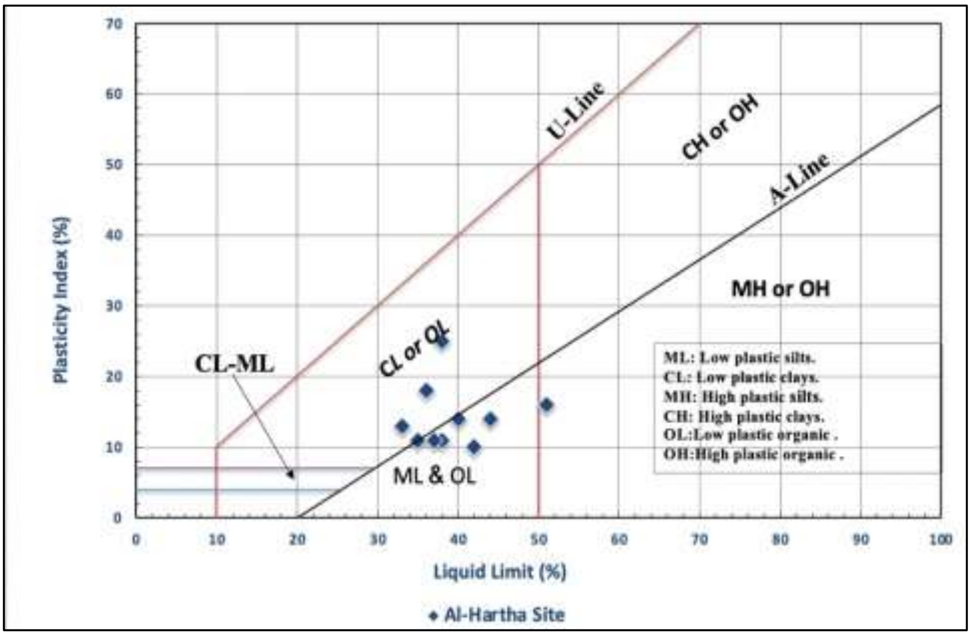

Figure 3 : Plasticity chart for the soil of Al-Hartha site.

4.3 Swelling Potential and Expansion

The maximum volume expansion a clay can undergo because of swelling in its natural environment is referred to as "swelling potential. The assessment of soil expansion is based on variables like activity, clay content and kinds, liquid limit, and plasticity index [12].

Eq. (1) is used to calculate soil activity [13]. The area under study's soil activity is categorized using [14] classification. As a result, the soil activity at the research site ranges from 0.297 to 0.785, with an average of 0.541, indicating inactive to normally active clay. (Table 5 and Fig- 5) [15].

Activity=PI/ Clay (less than 2 micron) %...... (1) [9]

Since PI = Plasticity index

$$S = K.ACT^{2.44}.C^{3.44} \text{ .... (2) [13]}$$

Since:
S = Swelling potential,
K = Constant $\approx 3.6 * 10^{-5}$
ACT = Activity
C = Clay content.

$$S = 3.75 * 10^{-4} * LL^{2.658} \text{ .... (3) [13]}$$

Since:
S = Swelling potential, LL =Liquid limit

According [14] classification, the soil activity in the study region is divided into three categories. As a result, the soil activity at the research location ranges from non-active to normally active clay (0.297 to 0.785), with an average of 0.541.

Fig 4 and (Table 5) The clay concentration and activity of the soil affect its ability to swell [15] Depending on the activity method, the swell potential values for the study area range from 0.175-3.245, with an average of 1.71 (Table 5).

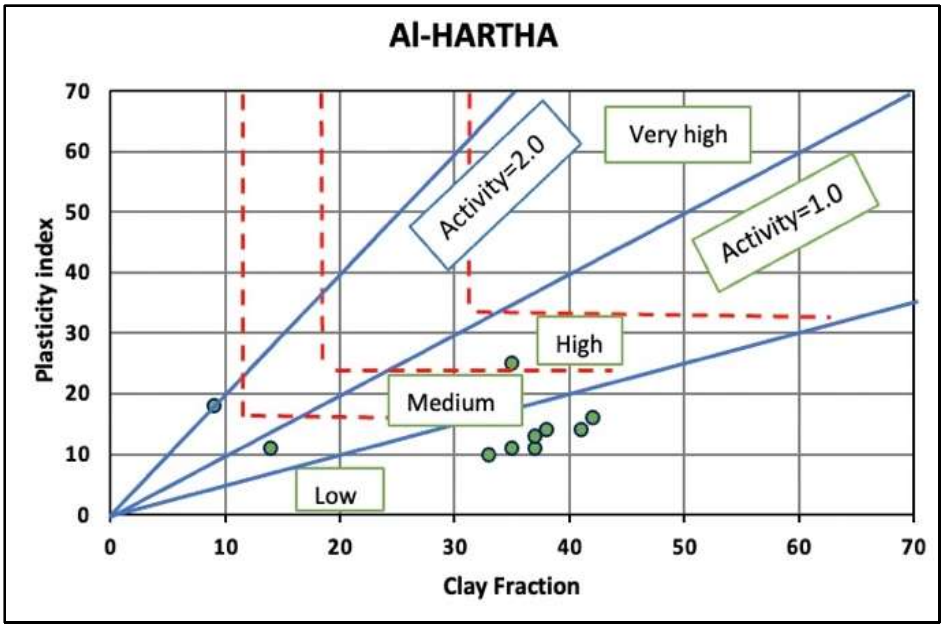

Figure 4: Activity values of samples of Al-Hartha site on activity chart [14].

Table 5: Activity, swelling and expansion degree for soil samples in the site of study.

Site	Depth (m)	Activity		Swelling potential and degree of expansion according to activity method	
				Swelling potential	Degree of expansion
Al-Hartha	1	0.297	Inactive	2.30	Medium
	2	0.380	Inactive	6.51	High
	3	0.341	Inactive	4.60	Medium
	4	0.351	Inactive	3.47	Medium
	5	0.368	Inactive	4.26	Medium
	6	0.314	Inactive	2.18	Medium
	7	2	Active	1.87	Medium
	8	0.785	Normally active	0.87	low
	9	0.714	Inactive	16.21	High
	10	0.303	Inactive	1.63	Medium

As shown by the results obtained from the investigated soils, 70% of samples have medium expansion degree, 20% of samples have high expansion degree and the remaining 10% have low expansion degree, according to the results of swelling potentials. Given that, swelling is influenced by the distribution of grain sizes and the quantity of clay in the soil [15].Thus, the decline in clay content may be responsible for the decrease in swelling potential value and, consequently, the degree of expansion (Table 2).

4.4 Influence of plasticity index and liquid limit on expansion

According to BIS1498 [16], a single parameter can be used to determine the expansion of soil based on the liquid limit or plasticity index Table 6. Thus, the studied area has a low-medium-high expansion (Tables 7 and Table 8). Hence, in the study area, 80% of samples have a medium expansion degree, with the remaining samples having a low and high expansion degree (10% for each one).

According to Chen (1975) [17], the investigated area possesses a low-medium plasticity index and medium-high expansion based on liquid limit Fig 7 and Fig 8. Thus, 60% of samples have a medium expansion degree and the remaining high expansion degree and 70% of samples have a medium expansion degree and the remaining low and high (10% for each one) based on plasticity index.

As stated in Eq. 3 by Seed et al. (1962) [13], the relationship between the soil's liquid limits and swelling potential has been used to calculate the soil's rate of expansion. As a result, 70% of samples, (all samples except S4, S7, and S8) have a significant expansion degree and the remaining samples have a medium expansion degree (Table 7).

Table 6: Prediction of soil expansion by plasticity index and liquid limit.

Expansion	**LL**		**PI**	
	BIS (1970)	**Chen (1975)**	**BIS (1970)**	**Chen (1975)**
Low	20-35	<30	<12	0-15
Medium	35-50	30-40	12-23	10-20
High	50-70	40-60	23-32	20-35
Very High	70-90	>60	>32	>35

Table 7: Estimation of soil expansion using the liquid limit.

Site	**Depth (m)**	**LL**	**Degree of expansion according to**			
			Seed et al. (1962)		**BIS 1498 (1970)**	**Chen (1975)**
			Swelling%	**Expansion degree**		
Al-Hartha	1	38	5.535	High	Medium	Medium
	2	51	12.1	High	High	High
	3	44	8.172	High	Medium	High
	4	33	3.804	Medium	Low	Medium
	5	40	6.343	High	Medium	High
	6	37	5.156	High	Medium	Medium
	7	36	4.794	Medium	Medium	Medium
	8	35	4.448	Medium	Medium	Medium
	9	38	5.535	High	Medium	Medium
	10	42	7.222	High	Medium	High

Table 8: Estimation of soil expansion using the plasticity index.

Site	Depth (m)	PI	Expansion according to	
			BIS 1498 (1970)	Chen (1975)
Al-Hartha	1	11	Low	Low-Medium
	2	16	Medium	Medium
	3	14	Medium	Low-Medium
	4	13	Medium	Low-Medium
	5	14	Medium	Low-Medium
	6	11	Low	Low-Medium
	7	18	Medium	Medium
	8	11	Low	Low-Medium
	9	25	High	Medium-High
	10	10	Low	Low-Medium

4.5 The impact of clay minerals on expansion

To assess an activity of soil for swelling potential, the types of clay minerals present in the soil were identified using an X-ray diffraction device. Most experts tend to concur that the type and quantity of clay minerals have an impact on soil expansion. Likewise, they tend to concur that clay minerals are primarily responsible for changes in soil volume [18].

Montmorillonite predominates among the three clay minerals present in the research area, followed by mixed layers of montmorillonite-chlorite, illite, and kaolinite (non-expansive clay minerals).

The type and nature of the clay mineral present in the samples affect its physical properties, due to the large presence of the clay mineral montmorillonite in the samples as indicated by the results of mineral analysis, which contributed to increasing the amount of water required to reach the liquidity limit in the sample due to the nature and structure of the mineral, as the basal spacing increases from 10Å to 20Å when adding water and thus increases in size and suffers swelling. As for other clay minerals, they are less affected by volumetric changes compared to montmorillonite [19].

Kaolinite and illite are the least active clays, while active clays have the greatest potential for swelling. The most active mineral, montmorillonite, can expand by allowing water molecules to enter its space lattice directly [20]. The least active clays are kaolinite and illite, whereas active clays have the greatest potential for swelling. As the most active mineral, montmorillonite, allows water molecules to enter its space lattice directly, so it can swell [21].

The soil of Basrah is clayey silt and silty clay textures with small amounts of sand. As the soft soil texture, helped to retain water for a long time under conditions of high evaporation and thus helped the emergence of saline soils, especially in low areas, and is characterized by the presence of a wide range of minerals non-clay, clay minerals [22]

5. Conclusions

From the discussions before, it is clear that:

- According to [11], liquid limit classification, the investigated area's soils have low-intermediate plasticity.
- Depending on the plasticity index categorized by [11], the research area's soils are low plastic (4 samples), moderate plastic (5 samples), and plastic (1 sample).
- According to the consistency index data, the soils are plastic.
- Values of activity show that the soils of Al-Hartha site are primarily (80%) inactive, with 10% being typically active and active.
- A significant fraction of the soil is expansive, according to the characteristics based on liquid limit, plasticity index, and activity.
- The results of evaluating soil expansivity based on index properties are different.
- A clay mineral content of Al-Hartha site is composed of montmorillonite, illite, and kaolinite, respectively.
- Clay minerals are composed mainly of montmorillonite (22.31%), followed by illite (5.38%) and kaolinite (9.18%).
- Calcite, quartz, feldspar, and dolomite represent the non-clay minerals in the study site.

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