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CHEMICAL PROPERTIES OF CLAY SOIL IN DIWANIYAH, IRAQ, AND THEIR ENGINEERING IMPLICATIONS

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SUMMARY

Characterizing clay soils in Diwaniyah, Iraq, is important because differences in mineralogy, salt content, and chemical composition can significantly affect the swelling tendency, strength, compressibility, and overall performance of foundation and subgrade soils for pavements. In this context, this research focuses on the study of chemical properties of the local clay soils along with physical and mineralogical properties. 16 samples of clay soils were collected from four sites (S1-S4) within a depth range of 0-2.0 m. The laboratory tests that were conducted included particle size distribution, Atterberg limits, pH, electrical conductivity, sulfate, chloride, calcium carbonate, organic matter content, soluble salts, major oxides, mineralogical composition, compaction, unconfined compressive strength (UCS), cohesion, friction angle, California Bearing Ratio (CBR), free swell ratio, and compression index. Soil compositions revealed a mean clay percentage of 59.32% and plasticity index of 28.15%, implying moderate-to-highly plastic behavior of soils. Mean pH and conductivity were 7.86 and 6.10 dS/m, respectively, but the high concentration of soluble salts varied chemically. The dominant mineral was quartz at 27.75%, and montmorillonite averaged 18.50%. Results from engineering tests showed a mean value of 179.50 kPa UCS, 5.60% CBR, 43.25% free swell, and 0.32 compression index. Soil composition S3 performed best in terms of engineering performance while S2 exhibited higher salinity and swelling potential along with inferior strength properties. From the above discussion, it is clear that soil chemistry and mineralogy are interrelated with engineering properties of soils, which could be applied in foundation design, paving construction, drainage, and stabilization of soils in Diwaniyah.

Key words: *clay soil, diwaniyah, soil chemistry, mineralogical composition, plasticity, swelling behavior, geotechnical properties.*

INTRODUCTION

It is essential to consider the geotechnical challenges associated with clay soils in Diwaniyah as their swelling capacity may have significant impacts on the stability and performance of foundations and other engineering structures [1]. Furthermore, the physical and chemical properties of soils in Al-Qadisiyyah and neighboring regions demonstrate that mineral composition and salinity directly impact the suitability of local clays for engineering applications [2]. Combined geotechnical and geophysical investigation of soil layers in Iraq indicates the significance of studying the subsurface features before choosing the foundation system and assessing the performance of the selected site [3]. The recent geotechnical studies in Iraq also emphasize the close correlation between changes in the chemical features of soils and physical parameters that should be taken into account while considering the engineering properties of soils [4]. The mineralogical investigation of soils in the Middle Euphrates region proves that the light and heavy mineral composition and weathering features have an impact on the soil behavior and stability [5]. The evaluation of the ground soils in various locations in Iraq proves the existence of substantial spatial variation in the geotechnical features of soils [6]. In addition, the assessment of the soils suggested for the residential construction proves that the engineering suitability of soils is highly dependent on the strength and consistency parameters and local geological environment [7]. Studies of the soils of Iraq with different mineral and textural composition prove the great influence of the particles' features and the material composition on the geotechnical performance of soils [8]. The investigations of soils carried out in southern Iraq also reveal the spatial variation of the soil properties which confirms the necessity of detailed testing of soils before the construction of foundations and infrastructures [9]. The correlation-based evaluation of soil features in central Iraq also proves the possibility of using the relationships among index, physical, and engineering parameters for more reliable prediction of soil behavior [10]. These findings prove the necessity of detailed assessment of the chemical properties of clay soil in Diwaniyah.

Key Contribution

- Provides an integrated study of the physical, chemical, mineralogical, and engineering characteristics of clay soils that have been collected from four sites in Diwaniyah, Iraq.
- Discusses important chemical parameters such as pH, EC, SO₄, CL, CaCO₃, OM, and soluble salts and how these can affect the behavior of soils.
- Illustrates the effect of the chemistry of soils and their mineralogy on the plasticity, swellability, compactibility, strength, and compressibility of clay soils.
- Offers guidelines for engineering applications of soils in the region of Diwaniyah.

The remainder of this paper is structured as follows. Section II reviews existing literature on clay mineralogy, soil chemistry, swelling properties, geotechnical properties, and stabilization techniques in Iraq and highlights the research gap. Section III is the methodology, which includes the conceptual framework, study location, soil sampling method, physical and chemical properties analysis, oxides and mineralogical composition analysis, engineering tests, and statistical methods. Section IV discusses the results of the physical classification of the clay soil, its chemical properties, major oxide composition, mineralogical properties, spatial variation of chemical properties, and engineering behavior of the clay soil. Section V gives the engineering implications of the results, focusing on the impact of the soil chemical properties on plasticity and behavior of foundation, pavements, and earthworks constructions. Section VI explained main key summary of research.

RELATED STUDIES

Previous research on Iraqi expansive soils has established that swelling potential is highly related to mineral composition in terms of quantity and proportion of active clay minerals, which influence moisture sensitivity and volume change [11]. Swelling pressure, expansion potential, and Atterberg limits have been used in investigations on expansive soils, showing strong relationships among the variables; hence, the consistency variables have been established as important predictors of clay problems [12]. In geotechnical and geochemical studies of soils from central Iraq, the combination of

chemical composition, soil texture, and engineering properties has been recognized as important factors in determining soil site suitability and stability [13]. The geochemical study of kaolinite clay deposits of western Iraq has established the importance of mineral composition and major elements in studying the genesis, variability, and engineering behavior of clay soils [14]. Studies on heavy and light minerals in soils of Iraq have established the difference in mineral assemblages from region to region, suggesting that parent rock material, weathering, and deposition play an important role in defining soil mineral differences [15]. Experimental studies on expansive soils have demonstrated that modifying soil mineral composition through feldspar additives can improve geotechnical properties and mitigate volume-change issues in highly expansive clays [16].

In other stabilization research, it has been found that the addition of sand glass powder to clay soil may result in improvement of some engineering properties of the clay soil, stressing the usefulness of minerals as soil stabilizers [17]. GIS-based analysis of soil composition and geochemical properties also showed how useful the spatial analysis techniques are in detecting the differences in soil properties within different regions of Iraq [18]. The studies carried out in Al-Diwaniyah area indicated that there are differences in the composition of water in terms of the dissolved chemicals in it, which may be helpful in understanding the interaction of the soil and water, as well as the chemical environment around soil near surface areas [19]. The preconstruction studies using electrical resistivity and geotechnical testing methods also stressed the importance of integrated site characterization techniques to detect subsurface variability and make reliable engineering decisions [20]. Distributed sensing and intelligent environmental monitoring systems are another approach that provides a new methodological approach to observe and manage environmental conditions; however, they do not focus on the geochemistry of clay soils [21].

Research Gap

Some investigations have already been conducted in the literature in relation to swelling potential, Atterberg limit, mineralogy, geochemistry, spatial variation, geotechnical parameters, and stabilization of expansive soils in various regions in Iraq. Nevertheless, there are few studies available that have analyzed the above aspects related to the specific clay soils from Diwaniyah while correlating the above-mentioned geochemical aspects such as pH, conductivity, sulfate, chloride, calcium carbonate, organic matter, and soluble salts with the mineralogy and geotechnical parameters such as plasticity, swelling, compaction, strength, and compressibility. Most of the existing studies in the past mainly concentrate on either the geochemical or geotechnical aspects in isolation, while very few studies are related to spatial variations in geochemistry and its impacts on the suitability of soil for foundations and pavement subgrades in Diwaniyah.

MATERIALS AND METHODS

Conceptual Framework Linking Clay Soil Chemical Properties to Engineering Implications in Diwaniyah, Iraq

The below diagram figure 1 presents an evident flow from soil investigation to engineering decision-making on clay soil in Diwaniyah, Iraq. It starts with studying the area and taking samples, where representative disturbed and undisturbed clay soil samples are obtained from some chosen locations. Next, these samples subjected to laboratory chemical characterization through analyzing their pH, electrical conductivity, sulfate, chloride, calcium carbonate, organic matter, and soluble salts and cations. Based on these findings, the chemical nature of the soil is considered in the context of its salinity level, alkalinity/acidity, sulfate aggressiveness, carbonate, and chemical variations. The diagram also suggests that these chemical characteristics directly affect the engineering behavior of clay soil in terms of plasticity, swell-shrink capacity, compaction characteristics, shear strength, compressibility, and durability/corrosion. These factors ultimately affect the soil's engineering significance for foundations, pavement/subgrade performance, earthworks, and the need for soil stabilization/construction recommendations.

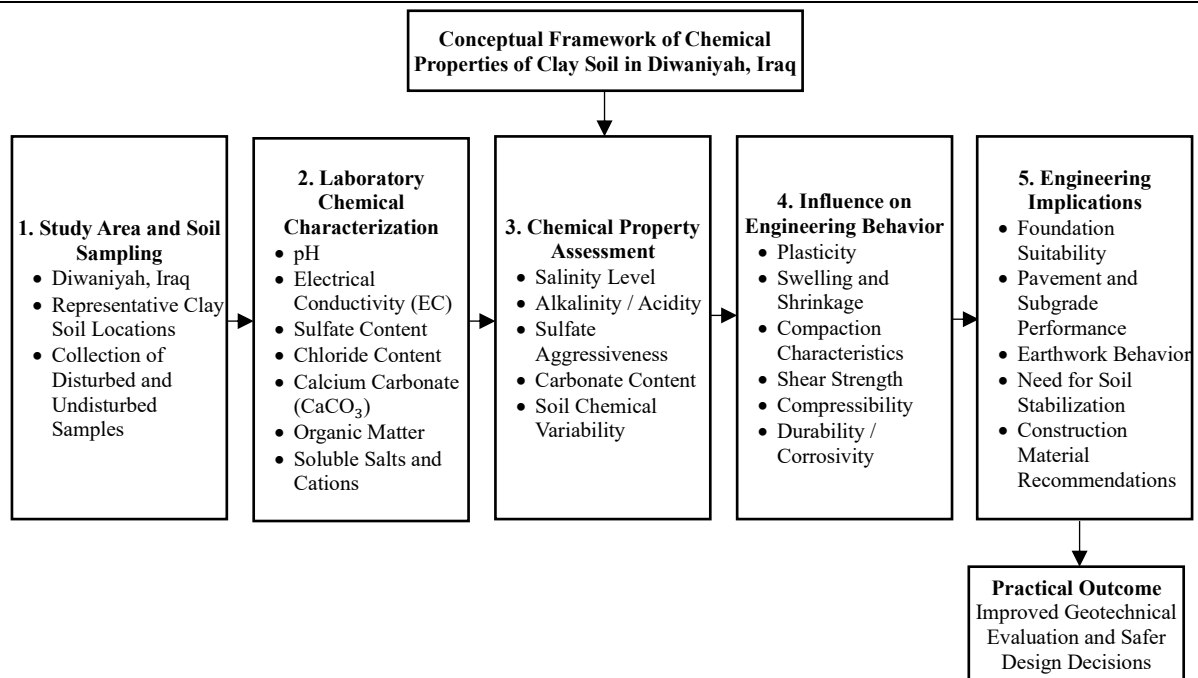


Figure 1. Conceptual framework of chemical properties of clay soil in diwaniyah, iraq

Study Area

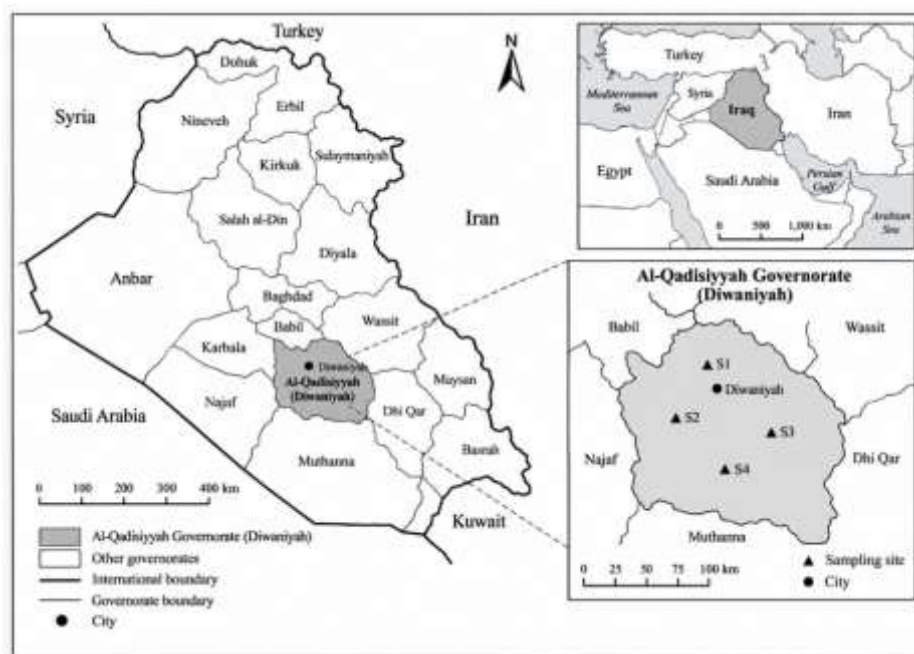


Figure 2. Study area of Al-qadisiyyah governorate (diwaniyah), iraq

Figure 2 shows that the experiment was carried out in Al-Qadisiyyah Governorate (Diwaniyah), which is located in the south-central part of Iraq. Babil, Wasit, Dhi Qar, Muthanna, and Najaf are neighboring governorates in the northern, northeastern, southeastern, southern, and western regions of the governorate, respectively. Diwaniyah city is an urban site of the governorate where this experiment is being conducted. Four sampling sites named as S1, S2, S3, and S4 have been identified for obtaining samples from the clay soil. These four sampling sites were chosen based on the geographical location because these locations would help the researchers find variation in chemical and physical properties of soil. This map also shows the location of Al-Qadisiyyah in relation to Iraq and the wider geographical location of Iraq.

Soil Sampling

In all, a total of 16 samples of clay soils were gathered from four sampling sites (S1, S2, S3, and S4) located in Al-Qadisiyyah Governorate. Four samples were gathered from each site at various depth levels so that the vertical distribution of soil is represented by them. The depth levels at which the samples were gathered ranged from 0 to 0.5 meters, 0.5 to 1 meter, 1 to 1.5 meters, and 1.5 to 2 meters. Thus, S1-1 to S1-4 samples were gathered from Site S1, S2-1 to S2-4 from Site S2, S3-1 to S3-4 from Site S3, and S4-1 to S4-4 from Site S4 in table 1.

Table 1. Sample soil collection

Site	Sample IDs	Depth ranges	No. of samples
S1	S1-1 to S1-4	0–0.5, 0.5–1.0, 1.0–1.5, 1.5–2.0 m	4
S2	S2-1 to S2-4	0–0.5, 0.5–1.0, 1.0–1.5, 1.5–2.0 m	4
S3	S3-1 to S3-4	0–0.5, 0.5–1.0, 1.0–1.5, 1.5–2.0 m	4
S4	S4-1 to S4-4	0–0.5, 0.5–1.0, 1.0–1.5, 1.5–2.0 m	4
Total	S1-1 to S4-4	0–2.0 m	16

Physical Characterization

Physical properties of the collected clay soil samples were analyzed to obtain their basic classification and index values. Physical properties examined in the analysis included moisture content, particle size distribution, specific gravity, liquid limit, plastic limit, and plasticity index. Physical properties were utilized to establish the texture and consistency of the soil as well as the degree of variation in soil samples taken from various sites and depths. The physical characterization formed the basis of analysis of the chemical and engineering properties of the soil.

Chemical Characterization

A chemical test was conducted to establish the major chemical properties of the clay soil samples. Parameters such as pH, electrical conductivity, sulfates, chlorides, calcium carbonates, organic matter, and soluble salts and cations were tested, and these have been classified as the major chemical properties for the purposes of this study. The parameters were used to establish the salinity level, acidity or alkalinity, sulfate aggressiveness, carbonates, and chemical variability of the soil. The findings were then correlated with the engineering behavior of the soil.

Mineralogical/Chemical Composition

The mineral and chemical compositions of the soil samples were analyzed to find out the main components that caused such behavior of the clay soil. The mineral composition analysis helped to establish the main types of clay minerals, while the chemical composition analysis helped to find out the major oxides and elements that composed the soils. The difference in mineral and chemical compositions of the samples was taken into consideration to explain the differences in plasticity, swelling capacity, strength, and other soil engineering properties.

Engineering Tests

Tests were conducted on the soil material as engineering tests in order to determine its suitability and performance when used as a construction material. These tests were done on the soil with an emphasis on factors such as plasticity, swelling and shrinking behavior, compaction, shear strength, compressibility, and durability or corrosiveness, all these factors being identified in the research framework as those affected by soil chemistry.

Statistical Analysis

Statistical analysis of the 16 clay soil samples obtained from four sampling sites (S1-S4), each having four depth-based samples, has been carried out to study the spatial variations of physical, chemical,

mineral, and engineering properties of the soil. CV has been utilized to compare the relative variability of parameters with different units of measurement. Pearson correlation analysis has been used to determine possible correlations between various chemical properties of soil including pH, EC, SO₄, Cl, CaCO₃, soluble salts, and engineering properties such as plasticity, UCS, CBR, free swell, and compressibility.

RESULTS

Physical and Classification Properties of the Clay Soil

Table 2. Physical and classification properties of the clay soil

Property	S1	S2	S3	S4	Mean	SD	CV (%)
Sand (%)	9.2	11.0	8.4	10.1	9.68	1.12	11.61
Silt (%)	31.5	32.1	29.8	30.6	31.00	1.01	3.26
Clay (%)	59.3	56.9	61.8	59.3	59.32	2.00	3.37
Natural moisture content (%)	22.8	24.1	25.7	23.6	24.05	1.22	5.09
Specific gravity	2.70	2.68	2.72	2.69	2.70	0.02	0.63
Liquid limit (%)	52.4	49.8	55.6	51.2	52.25	2.47	4.73
Plastic limit (%)	24.1	23.5	25.0	23.8	24.10	0.65	2.69
Plasticity index (%)	28.3	26.3	30.6	27.4	28.15	1.83	6.49

According to table 2, which summarizes the results of physical and classification tests, the soil under consideration is predominantly clay with 59.32% average clay content while silt and sand constitute 31.00% and 9.68%, respectively. Considering the low coefficient of variation of clay (3.37%) and silt (3.26%), one can say that the distribution of the particles is quite even among all four sampling areas. Natural moisture content changes from 22.8% to 25.7%, with an average value of 24.05%, while the specific gravity does not change much, being nearly 2.70 all the time. The liquid limit is from 49.8% to 55.6%, with an average value of 52.25%, and the plastic limit is 24.10%, on average. Hence, the plasticity index fluctuates from 26.3% to 30.6% with average value of 28.15%. Taking into account that location S3 has the highest values of clay content, liquid limit and plasticity index, may state that the soil of this location is more susceptible to moisture.

Chemical Characteristics of Soil Samples

Table 3. Chemical characteristics of soil samples

Chemical property	S1	S2	S3	S4	Mean	SD	CV (%)
pH	7.82	8.05	7.68	7.91	7.86	0.16	1.98
EC (dS/m)	5.80	7.20	4.90	6.50	6.10	0.98	16.12
Sulfate (mg/kg)	1850	2260	1620	2070	1950	276.53	14.18
Chloride (mg/kg)	940	1180	810	1060	997.50	158.82	15.92
CaCO ₃ (%)	18.6	21.4	16.8	19.7	19.12	1.93	10.10
Organic matter (%)	1.35	1.18	1.52	1.29	1.34	0.14	10.64
Soluble salts (%)	0.42	0.53	0.36	0.48	0.45	0.07	16.46

The chemical properties of the soil samples are presented in table 3. It shows that the soils have a slightly alkaline reaction, since the pH values vary from 7.68 to 8.05 and have a mean value equal to 7.86. Conductivity varies from 4.90 to 7.20 dS/m with a mean of 6.10 dS/m, which means there are some variations in the salt concentration at the sampling sites. The concentration of sulfates is equal to 1620 to 2260 mg/kg, while the concentration of chlorides is within the range of 810 to 1180 mg/kg, with respective means of 1950 mg/kg and 997.50 mg/kg. The average concentration of CaCO₃ is 19.12%, while organic matter is not high (the mean is 1.34%). The concentration of soluble salts is from 0.36% to 0.53% with a mean of 0.45%. As for the greatest spatial variability among all parameters considered, it concerns soluble salts, EC and chloride, their CVs being 16.46%, 16.12% and 15.92%, respectively, while pH is the most uniform parameter (CV is 1.98%).

Major Oxide Composition

Table 4. Major oxide composition

Major oxide (%)	S1	S2	S3	S4	Mean	SD	CV (%)
SiO ₂	52.8	50.9	54.2	51.7	52.40	1.43	2.73
Al ₂ O ₃	18.6	19.1	18.2	18.9	18.70	0.39	2.09
Fe ₂ O ₃	6.4	6.8	6.1	6.6	6.48	0.30	4.61
CaO	7.9	9.1	6.8	8.4	8.05	0.97	12.02
MgO	3.1	3.4	2.9	3.2	3.15	0.21	6.61
K ₂ O	2.4	2.5	2.3	2.4	2.40	0.08	3.40
Na ₂ O	1.6	1.8	1.5	1.7	1.65	0.13	7.82
Loss on ignition	7.2	6.4	8.0	7.1	7.18	0.66	9.13

Table 4 provides the description of the major oxide composition where it can be noted that SiO₂ is the main component which varies from 50.9% to 54.2% and has the mean value of 52.40% followed by the second largest component which is Al₂O₃ with the mean value of 18.70%. SiO₂ and Al₂O₃ constitute the main silicate and aluminosilicate fraction of the clay soil. Fe₂O₃ appears in the moderate amount with the mean of 6.48%, and CaO is the third largest major oxide with the mean of 8.05%. CaO is the most variable oxide among the major oxides with the coefficient of variation equal to 12.02%. MgO, K₂O, and Na₂O appear in the smaller amounts, and have the mean values of 3.15%, 2.40%, and 1.65%, respectively. Loss on ignition varies from 6.4% to 8.0% with the mean of 7.18%. The low coefficients of variation of SiO₂, Al₂O₃, Fe₂O₃, and K₂O point to the rather uniform mineral chemical composition in the four sampling sites.

Mineralogical Characteristics

Table 5. Mineralogical characteristics

Mineral (%)	S1	S2	S3	S4	Mean	SD	CV (%)
Quartz	28	26	30	27	27.75	1.71	6.15
Illite	22	23	20	22	21.75	1.26	5.79
Montmorillonite	18	16	21	19	18.50	2.08	11.25
Kaolinite	13	14	12	13	13.00	0.82	6.28
Calcite	12	14	10	13	12.25	1.71	13.94
Feldspar	7	7	7	6	6.75	0.50	7.41

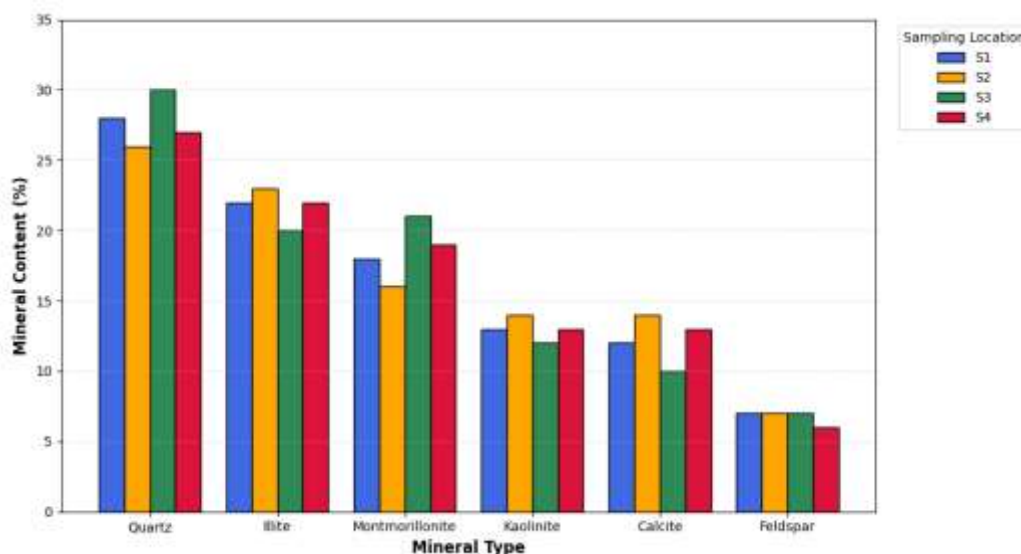


Figure 3: Mineralogical characteristics of clay soil

Table 5 and figure 3 show that the mineralogical properties indicate quartz to be the primary mineral, having a composition of between 26% and 30%, with a mean value of 27.75%, followed by illite with a

mean value of 21.75%. There is also montmorillonite mineral, whose content ranges at 18.50% on average, and it is highly variable mineral, having a coefficient of variation of 11.25%. The highest percentage composition of this mineral is recorded at S3, and this could be responsible for the plasticity and moisture sensitivity recorded at this point. The kaolinite mineral is uniformly distributed at all the sampling sites, with a mean value of 13.00%. The mean value for calcite is 12.25%, and it is the most variable mineral, with the coefficient of variation being 13.94%. The feldspar mineral is the least abundant, with a mean value of 6.75%.

Variation of Chemical Properties Among Sampling Locations

Table 6. Variation of chemical properties among sampling locations

Parameter	Minimum Location/Value	Maximum Location/Value	Range	CV (%)	Spatial Variation
pH	S3 / 7.68	S2 / 8.05	0.37	1.98	Low
EC (dS/m)	S3 / 4.90	S2 / 7.20	2.30	16.12	Moderate
Sulfate (mg/kg)	S3 / 1620	S2 / 2260	640	14.18	Moderate
Chloride (mg/kg)	S3 / 810	S2 / 1180	370	15.92	Moderate
CaCO ₃ (%)	S3 / 16.8	S2 / 21.4	4.6	10.10	Moderate
Organic matter (%)	S2 / 1.18	S3 / 1.52	0.34	10.64	Moderate
Soluble salts (%)	S3 / 0.36	S2 / 0.53	0.17	16.46	Moderate

The spatial variation in chemical properties as seen in table 6 is as follows: pH is the least variable chemical property with its variation between 7.68 at S3 and 8.05 at S2 with a coefficient of variation of 1.98%, indicating low spatial variation. On the other hand, EC, sulfate, chloride, CaCO₃, organic matter, and soluble salts have relatively high spatial variations. The electrical conductivity varies between 4.90 and 7.20 dS/m, while the sulfate and chloride content varies between 1620 and 2260 mg/kg and 810 to 1180 mg/kg, respectively. Soluble salts have the highest variability with coefficient of variation of 16.46%, followed by EC of 16.12% and chloride at 15.92%. Most of the salt related chemical properties have their maximum values at S2 and minimum values at S3, meaning that S2 has more chemical enrichment or salinity than S3. The organic matter, on the other hand, does not conform to this trend since it has the least value at S2 and the highest value at S3.

Engineering Properties of the Clay Soil

Table 7. Engineering properties of the clay soil

Engineering property	S1	S2	S3	S4	Mean	SD	CV (%)
Maximum dry density (g/cm ³)	1.73	1.69	1.76	1.71	1.72	0.03	1.73
Optimum moisture content (%)	18.2	19.4	17.6	18.8	18.50	0.77	4.19
UCS (kPa)	182	164	198	174	179.50	14.36	8.00
Cohesion (kPa)	52	47	56	50	51.25	3.77	7.37
Friction angle (°)	18.6	17.4	19.2	18.0	18.30	0.77	4.23
CBR (%)	5.8	4.9	6.4	5.3	5.60	0.65	11.57
Free swell (%)	42	48	38	45	43.25	4.27	9.88
Compression index	0.31	0.35	0.28	0.33	0.32	0.03	9.40

The engineering characteristics of the clay soil are listed in table 7 and demonstrate rather small to moderate variations in the studied areas. The maximum dry density varies from 1.69 to 1.76 g/cm³, the mean value is equal to 1.72 g/cm³, and the low coefficient of variation (CV) is 1.73%, meaning the soil compacting ability is uniform. The optimum moisture content is within the range of 17.6% to 19.4% with the mean value being 18.50%. The UCS is highly variable, its values vary from 164 to 198 kPa, and the average value is 179.50 kPa. Cohesion values vary from 47 to 56 kPa, the friction angle varies from 17.4° to 19.2°. The CBR varies from 4.9% to 6.4%; the highest relative variability of the strength-related characteristics is observed in this parameter (the CV is 11.57%). Free swell is within the range of 38% to 48% with the mean value being 43.25%, indicating the soil expansiveness; the compression index is also relatively high, it varies from 0.28 to 0.35. Generally, the most favorable engineering performance is characteristic of the S3 soil area with the maximum dry density, UCS, cohesion, friction angle, and CBR, as well as minimum free swell and compression index. S2

demonstrates rather weak engineering properties due to poor strength and expansiveness and compressibility.

Discussion and Engineering Implications

The findings reveal that the soils in Diwaniyah exhibit relatively uniform physical properties alongside significant spatial variations in chemical, mineralogical, and engineering characteristics. The high average clay content (59.32%) and plasticity index (28.15%) reflect a predominantly moderate-to-high plastic behavior across the sites. Chemically, the soils have slightly alkaline conditions, have some levels of salinity, and also vary in their electrical conductivity, sulfate, chloride, and soluble salts depending on where the soils are sampled from. From mineralogical findings, there are minerals such as quartz, illite, montmorillonite, kaolinite, and calcite; the latter gives moisture sensitivity and swelling behavior. Also, there are varying results from the engineering test done on the soil samples, with S3 having relatively good engineering properties and S2 having higher salinity, swelling, and less strength.

Influence of Soil Chemistry on Plasticity

The chemistry of the soil seems to play a significant role in determining the plasticity and water responsiveness of the tested clay. With the average liquid limit of 52.25% and plasticity index of 28.15%, this clay exhibits fairly high plasticity, but chemical properties like EC, soluble salts, sulfate, chloride, and CaCO_3 are different at the various sites. S3 has the highest percentage of clay content, liquid limit, and plasticity index; likewise, the analysis of mineral content indicates the highest percentage of montmorillonite at this site. This implies that the mineral content, along with the water chemistry of the pores, plays a role in influencing the water adsorption characteristics of the clay. High amounts of salts at site S2 can also play a role in determining the interaction of water and clay, as well as the structure of soil.

Implications of Foundation Performance

From the engineering properties, it is clear that the clay soils have certain restrictions when it comes to constructing foundations due to their moderate strength, higher plasticity, swelling tendency and compressibility. The UCS value is 179.50 kPa, the value of cohesion is 51.25 kPa, and the average value of compression index is 0.32, while the average value of free swell is 43.25%. These values show that the foundations which constructed in untreated clay soils may be subjected to settlements or movements if there is any change in the moisture conditions. The soil sample S2 deserves special consideration as it has the least UCS and cohesion value along with the maximum free swell and compression index value, whereas soil sample S3 has better strength than soil sample S2.

Implications for Pavement and Earthwork Construction

Based on the engineering characteristics evaluated, it is clear that the clay soil has limited natural capacity for subgrade pavements and earthworks in the absence of proper controls. CBR values range between 4.9% and 6.4% with an average of 5.60%, which signifies relatively low subgrade strength, with optimum moisture content and maximum dry density at averages of 18.50% and 1.72 g/cm³, respectively. It is evident that the relatively high plasticity and free swell values imply that the variations in moisture content can lead to expansion, shrinkage, reduction in strength, and deformations of the surfaces. The worst pavement performance among all the soil samples is observed in S2, but the highest CBR and maximum dry density values are recorded in S3.

Soil Improvement and Stabilization Requirements

Taking into account the results of the soil study in relation to its physical, chemical, mineralogical and engineering characteristics, soil stabilization may be required in those areas which have high values of salinity, swelling and compressibility. High value of free swell (43.25%), plasticity index (28.15%) and low value of CBR (5.60%) indicate that the use of untreated clay may not provide sufficient performance in the case of foundation bearing or road subgrade layers. Soil stabilization through the addition of lime

or cement can be recommended to minimize the plasticity and swelling effect of the soil and to increase its strength. In cases when the soils are saline or sulfate-bearing (as in case S2), the choice of chemicals for soil stabilization should consider the chemical compatibility issues as well.

CONCLUSION

Chemical characteristics of clay soils in Diwaniyah, Iraq were studied in this research and effect of changes in chemical compositions and mineralogy on soil behavior was evaluated. Sixteen soil samples were taken from four sites at depth ranging between 0 and 2.0 m. It was found that clay and plasticity indices are 59.32% and 28.15%, respectively, which indicate moderate to high plastic soils. Average pH and EC values are 7.86 and 6.10 dS/m, respectively. Soluble salts, EC and chloride contents have shown the highest spatial variability. Quartz recorded a mean content of 27.75%, while montmorillonite averaged 18.50% with a notable coefficient of variation (11.25%). The engineering test results indicated a UCS of 179.50 kPa, CBR of 5.60%, free swell of 43.25%, and compression index of 0.32. It was observed that S3 performed better than S2, which indicated more salinity and swelling but less strength. This clearly demonstrates that the chemical and mineral differences have a considerable influence on the behavior of the foundation and subgrade. Future research should focus on expanding site characterization by increasing both sampling intensity and investigation depth while assessing seasonal fluctuations in soil-water chemistry. Additionally, long-term field testing and performance evaluations of soil stabilization using lime or cement are recommended.

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