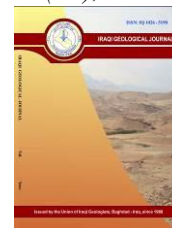




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Evaluation of Soil Characteristics for Engineering Purposes at Selected Locations in Mandli District, Diyala Governorate, Eastern Iraq

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Abstract

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The study area is located in a part of Mandli district. Diyala Governorate, eastern Iraq. It represents an important region within urban growth areas that require detailed engineering designs. Therefore, the research evaluates the engineering characteristics to achieve various engineering purposes with their development. A total of 15 soil samples were collected from distributed locations, in which then Physical, geotechnical, chemical, and mineral analysis tests in the laboratory were achieved. Depend on the rates of sieve analyses the soil samples are classified into three classes as low plasticity clay (CL); low plasticity silt (ML) and a transitional (CL–ML); moreover the hydrometer test and atterberg limits by using the (USCS) were also be revealed. It is indicated a dominance of fine-grained soils controlling engineering behavior. Dry density and water content are shown contrast in most sites in additional; it reflected the moderate compaction, swelling and soil plasticity states in some sites. Direct shear tests showed the cohesion varying from (0 to 16.94) kN/m² while internal friction angle ranges from (11° to 38°). However, the results show that it is related with clay silt and sand content, whereas lower values correspond to higher moisture sensitivity and clay mineral dominance. The Unconfined Compressive Strength test manifested that , the soil sites need for treatments in some sites and others in order to be suitable for settlement and compressively. Chemical analysis indicates moderate to very high for TDS and EC while (pH) values ranged from 6.8 to 7.1. Mineralogical analysis showed the dominance of clay minerals such as illite and chlorite which governs plasticity, compressibility, and reduced shear resistance. Gypsum; chlorides; sulfates and carbonates content from the chemical analysis revealed their variation given as (0.74% to 6.54%); (2.08% to 5.73%);(20.5% to 47.5%) and (0.34 to 3.05%) respectively. Thus, the chemical properties of soils show their influencing on the engineering behaviors with suitability for building and urban growth after soil treatment in most study areas.

Keywords: Evaluation, Soil characteristics, Soil analysis; Mandali Distict;Diyala Govenorate; E-Iraq

1. Introduction

The study region is a portion from Mandali alluvial fan, extending approximately 250 km. It is located within Diyala governorate in eastern Iraq, near the Iraqi-Iranian border. The study area extends between (45°35'19"–45°28'11") eastern longitudes and (33°42'30"–33°47'20") northern latitudes as shown in Fig. 1. The study aims to evolution: physical and mechanical characteristics of Mandali sidements ; mineral components and chemical properties for the deposits ; Advise detection treatment

methods for protecting and stabilizing of soil sites for engineering project development by urban growth and residences construction. (Abed and Azzubaidi, 2020) discussed the characteristics of the soil that is rich in gravel and sand within the Mandali basin and how these characteristics impact on engineering properties. (Hussain, 2023) was shown that sand and gravel deposits have a high level of permeability in the upper part of the Mandali basin. (Al-Sudani, 2025) was revealed that the Mandali basin has thickness may reach 46 m, the permeability or transmission rate of 112 m²/day, a maximum output of (655 m³/day while the flow direction of water is to the south west. This study also shows that the type of water is saline to brackish primarily composed of calcium sulfate with varying levels of salinity, having limited appropriateness for both drinking and farming purposes. (Al-Musawi et al., 2020) on the other hand, concentrated in their study on the engineering evaluation of the geomorphological indicators for the effects of the tectonic movements on the drainage systems and alluvial fans in the Hamrin area near the study one.

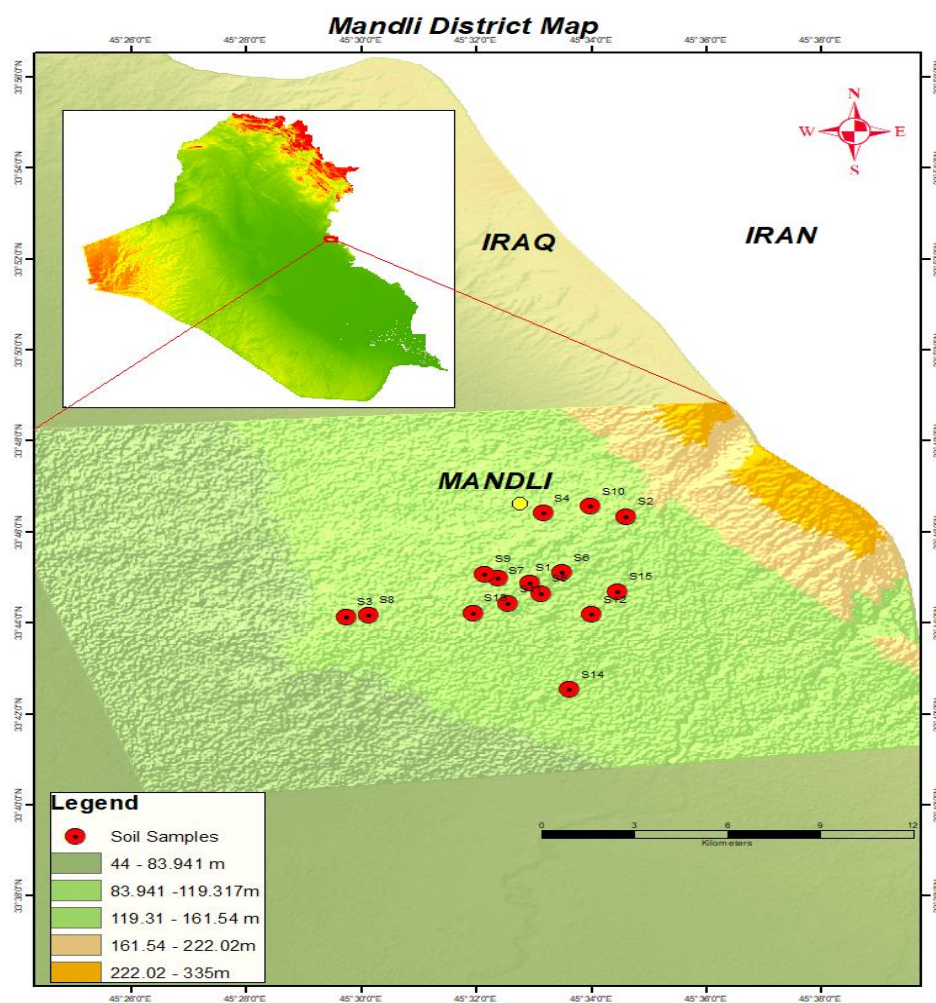


Fig. 1. Location of the soil samples in Mandli alluvial fan deposits (DEM from USGS Site)

2. Geology of the Study Area

The Mandali district in eastern Iraq is an important tectonic change area located between the Foothill Zone and the Mesopotamian Plain.

It is a portion of the Arabian Plate's Unstable Shelf, formed by the kinematic activities of the Zagros fold-thrust belt, which provides its folds a northwest-to-southeast trend (Buday, 1980).

The study area is covered with Quaternary deposits and adjacent area was included Injana, Mukdadiya, and Bai Hassan formations as shown in Fig. 2. The sequence period was extended from

(Pleistocene to Holocene). The Quaternary deposits in the study area are comprised of alluvial fan deposits; slope deposits; floodplain deposits; valley fill deposits and runoff deposits (Jassim and Goff, 2006).

The hydromorphometric characteristics of the Mandli alluvial fan reflect the geological control of groundwater recharge, where increased surface runoff and decreased specific discharge are related with the permeability rate and recharge of the aquifer in the Quaternary deposits. also associated to the mineral composition such as (quartz and carbonate content), which controls permeability and soil engineering properties such as compressibility and stability (Al-Naami,2024).

The geological sources are classified the fans into five sequential tectonic stages agreeing to recent periods of tectonic and morphological elevation of the area (Sissakian and Al-Jiburi, 2012).

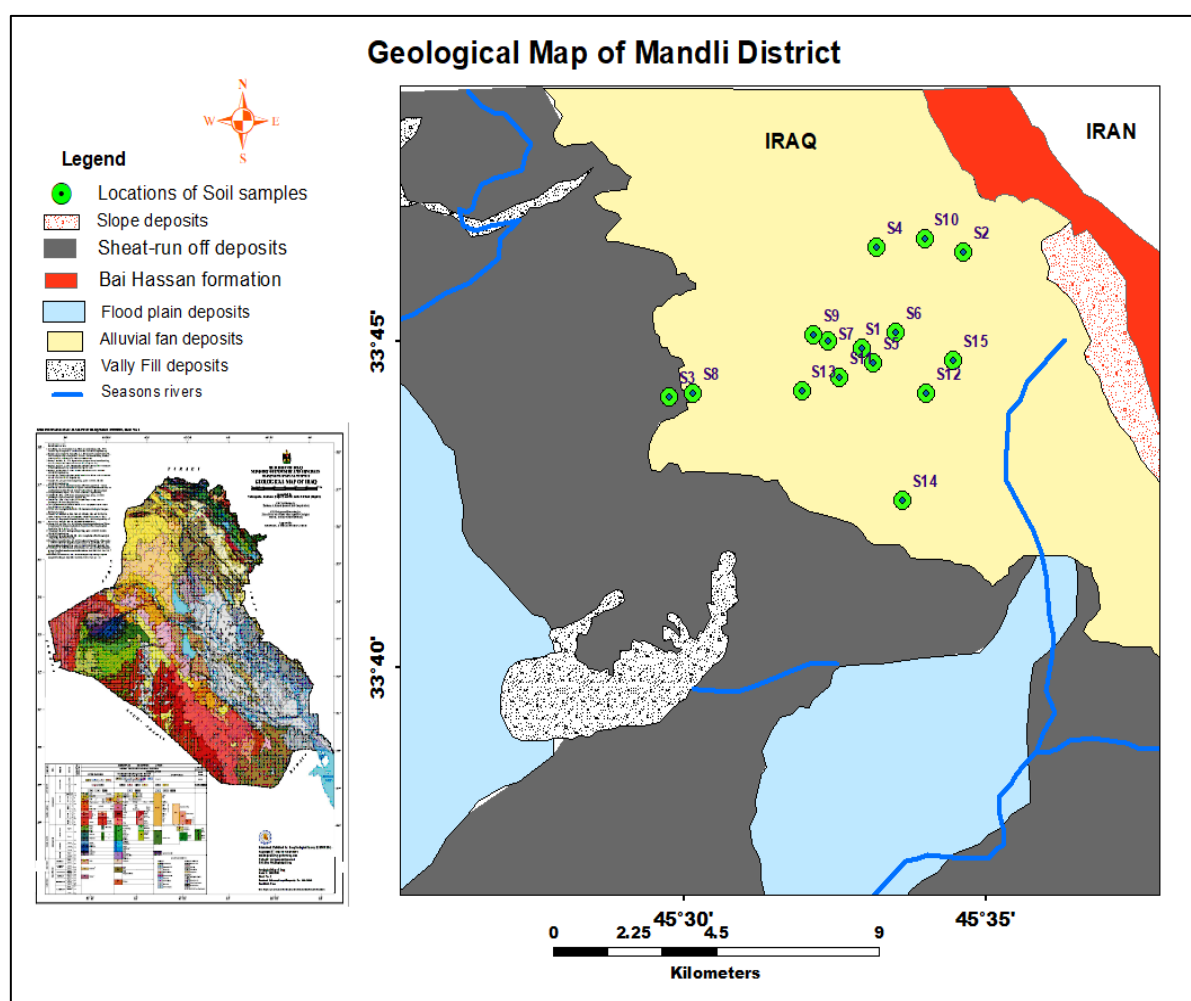


Fig. 2. Geological map of the study area, prepared by the researcher based on the Geological Map of Iraq

3. Methodology and Materials

The fieldwork stages included: collecting maps and references pertinent to the study region; the overall count of locations for evaluating engineering characteristics totaled 15 sites, as shown in Fig. 3 above. Soil samples were collected from different sites across the study area, whereas the laboratory tests of these soil samples are included (Physical tests; Engineering Tests; Chemical analyses and Mineralogical composition).

3.1. Physical Tests include

- Grain Size Analysis: Achieved using sieves for sand and silt, hydrometer analysis for fine particles for describing the soil type and the permeability behavior with the standards of the test according to ASTM D422-63, 2014.
- Atterberg Limits: Showed the use of liquid limit device and plastic limit device to determine their liquid and plastic limits. It describes soil stability and its shrink swell behavior with water content.
- Unified Soil Classification System (USCS): Created on grain size distribution and Atterberg limits using standard classification charts to classify soil type. It helps in selecting suitable design and building methods. (ASTM D 698-2012)
- Dry Density and Water Content: Determined by weighing the sample before and after oven drying to calculate water content and dry density. It indicates compaction level and soil suitability for building. (D845-2010)

3.2. Engineering Tests, Include

- Direct Shear Test: The soil sample is placed in a shear box and subjected to vertical and horizontal forces until failure. It provides cohesion (c) and internal friction angle (ϕ). (ASTM D3080-98, 2000)
- Unconfined Compressive Strength (UCS) Test: A cylindrical soil sample is axially loaded in a testing machine without lateral detention until failure. It determines the strength of cohesive soils and their load-bearing capacity. American standard (ASTM D2166-00, 2003).

3.3. Chemical Tests (British Standard, 1990)

These tests evaluate the chemical composition of the soil and its impact on the construction materials:

Soil Chemical Analysis: By using laboratory devices for measuring EC, TDS, pH, sulfates, chlorides, and Carbonates. It indicates soil violence and their effect on the concrete and building materials.

3.4. Mineralogical Analysis

This test is achieved by using X-ray diffraction (XRD) to identify soil minerals exactly. It explains soil behavior such as swelling, shrinkage, strength, and long-period stability.

4. Results and Discussion

4.1. Physical Tests

Table 2 shows the results of the soil tests in urban expansion area of Mandli district. It showed that the clay ratio is greater than both : silt and sand ratios, where:-

The maximum and minimum rates of clay, silt and sand were (71.2 %, 51.7%), (11.3%, 2.8%) and (43.9 %, 26.8%) in sites (S14, S4); (S15, S14) and (S2, S14), respectively, in which their average was (58.53%); (5.1%) and (36.8%), respectively.

These results are given from the analysis of the grain size and the hydrometer tests that used to classify the soils as given by (USCS). Also, they assist in calculating the engineering properties of the soils, including determining settlement, evaluating the soil's load-bearing capacity, evaluating the permeability and detecting the probability for compression and expansion. In addition, these obtained results create a foundation for the planning of engineering projects, selecting suitable foundation types, evaluating soil quality and its suitability for building purposes.

The maximum and minimum rates of atterberg limits (LL; PL and PI) values were given as (38.02%, 17.76%); (25%, 10%) and (27.68%, 0.4%) respectively at site (S13, S7); (S14, S12) and (S12, S7) respectively. All these sites show that (L L) values were below 50%. Soils with a higher plasticity index (PI) were generally clay, detected at sites (S6, S9, S10 and S13), whereas those with a lower (PI) are naturally silt, noted at sites (S11 and S15). In addition, soils that display plasticity index was (zero) (non-plastic) be expected to show slight with no presence of silt or clay. Urban expansion area deposits in Mandli district are classified by using (USCS) to recognize the Little plasticity when (LL) is greater than 50% or high plasticity if LL is less than 50%.

A- Low plasticity including the following sites: (1, 6, 7, 9, 10 and 13) (CL).

B- Moderate plasticity including the following sites: (3, 4, 11, 12 and 15) (ML)

C-Some sites including the following sites: (2, 5, 8 and 14) were (CL-ML)

The water content of the soil is ranging from the maximum value of (25%) in site S5 to the minimum value of (18.2 %) in the site (S13). In clayey soil when water content increases, it causes swelling and directly affecting the deposits characteristics (Lambe, 1951).

The values of dry density for the study area soil are found to be ranged from the maximum rate as (2.1) g/cm³ in the site (S7) to the minimum rate as (1.4) g/cm³ in the site (S9)

The variations in the results are shown in the study area due to the different sites of the collected samples, which indicate that the soil deposits which present in those locations are influencing the engineering characteristics and behavior of these soils.

Table 1. The results of some physical tests of soil samples in Mandli alluvial

Sample Number	Analyses of grain size and Hydrometer test			Atterberg limit			W.C	System USCS	Specific gravity	Dry Density g/cm3
	Clay %	Silt %	Sand %	LL	PL	PI %				
S1	67.32	4	28.68	25.4	22.22	3.23	21.36	CL	2.63	1.7
S2	52.64	3.4	43.96	29.42	23.33	6.09	21.65	CL-ML	2.63	1.6
S3	55	6	39	32.91	19.44	13.47	23.46	ML	2.63	1.9
S4	51.7	5	43.3	31.08	19.44	11.64	21.95	ML	2.63	1.8
S5	59.05	6	34.95	22.21	18.1	4.12	25	CL-ML	2.63	2
S6	61.64	3.41	34.95	28.17	17.86	10.31	22.25	CL	2.63	1.8
S7	54.77	2.83	42.4	17.71	17.32	0.4	21.36	CL	2.75	2.1
S8	64.16	3.4	32.44	23.23	18.18	5.05	18.48	CL-ML	2.63	1.7
S9	54.49	3.11	42.4	28.95	11	17.95	21.95	CI	2.63	1.4
S10	58.88	5	36.12	25.8	18.18	7.62	21.36	CI	2.63	1.9
S11	53.03	6	40.97	23.72	18.75	4.97	24.38	ML	2.63	1.8
S12	57.7	7	35.3	37.67	10	27.68	19.05	ML	2.63	1.7
S13	55.66	3.34	41	38.02	20	18.02	18.2	CL	2.63	1.8
S14	71.2	2.8	26.8	34.8	25	9.8	22.25	CL-ML	2.63	1.9
S15	54.8	11.3	33.9	29.01	22.22	6.79	20.48	ML	2.63	2
Min	51.7	2.8	26.8	17.71	10	0.4	18.2	-	2.63	1.4
Max	71.2	11.3	43.96	38.02	25	27.68	25	-	2.78	2.1
average	58.53	5.1	36.878	28.4605	18.59	10.31	21.54	-	2.64	1.8

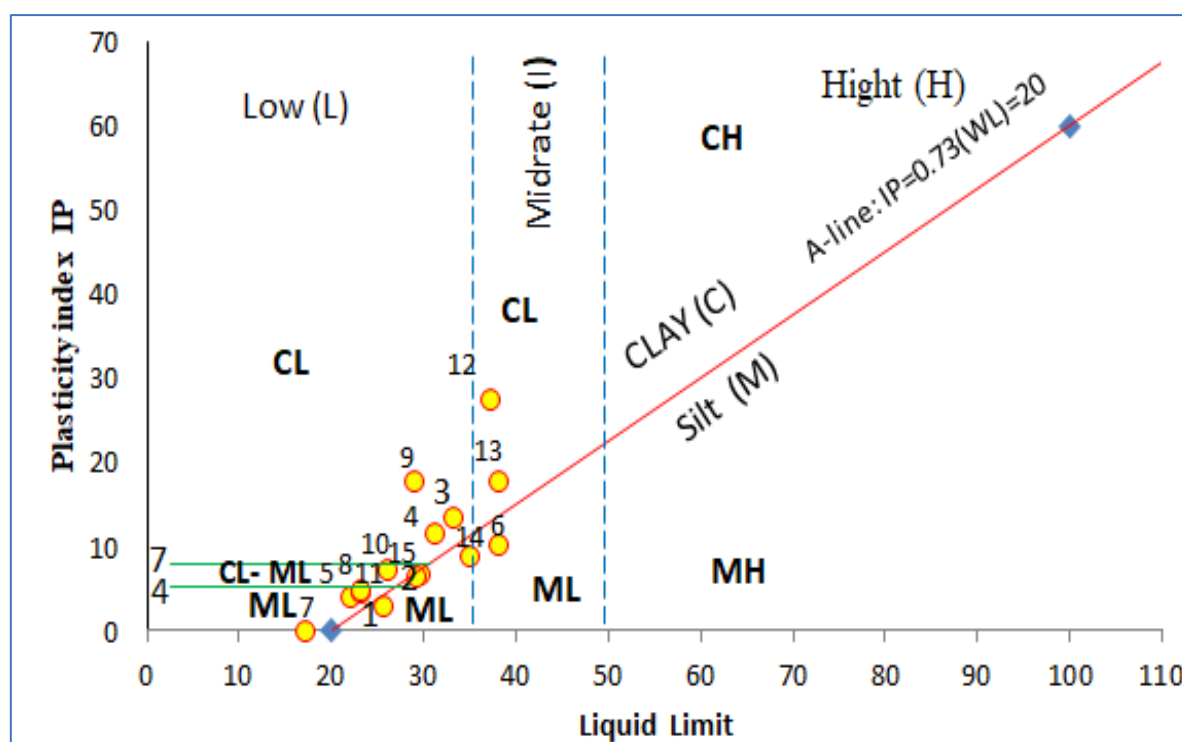


Fig. 3. Plasticity diagram and classification of deposits in the study area

4.2. Engineering properties of soil

4.2.1. Direct shear strength

Direct shear strength test for the undisturbed samples relatively decreased due to remolding development. The sensitivity phenomenon is the ratio between the shear of the undisturbed and disturbed soil (Jumikis, 1962.). The high measurements of (ϕ°) when above (30°) and the increased readings of (ϕ°) resulting from the presence of clay type minerals such as, illite, mica, and chlorite which lead to slipping and decrease in their strength through the shear process. However, the results of the direct shear strength were shown in Table 2. The value of internal friction angle (ϕ°) is ranging from (11° to 38°) in the site (S13 and S15) respectively. Other soil samples (CL), on the other hand, was found to be over the typical limits rates of friction angle and it ranges from the maximum rate from (11° to 34°) in the site (S13 and S10) respectively. Therefore, most of the study deposits are classfid to (CL-ML) and taking rates of (ϕ°) ranging between (14 to 33) in the sites (8 and 2) respectively.. The direct shear values of the soil in the same sites are shown in the Table. 2. The results which derived from the direct shear test, exposed that cohesion (c) values were ranged from (0 to 16.94 kN/m²) at the sites (S10 and S8). Increased cohesion values were detected in their locations striking by a higher concentration of silt and clay, so that showing a marked inverse relationship between particle size and cohesion, where in the presence of finer particles improves antiparticle attachment which then contributes to the soil plasticity.

This variability substantial was influenced the grain size distribution and clay mineral composition on shear resistance, as soils abundant in the clay which were found to reduce frictional resistance due to the orientation and movement of particles. These results are main for geotechnical engineering applications, as cohesion and friction angle in which directly is controller the soil stability, bearing capacity and slope exhibition. Therefore, the detected inconsistency is the best part of the meaning for soil composition in calculating the engineering behavior which then in the planning suitable ground improvement measures where necessary.

4.2.2. Unconfined Compression Test (UCS)

The unconfined compression test (UCS) is a fast and simple method which used for approximation the shear strength of cohesive soils, particularly clay and silt materials. It evaluates the soil's ability to resist axial loading without lateral imprisonment, and therefore reflects the untrained shear strength under field conditions (Table. 2).

The results of the study area for remolded samples at (18.2%) water content showed that the unconfined compressive strength ranged from (8.17 to 52.2 kN/m²) at the site (S4 and S13) respectively. This variation is mainly controlled by the soil composition, structure, and water content, where higher clay content generally increases strength due to cohesion, while higher water content reduced particle connecting and strength.

These results are important in geotechnical engineering because (UCS) values are directly related to the soil bearing capacity and stability of foundations. They also provide a practical display for classifying soil constancy and evaluating suitability for building mechanism in the study area, especially for cohesive soils such as clay and silt mixtures.

Table 2. The results of some physical tests of soil samples in Mandli district

No	Type of samples	Type of soil	UCS kn/m ²	Shear strength parameters	
				Ø (deg)	C (kn/m ²)
Sample (S1)	Disturbed (Remoulded)	CL	-	-	-
Sample (S2)	Disturbed (Remoulded)	CL-ML	-	33	5.26
Sample (S3)	Disturbed (Remoulded)	ML	-	-	-
Sample (S4)	Disturbed (Remoulded)	ML	8.178	32	15.11
Sample (S5)	Disturbed (Remoulded)	CL-ML	-	-	-
Sample (S6)	Disturbed (Remoulded)	CL	-	-	-
Sample (S7)	Disturbed (Remoulded)	CL	-	-	-
Sample (S8)	Disturbed (Remoulded)	CL-ML	31.453	14	16.94
Sample (S9)	Disturbed (Remoulded)	CI	16.919	-	-
Sample (S10)	Disturbed (Remoulded)	CI	46.551	34	0
Sample (S11)	Disturbed (Remoulded)	ML	-	-	-
Sample (S12)	Disturbed (Remoulded)	ML	-	-	-
Sample (S13)	Disturbed (Remoulded)	CL	52.276	11	15.24
Sample (S14)	Disturbed (Remoulded)	CL-ML	-	-	-
Sample (S15)	Disturbed (Remoulded)	ML	9.436	38	8.56
Max			46.551	38	16.94
Mine			8.178	11	0
Average			27.36	24.5	8.47

4.2.3. Chemical properties of soil

The results of chemical test are shown in Table 3, where , pH readings taken from Mandli district deposits is ranging from the rate equal to (6.85 to 7.4) at the sites (S11 and S1). It was indicating a slight decrease in soil alkalinity.

Electrical conductivity (EC) is effected by the heights of dissolved salts and the temperature of the water. (Hem,1989 ; Drever, 1997). The (EC) values of the soil deposits in Mandli district are ranging from (11.5 to 33.22 mhos/cm) in the sites (S5, S2 and S3)

The classification of the salinity as (TDS) for every site levels are found to be varied from moderate to very high salinity (FAO, 1996; Drechsel et al., 2023) due to the influence of gypsum and others rock types. However, low optimal dry density and enhances the water content ratio are decreasing the soil's resistance and the potential for swelling soils gypsum (Al-Zubaydi, 2006). The majority of the secondary gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) is present near the border line of Iraq. Gypsum rate in the studied area ranged from 0.74% to 6.547% at sites S7 and S6, respectively.

The chlorides have a wide extension to damage soil when their rate exceed 0.5%. The presence of chlorides in groundwater is mainly due to the filtering from the sedimentary rock formations that underlie these areas and season rivers flow above (Kazdi,1974). chloride rate was ranging between a max rate which equal to (2.08% to 5.73%) at the sites (S12 and S1) respectively.

High rates of sulphate which existing in the study area was found to be ranged from (0.044 to 3.05%), detected at sites S7 and S6. The increased amount of sulfate suggests a probable variation in the soil's engineering properties, especially when mixed with cement. Sulfates can interact with concrete or soils treated with cement, resulting in the creation of wide mixes similar to ettringite. This reaction may cause the soil to be expanded and crack, so that impacting the strength of the soil and stability of structure developments.

The soil in the study area contains calcium carbonate (CaCO_3) due to deposits from the water and rocks, which occurs as limestone and dolomite rocks undergo weathering, marked through different geological layers along line border between Iraqi and Iranian (Al-Rawi, 1981; Drever, 1997). The carbonate levels (CaCO_3) which have values ranging from (20.5% to 47.5%) were exist in the site (S8 and S6) respectively. The cohesion of the soil contrasts which found is not constant, leading to the changeability of the soil properties over a long time. Also, soils with significant carbonate content may be prone to failure upon exposure to water due to the dissolution of carbonates, possibly causing sudden subsidence and a reduction in strength. Additionally, with the passage of time, the degradation of carbonates can result in voids founding within the soil, affecting the dependability of foundations and construction activities.

Table 3. The results of chemical analysis tests of soil samples in Mandli alluvial fan deposits

No	PH	EC (Mhos/cm)	Classification TDS	Gypsum %	Cl %	CaCO3 %	SO4 %
Sample (S1)	7.4	18.14	High	1.339	5.73	45	0.624
Sample (S2)	6.9	33.22	Very high	1.969	4.95	45	0.917
Sample (S3)	6.8	33.22	Very high	4.744	3.52	44.5	2.210
Sample (S4)	7.08	19.00	High	1.317	2.74	32.5	0.613
Sample (S5)	7	11.92	Moderate	1.221	3.52	45	0.569
Sample (S6)	7.1	18.42	Moderate	6.547	2.94	47.5	3.050
Sample (S7)	7.3	15.76	High	0.747	2.92	26	0.348
Sample (S8)	7.2	28.20	Very high	1.737	3.13	20.5	0.809
Sample (S9)	7.3	25.76	Very high	1.891	2.35	46	0.881
Sample (S10)	7.2	21.76	High	1.656	2.92	45	0.771
Sample (S11)	6.85	28.20	Very high	3.419	3.07	45	1.593
Sample (S12)	7.1	11.52	Moderate	1.030	2.08	45	0.480
Sample (S13)	7.23	11.52	Moderate	0.875	3.07	45	0.408
Sample (S14)	7.2	33.22	Very high	4.464	3.02	43.5	2.080
Sample (S15)	7.22	19.48	High	0.931	2.92	44.5	0.433
Max	7.4	33.22		6.547	5.73	47.5	3.05
Min	6.85	11.52		0.747	2.08	20.5	0.34
Average	7.15	20.68		2.37	3.04	39.54	1.10

4.2.4. Mineralogical analysis

The results of X-ray diffraction analyses for the soil samples which indicated the mineral composition in mandli sediments are primarily made up of quartz; kaolinite; montmorillonite; illite and chlorite as shown in Fig. 4. Mineral analysis of soil samples was carried out for samples (S1, S2, S3 and S4).

(XRD) analysis was implemented on the samples after sieving them in sieve No. 200 with an amount of 2g for each sample.

The (XRD) arrays of samples (S1, S2, S3 and S4) show similar clay mineral compositions but with varied mineral proportions, which are indicative of different depositional environments.

S1 contains illite, interstratified montmorillonite–chlorite, kaolinite–chlorite, whereas gypsum denotes evaporitic and saline conditions. While heating to 550°C reduces these peaks and emphasizes the thermal resilience of illite and chlorite, ethylene glycol treatment produces peak shifts that validate expandable clays.

S2 exhibits a similar mineral accumulation, but there is no visible gypsum, suggesting a lower evaporitic influence. It also reacts to ethylene glycol with peak shifts that indicate expandable clays; heating increased the prominence of illite and chlorite while reduced unstable phases.

S3 consists of layers of illite, montmorillonite–chlorite, and kaolinite. Upon increasing the temperature to 550°C, these peaks decrease, representing the thermal resistance of illite, chlorite and removed kaolinite. when exposed to ethylene glycol, makes peak changes that remain.

S4 consists of layers of illite, chlorite, and kaolinite. When increasing the temperature to 550°C, these peaks decrease with stay of illite, chlorite and removed kaolinite. when exposed to ethylene glycol, makes peak changes with fixed the clay minerals .

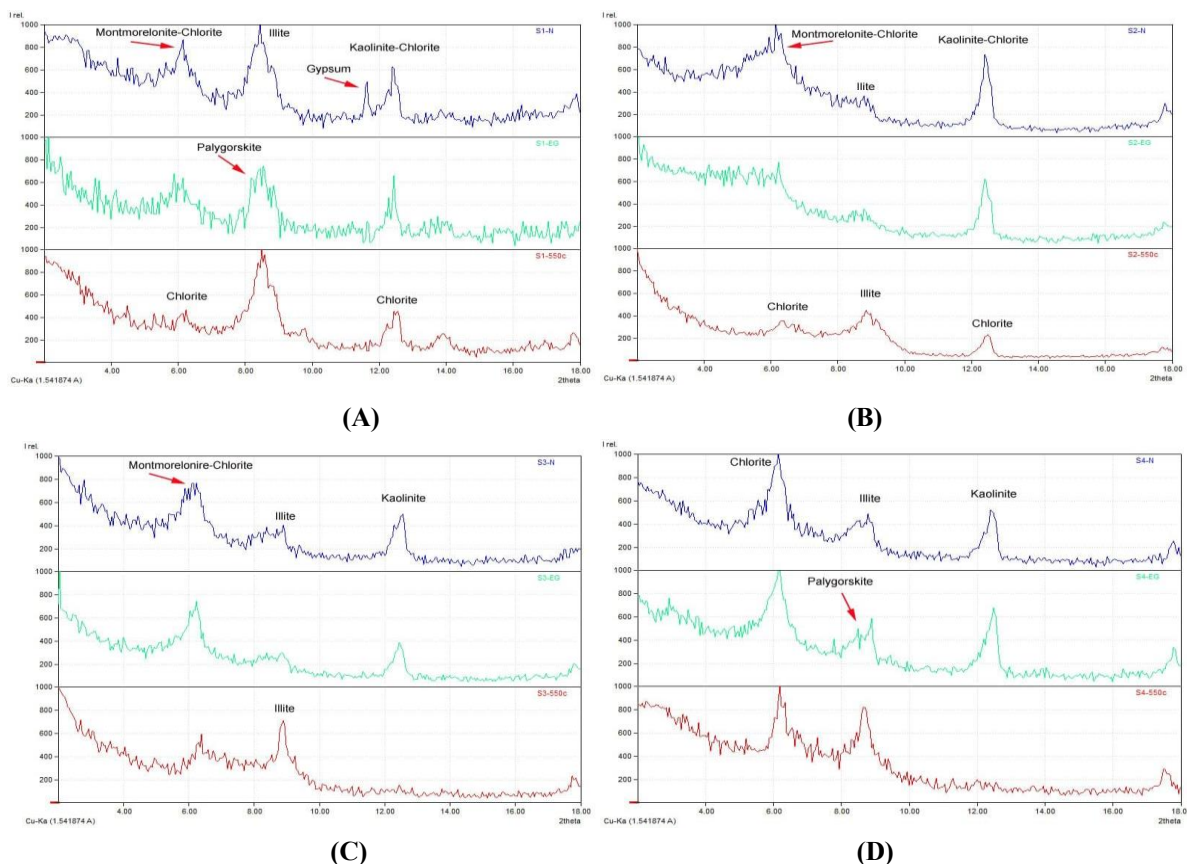


Fig. 4. The diagram of X-ray diffraction for site A) represented (S1); B) represented (S2); C) represented (S3); D) represented (S4) in the study area

5. Conclusions

The evaluation of particle size for the sediment distribution in the study sites indicated that the soil is made up of 26.8% - 43.9% sand, 2.8%-11.3% silt, and 51.7%-71.2% clay; therefore, by using the (USCS) classification, these were classified into three types as (CL; ML and CL-ML). These results reflect the grain size of the soil which then provide an initial evaluation of their permeability and engineering abilities.

Atterberg limits indicated a liquid limit (LL) of 7.71-38.02 %, a plastic limit (PL) of 10-25 %, and a plasticity index (PI) of 0.4-27.68 %. These records indicate the soil's plastic behavior and potential susceptibility to the compression, shrinking, and swelling, agrees with the results from the particle size distribution analysis.

The result of physical properties which shown the water content; specific gravity and dry density were given as (18.2-25 %); (2.6-2.78%) and (1.4-2.1 g/cm³) respectively and these exposed the true state of the soil and their influence to its characteristics that related to the compaction, shear strength, and settlement.

The direct shear test displayed cohesion values of (0–16.94 kN/m²) and friction angles of (0–38°) which measured mainly by grain soil and clay mineral content Clay and silt soils showed higher cohesion but lower friction angles due to reduced shear confrontation. The unconfined compressive strength was found to be ranged from (46.55 to 98.17 kN/m²), representing that soil composition and water content were strongly effected the physical and engineering properties.

The chemical analysis showed that the soil samples had pH values ranging from (6.85 to 7.40), EC values of 11.52–33.22 dS/m, and TDS levels from moderate to very high. Gypsum, chloride, sulfate, and carbonate contents were ranged from (0.74–6.54%); (2.08–5.73%); (0.34–3.05%) and (20.30–47.50%) respectively. These chemical components suggestively influence the soil's physical and engineering properties, including salinity, compressibility, strength, and stability. Therefore, most of the study soils area require a suitable treatment before building to ensure suitable engineering characteristic properties.

6. Recommendations

- Using vegetation treatment to improve the soil such as shrubs, grasses, trees, and other plant structures, represents one of the most effective methods which available for all sites.
- The technology in this time, stabilization can be applied in specific areas in the southern and western sites that is consisted of clay moderate plasticity (CL and CL-ML).
- The fly ash stabilization method can be used in northern and eastern locations to reduce swelling pressure due to the reduce water absorption capacity of the treated clay. and it may be used in the slopes of urban expansion area deposits, where cracks and channels are located in the center of the study area.
- Riprap techniques are commonly useful in the areas with significant erosion.

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- Data curation: Qassim, A. A. AL-Tamimi; Haider, A. S. Al-Amar
- Formal analysis: Qassim, A. A. AL-Tamimi; Haider, A. S. Al-Amar
- Methodology: Qassim, A. A. AL-Tamimi
- Project administration: Qassim, A. A. AL-Tamimi
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- Supervision: Haider, A. S. Al-Amar.
- Writing – Qassim, A. A. AL-Tamimi.

Declaration of Competing Interest

The authors declare that they have no competing financial interests or personal relationships that could influence the work reported in this study.

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Data Availability

All data generated or analyzed during this study are included in this published article.

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