



Geotechnical Evaluation of Soil in Taza District, Southeast of Kirkuk, Iraq: Correlation Between Chemical and Some Physical Properties

Mohammed S. Ahmed ^{1*} , Burkan S. Othman ² , Fouad A. Al-jalabi ³ 

¹Department of Applied Geology, College of Science, University of Kirkuk, Kirkuk, Iraq.

²Department of Applied Geography, College of Arts, University of Kirkuk, Kirkuk, Iraq.

³Department of Civil Engineering, College of Engineering, University of Kirkuk, Kirkuk, Iraq.

Article information

Received: 28- Nov -2024

Revised: 04- Jan -2025

Accepted: 16- Feb -2025

Available online: 01-Apr -2026

Keywords:

Taza,
Soil,
Plasticity,
Correlation,
Regression,

Correspondence:

Name: Mohammed Shahab

Ahmed Hussein

Email:

mosh781161228@gmail.com

ABSTRACT

Soil is one of the most important natural resources. A comprehensive geotechnical soil assessment must be performed when starting any engineering project to avoid future damage. The properties of soil and concrete are greatly affected by the chemical composition, which makes understanding statistical relationships between soil properties essential in the study, planning, and preliminary design stages of engineering projects, saving time and money. This research aims to evaluate some geotechnical properties of the soil in Taza district, SE of Kirkuk for ten locations distributed across the district and use mathematical relationships to predict the physical properties (finer ratio, LL, PL, PI) based on the chemical properties of the soil (pH, TDS, OM, SO₃, Cl⁻, gypsum) Using simple and multiple linear regression analysis. The results of particle size analysis show that coarse soils predominate in sites T1, T2, and T10(1), while fine soils, especially silt, in sites T3–T10, with an average of 50.53% for all sites. The soil can be classified into low-plastic clay (CL) and low-plastic silt (ML) according to the plasticity chart, with medium liquidity and plasticity index values ranging from low to medium. The results of the standard compaction test show similar values for the optimum moisture content and maximum dry density. Specific gravity values range between 2.64 and 2.81, and chemical tests show that site T10 recorded clear increases in most properties. The results of Simple Linear Regression Analysis (SLRA) show an inverse relationship between the chlorine percentage and some physical properties, while Multiple Linear Regression Analysis (MLRA) shows stronger relationships between the variables.

DOI: [10.33899/injes.v26i2.56083](https://doi.org/10.33899/injes.v26i2.56083), ©Authors, 2026, College of Science, University of Mosul.

This is an open-access article under the CC BY 4.0 license (<http://creativecommons.org/licenses/by/4.0/>).

تقييم جيوتكنيكي للتربة في ناحية تازة جنوب شرق مدينة كركوك، مضاهاة بين الخواص الكيميائية وبعض الخواص الفيزيائية

محمد شهاب احمد حسين ^{1*} ID، بركان سعيد عثمان ² ID، فؤاد عبدالله محمد علي الجليبي ³ ID

¹ قسم الجيولوجيا التطبيقية، كلية العلوم، جامعة كركوك، كركوك، العراق.

² قسم الجغرافية التطبيقية، كلية الآداب، جامعة كركوك، كركوك، العراق.

³ قسم الهندسة المدنية، كلية الهندسة، جامعة كركوك، كركوك، العراق.

المخلص	معلومات الارشفة
تعد التربة من اهم الموارد الطبيعية. يجب إجراء تقييم جيوتكنيكي شامل للتربة عند بدء أي مشروع هندسي لتجنب الأضرار المستقبلية. تتأثر خواص التربة والخرسانة بشكل كبير بالخصائص الكيميائية، مما يجعل فهم العلاقات الإحصائية بين خواص التربة ضروريًا في مراحل الدراسة والتخطيط والتصميم الأولي للمشاريع الهندسية، مما يوفر الوقت والمال. يهدف هذا البحث الى تقييم بعض الخواص الجيوتكنيكية للتربة في ناحية تازة، جنوب شرقي مدينة كركوك لعشرة مواقع موزعة على الناحية واستخدام العلاقات الرياضية للتنبؤ بالخواص الفيزيائية للتربة (نسبة الناعم، حد السيولة، حد اللدونة، معامل اللدونة) وبناءً على الخواص الكيميائية (pH, TDS, OM, SO ₃ , Cl ⁻ , الجبس) باستخدام تحليل الانحدار الخطي البسيط والمتعدد. أظهرت نتائج التحليل الحتمي الحبيبي أن الترب الخشنة تسود في الموقعين T1 و T2، حيث يشكل الرمل النسبة الأكبر، بينما تغلب الترب الناعمة، خاصة الغرين، في المواقع T3-T10، بمتوسط 50.53% لجميع المواقع. تم تصنيف التربة إلى طين قليل اللدونة (CL) و غرين قليل اللدونة (ML) وفقاً لمخطط اللدونة، مع سيولة متوسطة وقيم معامل لدونة تراوحت ما بين منخفضة ومتوسطة. أظهرت نتائج اختبار بروكتور القياسي قيم متقاربة للمحتوى الرطوبي المثالي والكثافة الجافة القصوى. كما تراوحت قيم الثقل النوعي ما بين 2.64 و 2.81 كما أظهرت الفحوصات الكيميائية أن الموقع T10 سجل زيادات واضحة في معظم الخواص. بينت النتائج وجود علاقة عكسية ما بين نسبة الكلوريد وبعض الخواص الفيزيائية، بينما أظهرت نماذج الانحدار المتعدد علاقات أقوى بين المتغيرات.	<p>تاريخ الاستلام: 28- نوفمبر - 2024</p> <p>تاريخ المراجعة: 04- يناير - 2025</p> <p>تاريخ القبول: 16- فبراير - 2025</p> <p>تاريخ النشر الإلكتروني: 01- ابريل - 2026</p> <p>الكلمات المفتاحية:</p> <p>تازة، تربة، لدونة، المضاهاة، الارتباط،</p> <p>المراسلة:</p> <p>الاسم: محمد شهاب احمد حسين</p> <p>Email: mosh781161228@gmail.com</p>

DOI: [10.33899/injes.v26i2.56083](https://doi.org/10.33899/injes.v26i2.56083). ©Authors, 2026, College of Science, University of Mosul.
This is an open-access article under the CC BY 4.0 license (<http://creativecommons.org/licenses/by/4.0/>).

Introduction

As soon as humans started building structures such as homes, tombs, or temples, they treated the soil as a foundation material and selected the right soil to sustain the building they desired (Al-Kasabi, 1993). The necessity to build massive facilities has arisen as a result of urbanization and the overcrowding of buildings and facilities in cities. In nature, soils can be classified as soft and weak with low bearing capacity, medium stiff with high bearing capacities, or very stiff with high bearing capacities (Aljuboori and Çetin, 2019; Mohamed et al., 2024a). Building engineering structures on difficult soils has become essential due to the rise in demand and the decline in locations with adequate usable foundation soil. Problematic soils typically have insufficient bearing capacity and can lead to significant liquefaction or settlement rates (Mohamed et al., 2024b). In addition, one of the most crucial ideas in geotechnical engineering is the stability of natural structures such as slopes and engineered structures, including buildings, tunnels, bridges, and dams (Roodposhti et al., 2019). A set of engineering parameters can be provided without the requirement for in-depth soil investigations by using the statistically derived connections between soil characteristics (Al-Kahdaar and Al-Ameri, 2010).

Concrete and soil are significantly impacted by chemical properties. Predictive mathematical correlations between chemical and physical qualities can be developed to comprehend the relationship between them, saving effort and money.

Ibrahim and Tokmachy (2023) studied the evaluation of the suitability of clays from the Injana Formation in the Laylan and Dibs areas, Kirkuk Governorate, for making building blocks. The findings demonstrated that the research area's soil has low to medium plasticity, with over 50% of the samples collected from the area being fine-grained. Al-Sultani et al. (2023) studied geotechnical properties of soil slopes of the Great Musaiyab Project, Babylon, Middle of Iraq, and according to the study's findings, the majority of the soils are sandy poor grade (SP), silty clay with limited plasticity (CL-ML), and clayey with low plasticity (CL). The soil's proportion of organic matter varied from 1.407 to 3.869% with low levels of gypsum, sulfate, and total dissolved solids. There aren't many studies in the Arab world that use physical properties to predict the chemical properties of soil. However, there are some worldwide studies, like Khairul et al. (2016), who studied the correlations between chemical and index properties for soft clay of Peninsular Malaysia and obtained a good relationship between the percentage of organic matter and moisture content as well. Karira et al. (2018) carried out a geotechnical correlation between the chemical properties and index properties of the soil in the Hyderabad region in Pakistan. The results showed that the highest value of the coefficient was between organic matter and the liquidity limit of 0.4198, and a relative improvement in the correlation is obtained when using multiple linear regression analysis (MLRA) compared to simple linear regression analysis (SLRA). The main aim of this paper is to use the geotechnical prediction to estimate the chemical properties of soil through the physical properties.

Location and Geology of the Study Area

The study area is located in the Taza district in the southeastern part of Kirkuk Governorate. It is considered a strategic location as it is located on the road connecting Kirkuk and Baghdad governorates, close to some industrial facilities. It is about 25 km² away from the center of Kirkuk City, between longitudes (44° 18' 30") and (44° 21' 0") east and latitudes (35° 16' 30") and (35° 20' 30") north.

Understanding the geology of any area is crucial because it can reveal information about the rich past of the area, including the discovery of oil and groundwater, concentrations of raw materials, and understanding the geometry of the formation if a dam or other project were built there (Karim, 2011).

Fouad (2015) divided Iraq into two parts: one is located within the Arabian Plate and the other is within the Iranian Eurasian Plate; moreover, the part located within the Arabian Plate was divided into internal shelf and external shelves, and the external shelf was divided into: Low Folded Zone, High Folded Zone, Imbricate Zone, and Suture Zone. Therefore, the study area is located in the Low Folded Zone. Structurally, the Alpine movements of the Late Tertiary had an impact on this area. This region is characterized by a thick sedimentary layer and long and narrow anticlines with parallel axes separated by wide concave folds with deep faults parallel to the anticlines, which divide the region into two secondary belts: Hamrin-Makhul Subzone and Chemchemal-Butmah Subzone) (Buday and Jassim, 1987). The study area is located within the Hamrin-Makhul belt.

In Kirkuk, a variety of exposed geological formations are observed; some others are covered by more recent sediments of Middle Miocene to Holocene (Ali et al., 2021).

Pleistocene-Holocene sediments cover most parts of the region represented by Quaternary sediments, while the edges of the region are covered by sedimentary rock formations of Miocene-Pliocene age represented by Fatha-Injana-Muqdadiya-Bai Hassan formations (Fig. 2).

More than a third of Iraq's land area is covered by Quaternary sediments, most of which are located in the Mesopotamian plain. These deposits contain varying amounts of gravel, sand, clay, and silt. The types of deposits widespread in the study area are: valley filling deposits (Holocene), flood plain deposits (Holocene), river terrace deposits (Pleistocene), and topsoil.

Materials and Methods

The initial phase of fieldwork, lasting over a month, has comprised four site visits, during which all necessary tools were gathered and prepared (drilling equipment, hammers, measuring tapes for determining depth, plastic bags for preserving moisture content, and molds for assessing field density). Additionally, the coordinates of the study area were recorded using GPS. Five soil samples were collected from five distinct locations, with depths ranging from approximately 15 cm to 3.5 m. Following the field density measurements at each site, the samples were prepared for laboratory testing and analyses, including physical property tests such as moisture content, specific gravity, grain size distribution, and Atterberg limits. These tests were conducted in the Geotechnical Laboratory at the Department of Applied Geology, College of Science, Kirkuk University. Furthermore, the data collected from the five locations were integrated with additional data obtained from the Kirkuk Construction Laboratory, derived from school building reports. These supplementary data points are marked on the map in green and coded as (T6, T7, T8, T9, T10) as shown in Figure 1.

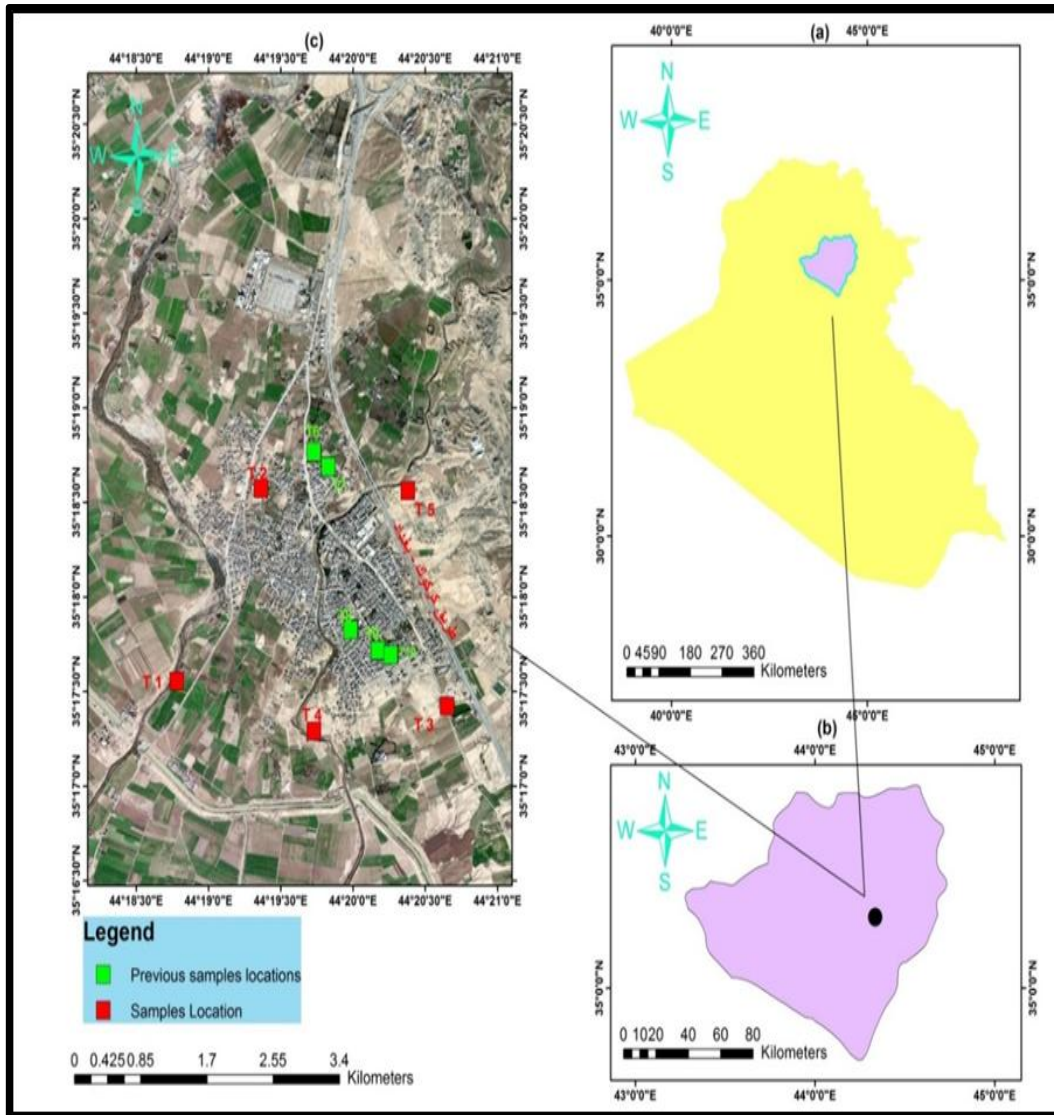


Fig. 1. Site maps of the study area showing sampling locations; (a) Map of Iraq; (b) Map of Kirkuk; (c) Aerial photo (Bing map) of Taza district using the Sas Planet program.

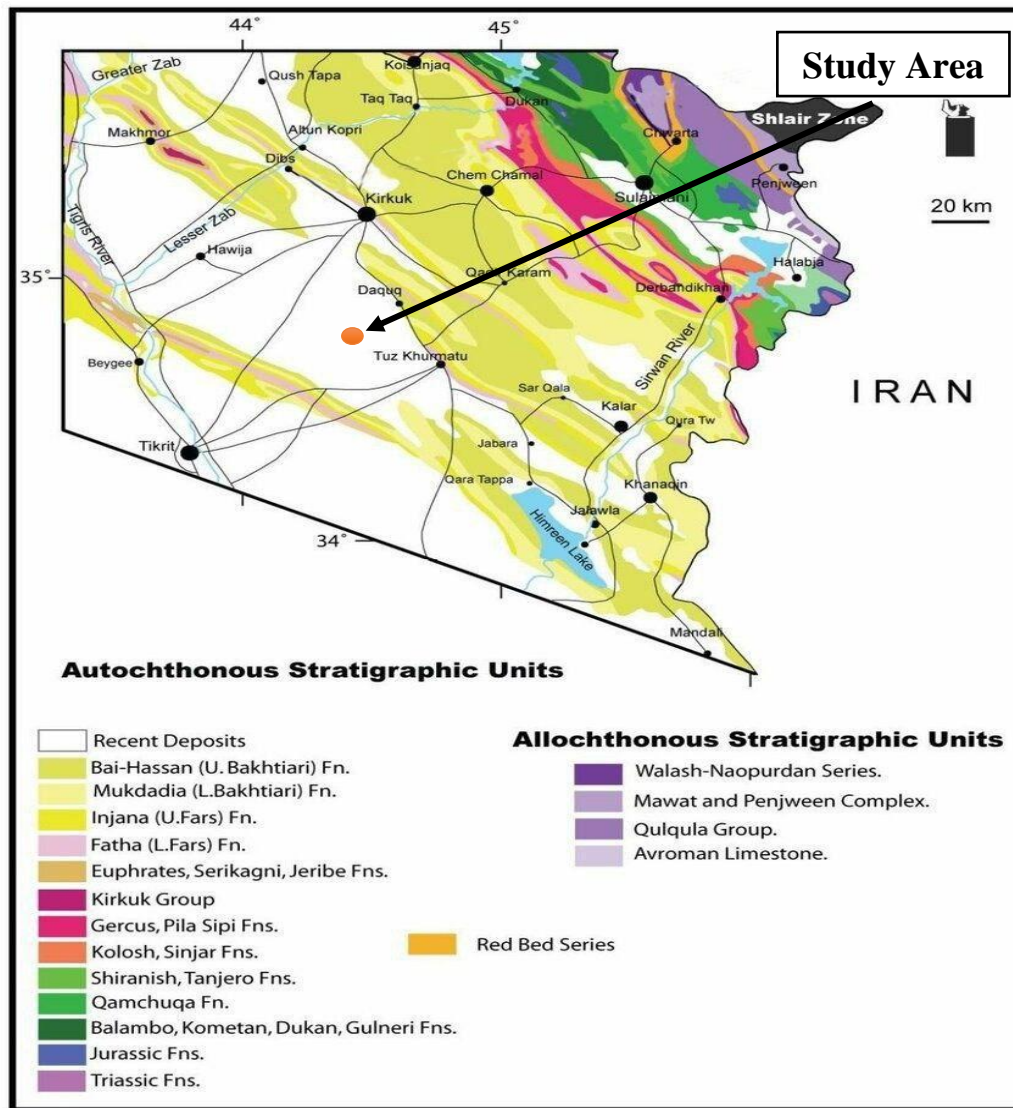


Fig. 2. Geological map of northern Iraq showing the location of the studied area (Modified from Sissakian, 2000).

Physical Properties

Grain size distribution test is conducted in both types (dry and wet) according to the standard (ASTM D-422, 2004). Soil particle sizes directly affect other soil properties such as porosity, permeability, specific gravity, and void ratio (Verma *et al.*, 2017).

Field Density was conducted following (ASTM D2937-10, 2016). The density is checked on site by pushing a metal ring with known dimensions at the required depth, cutting off the excess parts, obtaining undisturbed samples, and then fixing their weight and dimensions. Many factors, such as soil type, moisture content, and sampling techniques, affect the results of field density testing (Certified MTP, 2024).

Moisture content represents the proportion of the weight of water to the weight of solid soil particles, indicated by the symbol %Mc. The test was carried out in accordance to standard (ASTM D2216-80, 2004).

Specific gravity is the ratio between the weight of soil in a certain volume and the equivalent weight of the same volume of distilled water at a temperature of 20 °C. The samples were measured according to (ASTM D854-14, 2014).

Atterberg limit is the consistency of the soil, mainly affected by the percentage of water content, as it controls the extent of fraction and cohesion of its particles. Liquid and plastic

limits are tested according to the American standard (ASTM D4318-14, 2004). Plasticity index is expressed in the following relationship:

$$PI = LL - PL \text{-----} (1)$$

Where: *PI*: Plasticity index; *LL*: Liquid limit; *PL*: Plastic limit

Engineering Properties

Standard Proctor is conducted according to the American standard (ASTM D-698, 2004). Compaction is the process of soil condensation through the application of mechanical force (Holtz and Kovacs, 1981). Compression increases the soil's bearing capacity, density, and shear resistance, but reduces porosity, permeability, void ratio, and settling, and this helps stabilize the site's soil when constructing airstrips, roads, and earth dams (Prakash and Jain, 2002).

Chemical Properties

Chemical tests provide the necessary information about the suitability of using soil in construction or engineering projects in general. All tests are conducted according to British standards (BS 1377-3-1990).

pH: It is a measure of the acidity or alkalinity of soil. When the pH value is high (i.e., alkaline), this reduces water infiltration and increases compaction in the soil (Dewangan et al., 2023).

Gypsum content (Gyp): When the percentage of gypsum in the soil increases, this weakens the plasticity of the soil and reduces its ability to swell, and when it dissolves, it leaves voids and the resulting problems in these soils (Al-Abdullah, 2015).

Organic Materials Content (OMC): Organic matter is defined as a mixture of the remains of living organisms, whether plant or animal, in addition to other microorganisms. Sheikhil et al. (1999) mentioned that organic materials reduce compressibility, bearing capacity, and shear resistance, and they affect moisture content, leading to consolidation.

Chlorine (Cl⁻): Although it does not often cause chemical damage to concrete, it can deteriorate concrete through a physical process that involves the crystallization of chloride salts near the concrete surface. This is sometimes referred to as salt weathering (BRE, 2005).

Sulfates (SO₃): One of the structural problems faced by concrete works is the attack of sulfate ions (Abbas, 2002). The durability of concrete may be attacked by liquids and soils containing sulfates, a phenomenon known as "sulfate attack." Damage occurs if the mortar or concrete is not resistant enough to the sulfate ions that attack it (Skalny et al., 2003).

Total Dissolved Salts (TDS): It is a measurement of the concentration of all dissolved salts in the soil. The presence of salts and their dissolution in the soil leads to major engineering problems, as they affect most of the geotechnical properties and cause corrosion of foundation concrete. Rocks found in the geological layers are the main source of salts in the soil (Tanji, 2004).

Correlation and Regression

It is the statistical relationship between variables to support the local construction industry; it is important to develop appropriate formulas that accurately represent soils to understand the geotechnical properties of soils in the study area (Karira et al., 2018). Correlation can be used to predict the chemical properties of soil from its physical properties, thus improving engineering design and saving time and money. Simple linear regression and multiple linear regression are used.

Simple Linear Regression Analysis (SLRA): It is the analysis of the relationship between two variables, one of which is dependent, and the other is independent.

Multiple Linear Regression Analysis (MLRA): It is the analysis of the relationship between more than two variables, one of which is dependent and the other variables are independent.

The chemical property is a function of the other properties according to the equation:

$$Y = b_1 X_1 + b_2 X_2 + b_3 X_3 + b_4 X_4 + \dots + b_n X_n \text{ (Moore et al., 2007)-----(2)}$$

where: Y : dependent variable; b : constant; X : independent variable.

Physical properties were considered dependent (Finer percent, PL, LL, PI) and chemical properties independent (pH, Gyp, OM, TDS, SO_3 , Cl^-).

Results and Discussion

The United Soil Classification System (USCS) is relied upon to classify the soils of the study area. The grain size distribution results across the study area highlight a clear distinction between coarse soils in sites T1, T2 and T10 (1), where sand constitutes over 60% in sites T1 and T2 while gravel ratio reaching 43% in one of the samples from Site 10, and fine soils predominant in sites T3–T10, with an average silt content of 50.53% as demonstrated in Table (1) and Figure (3). Coarse soils, characterized by their high permeability and poor gradation, are more suitable for drainage but may require treatment for load-bearing applications. In contrast, fine soils exhibit cohesive properties, making them more stable under certain conditions but potentially problematic due to shrink-swell behavior. These findings align with the objectives of the study to evaluate soil suitability for engineering purposes.

Table 1: Results of grain size distribution.

Location	Gravel %	Sand %	Silt %	Clay %	USCS Sym *
T1	7	63	17	13	SM
T2	0	62	23	15	SM
T3	2	33	49	16	ML
T4	0	28	56	16	CL
T5	19	24	32	25	CL
T6	0	6	58	36	CL
T7	0	11	52	37	CL
T8	0	8	54	38	CL
T9	2	39	39	20	CL
T9	0	7	93	0	ML
T10	43	26	28	3	GC
T10	0	5	86	9	ML

*SM = Silty Sand; ML = Silt; CL = Clay; GC = Clayey Gravel

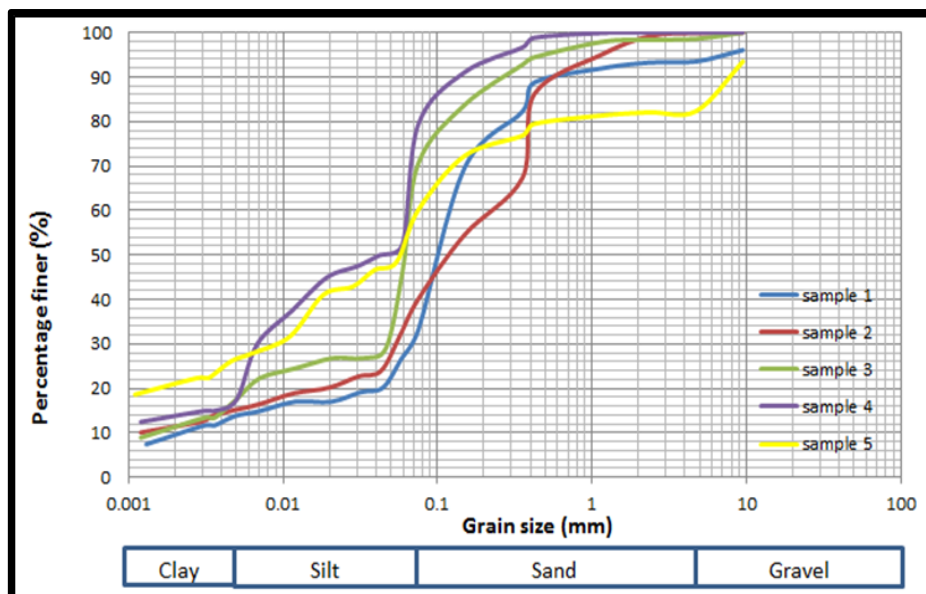


Fig. 3. Grain size distribution curve.

The results in Table 2 provide a key overview of the soil physical properties, including specific gravity, moisture content (Mc%), field density, and Atterberg limits. The field density results range from 1.47 gm/cm³ (T1) to 1.64 gm/cm³ (T5), indicating site-specific variations in compaction and soil properties. T1 shows the lowest density, likely due to poor compaction or high organic content, while T3 (1.82 gm/cm³) exhibits the highest, reflecting optimal compaction and favorable soil conditions. T2, T4, and T5 display intermediate densities influenced by factors such as moisture content, soil type, and compaction effort. These variations highlight differences in the load-bearing capacity and stability of the sites. Specific gravity values range from 2.64 to 2.81, indicating variations in mineral composition, with higher values observed in locations T3 and T5. Moisture content varies significantly; the lowest values are in T1 and T2 due to their coarse soil texture, while the fine-grained soils in T3–T5 exhibit higher moisture retention. Atterberg limit results classify most of the soils as cohesive (CL) except for T1, which exhibited non-plastic behavior due to its high sand content. These findings suggest that while coarse soils in T1 and T2 are suitable for drainage, fine soils in other locations may exhibit shrink-swell behavior requiring stabilization for engineering applications.

The plasticity chart illustrates the classification of soils based on Atterberg limits. Most samples are plotted within the CL (low plasticity clay) and ML (low plasticity silt) zones, indicating cohesive soils with moderate to high plasticity. Samples from T1 and T2, characterized by low liquidity indices, fall outside the cohesive zones, reflecting their sandy nature. These results align with the grain size distribution data and demonstrate that while CL and ML soils provide moderate stability, their plasticity requires careful consideration during construction, especially in areas prone to moisture changes, as shown in Figure 4. Table 2 represents the results of the Atterberg limits.

Table 2: Results of physical properties.

Location	Specific gravity	Mc%	PL%	LL%	PI%	Field density (gm/cm ³)
T1	2.64	8.48	Non P.			1.47
T2	2.74	6.82	23.34	28.345	5.005	1.59
T3	2.71	13.36	27.26	36.742	9.482	1.82
T4	2.74	14.81	17.33	30.911	13.581	1.53
T5	2.81	17.74	24.27	39.751	15.481	1.64
T6	/	15	22	49	27	
T7	/	20	/	/	/	
T8	/	/	18	32	14	
T9	2.72	21	27	42	15	
T10	2.61	4.4	18	33	15	

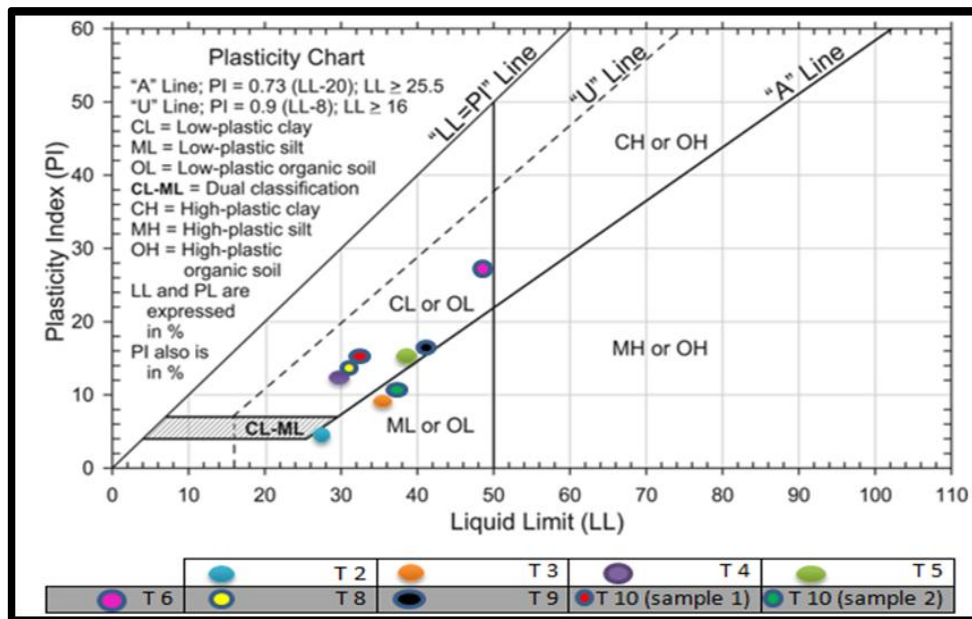


Fig. 4. Plasticity chart.

The results presented in Table 3 show slight variations in the optimum moisture content and maximum dry density across the five sites. The optimum moisture content ranges from 7% (T2 and T3) to 9.5% (T5), while the maximum dry density varies from 1.58 gm/cm³ (T5) to 1.69 gm/cm³ (T3). These differences can be attributed to the similarity in granular distribution and mineral composition across the sites. The higher moisture content in T4 and T5 may be due to the presence of higher salt content or organic materials, which require more moisture to achieve optimal compaction. Overall, the results indicate that the soil characteristics are relatively similar across the sites, which is reflected in the comparable values of dry density and moisture content.

Table 3: Results of standard compaction test.

Location	Optimum moisture content (%)	Maximum dry density (gm/cm ³)
T1	8.8	1.64
T2	7	1.676
T3	7	1.69
T4	9.4	1.568
T5	9.5	1.58

The soil pH levels varied across the study sites. Locations T1 to T7 exhibited a neutral to alkaline pH, while location T8 is classified as highly alkaline. Location T9 shows a moderate to slightly acidic pH, and location T10 is characterized as highly acidic, as per the classification by Raine et al. (2003). In terms of Gyp%, the soil in location T8 is found to be non-gypsum, whereas locations T1, T4, T6, and T7 have very low gypsum levels. Locations T2, T3, T5, and T9 are classified as low in gypsum, while location T10 is identified as having medium gypsum content based on the criteria established by Barzanji (1973).

According to Mahmood (1997), OMC in locations T3, T4, T6, T7, and T8 was considered ineffective, whereas locations T1, T2, T5, and T9 showed relatively significant levels, with values exceeding 2% in location T10. Cl⁻ concentrations were reported to be high in locations T2, T3, and T5, while the other locations exhibited normal levels, as per (NCCL, 2001). Concerning SO₃, all sites except for location T10 were within normal limits according to (NCCL, 2001). Finally, TDS in all samples from the study sites were within permissible limits, also in accordance with (NCCL, 2001). The detailed results of the chemical tests are summarized in Table 4.

Table 4: Results of chemical properties

Location	Gypsum%	O.M %	SO ₃ %	pH	Cl-%	T.D.S%
T1	1.9	1.12	0.88	8.02	0.091	2.14
T2	4.19	0.89	1.95	7.98	0.117	5.2
T3	3.8	0.43	1.77	8.03	0.120	4.1
T4	2.2	0.16	1.02	7.85	0.087	3.4
T5	4.8	1.67	2.25	8.05	0.116	5.28
T6	0.58	0.15	0.27	8	0.023	1.55
T7	0.789	0.35	0.367	8	0.005	1.47
T8	0.24	0.27	0.11	9	0.07	0.61
T9	6.390	0.997	2.972	5	0.065	6.686
T10	12.34	2.931	5.738	4.9	0.043	6.679

In light of the results of correlation and regression relationships between the physical properties as dependent variables and the chemical properties as independent variables, the results of simple regression (SLRA) showed that there are weak relationships between the percentage of sulfate, pH, TDS, OM, and gypsum with the dependent variables separately, as the R² value did not exceed 0.2 in most cases. The relationships shown in the figures below (Fig. 5-Fig. 28), except for chlorine, where R² for the relationship between chloride and the plasticity index was (0.62) as presented in Figure 7, and between chlorine and the percentage of fines was (0.478) as indicated in Figure 5.

On the other hand, the results of the multiple linear regression analysis (MLRA) presented in Table 5 reveal strong correlations between plastic limit (PL), as the independent variable, and several dependent variables. The relationships included plastic limit (PL), with the TDS+pH+SO₃+Gyp, yielding an R² value of 0.9810; (PL) with TDS+SO₃+pH, also 0.9810; percentage of fines (F%) with Cl⁻+SO₃+OM+pH, a value of 0.9605; and PL with two variables (SO₃-pH%), achieving an R² of 0.9061. These findings suggest that other variables are significantly influenced by PL variations.

Additionally, a strong correlation was observed between plastic limit and TDS, SO₃, pH, and Gyp (R² = 0.9513), and between plasticity index (PI) with (SO₃-pH-Cl⁻%) (R² = 0.9423). The relationship between total dissolved solids (TDS) and the dependent variables yielded a correlation coefficient exceeding 0.8, indicating a high level of accuracy. The study by Arasan and Yetimoglu (2008) found that increasing salt concentration raises the plastic limit of clay, while a decrease in salt concentration reduces it.

Regarding sulfate, organic matter, and gypsum content, and their relationships with dependent (physical) variables, the R² values ranged from 0.43 to 0.59, suggesting a low level of interpretation. Gu et al. (2022) reported that the liquid limit and plasticity index decrease with increasing sulfate content. Odell et al. (1960) observed that Atterberg limits increase with higher organic matter content, while Busch and Keller (1981) found a positive correlation between Atterberg limits and organic matter content. Ahmed et al. (2023) further explained that the plasticity index decreases with an increase in gypsum content.

It is noted that the strongest relationships when using simple and multiple regression are those for chlorine. Mahmoud and Jaafar (2017) mentioned that the Atterberg limits decrease with the increase in the percentage of chlorine.

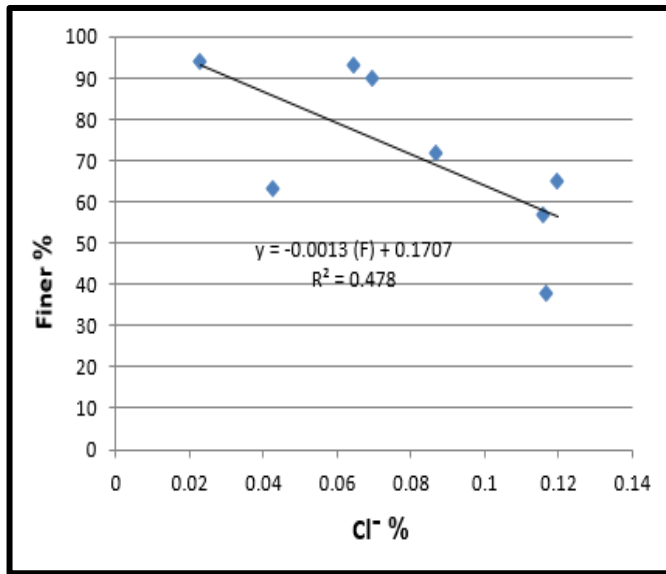


Fig. 5. Relationship between Finer% vs. Cl⁻%.

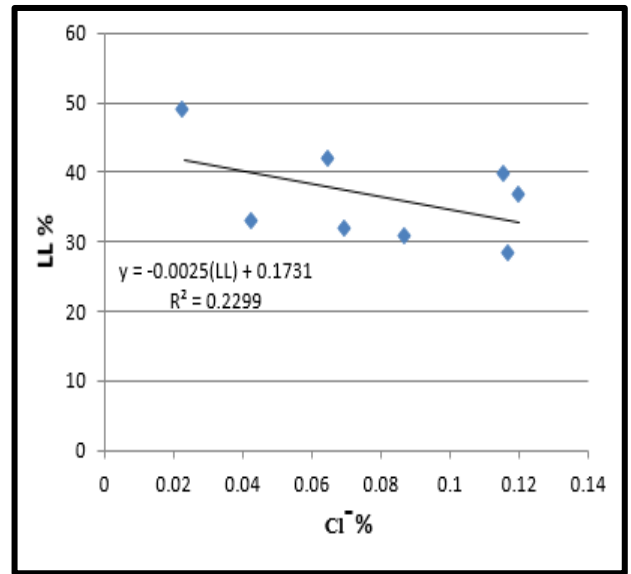


Fig. 6. Relationship between LL% vs. Cl⁻%.

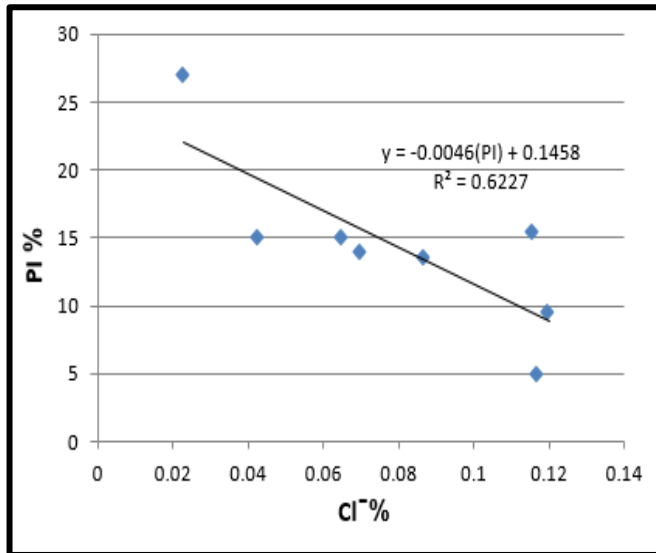


Fig. 7. Relationship between PI% vs. Cl-%.

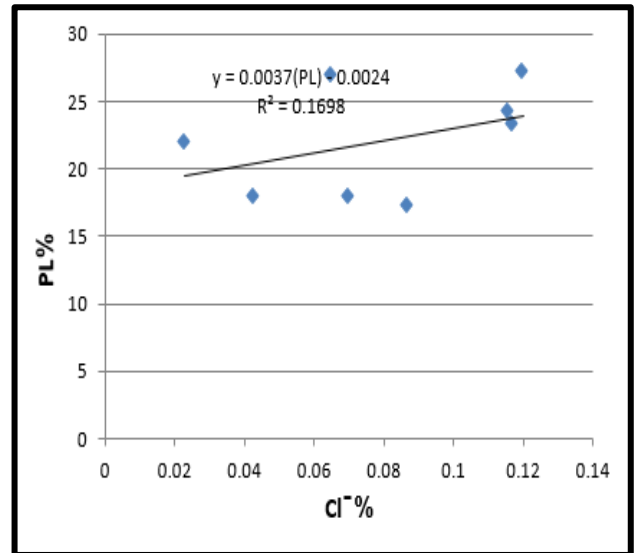


Fig. 8. Relationship between PL% vs Cl-%.

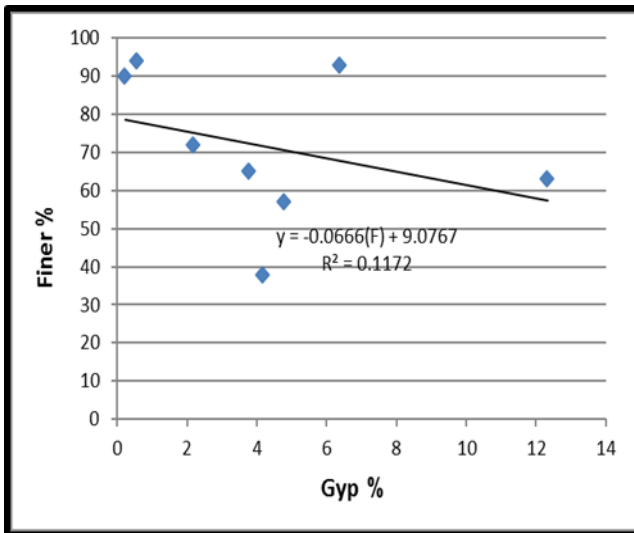


Fig. 9. Relationship between Finer% vs. Gyp%.

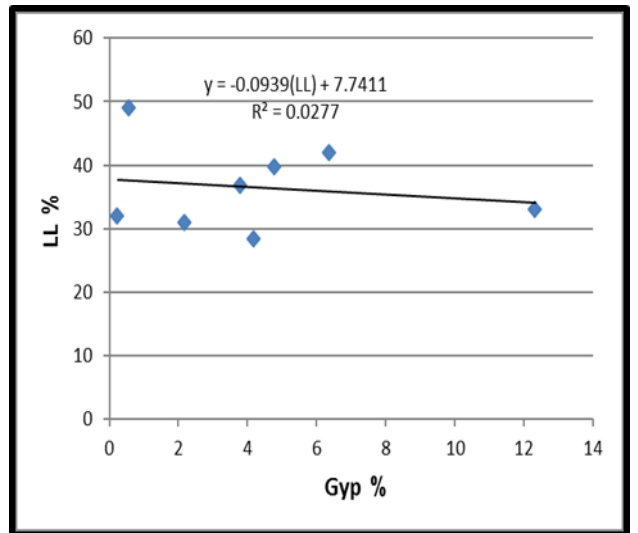


Fig. 10. Relationship between LL% vs. Gyp%.

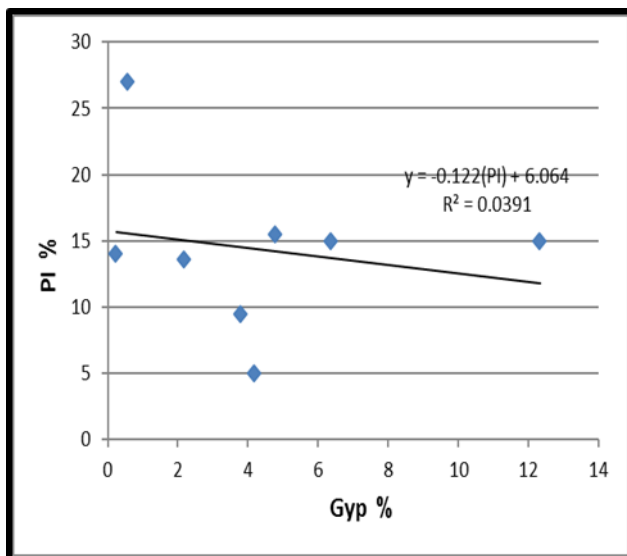


Fig. 11. Relationship between PI% vs. Gyp%.

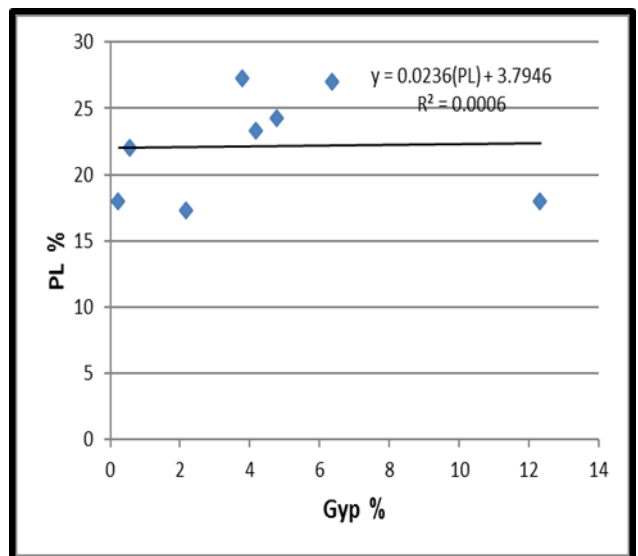


Fig. 12. Relationship between PL% vs. Gyp%.

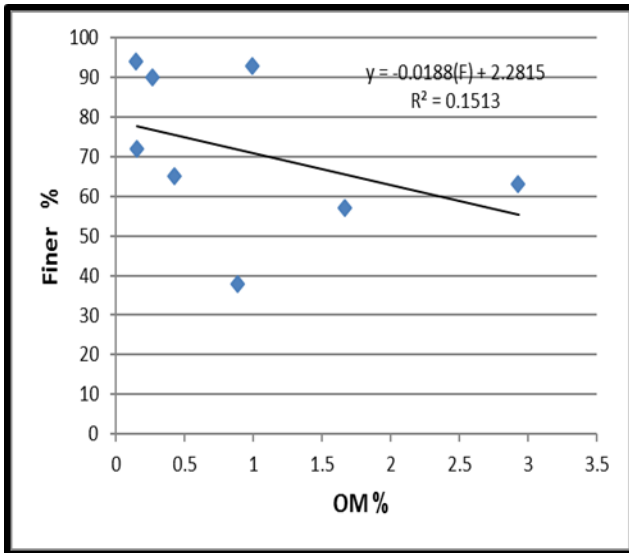


Fig. 13. Relationship between Finer% vs. OM%.

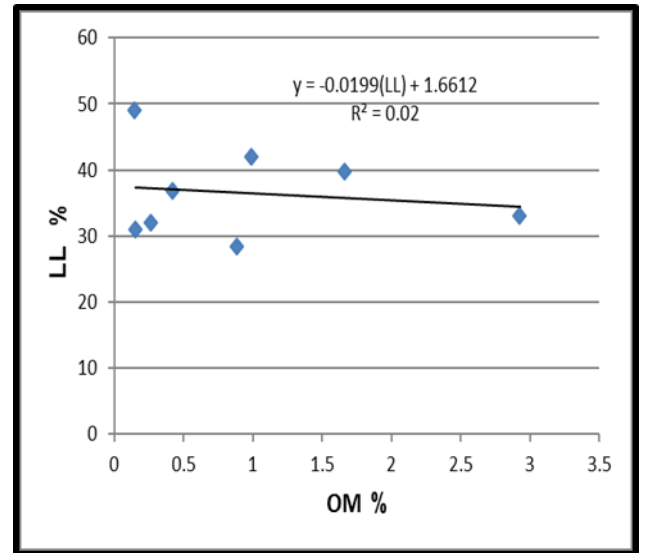


Fig. 14. Relationship between LL% vs. OM%.

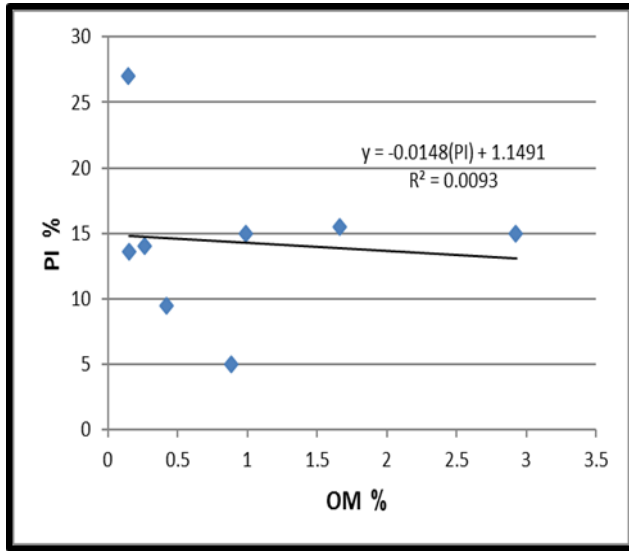


Fig. 15. Relationship between PI% vs. OM%.

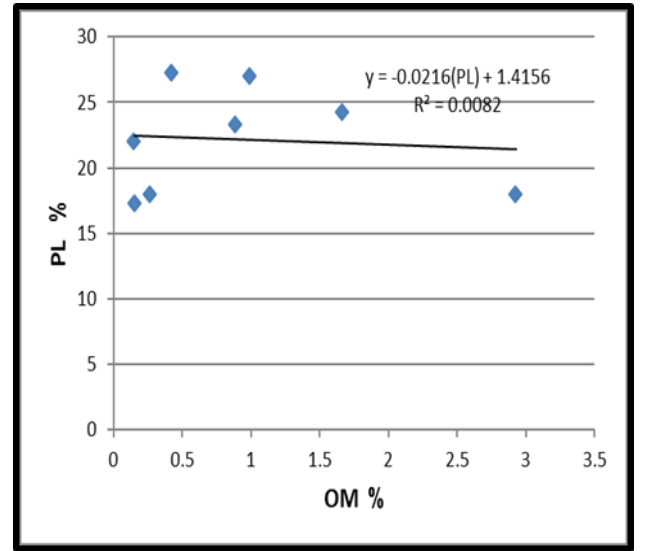


Fig. 16. Relationship between PL% vs. OM%.

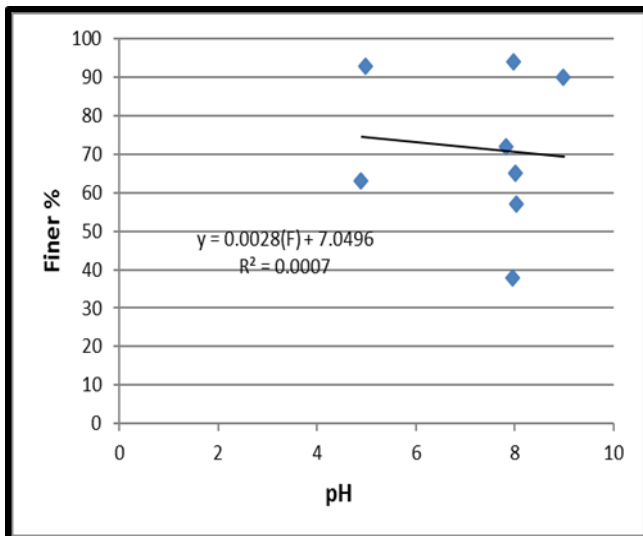


Fig. 17. Relationship between Finer% vs. pH%.

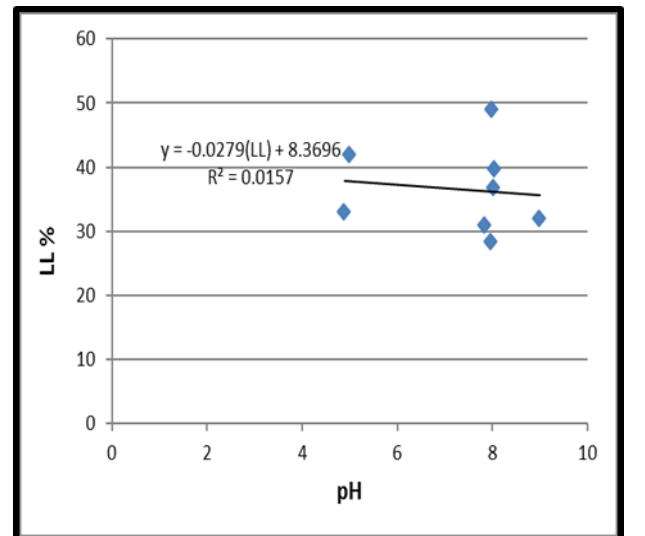


Fig. 18. Relationship between LL% vs. pH%.

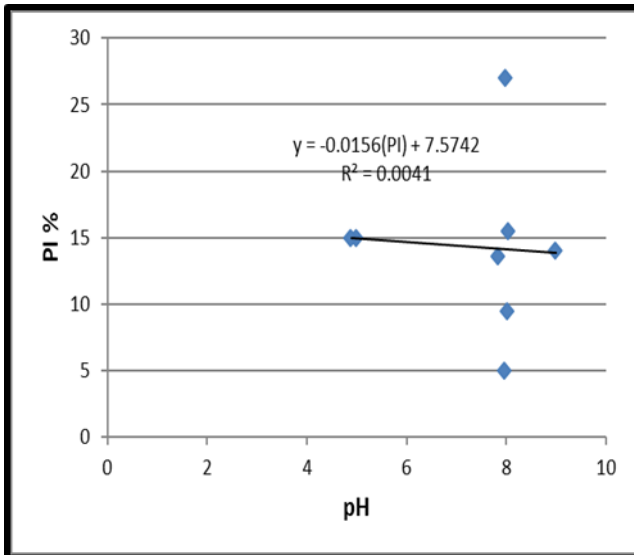


Fig. 19. Relationship between PI% vs. pH%.

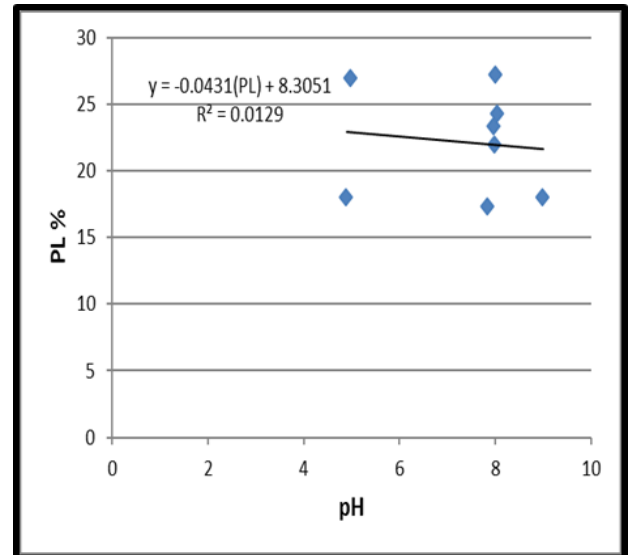


Fig. 20. Relationship between PL% vs. pH%.

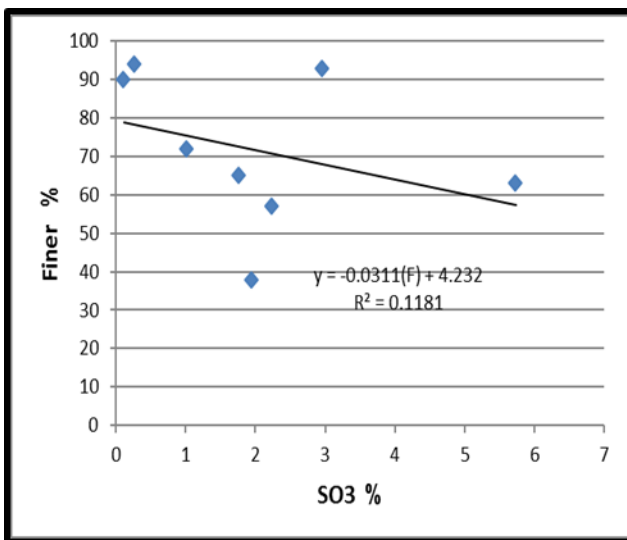


Fig. 21. Relationship between Finer% vs. SO₃%.

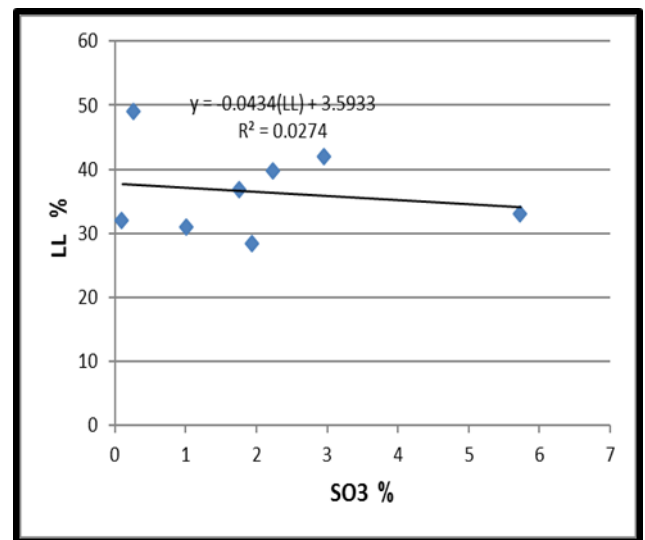


Fig. 22. Relationship between LL% vs. SO₃%.

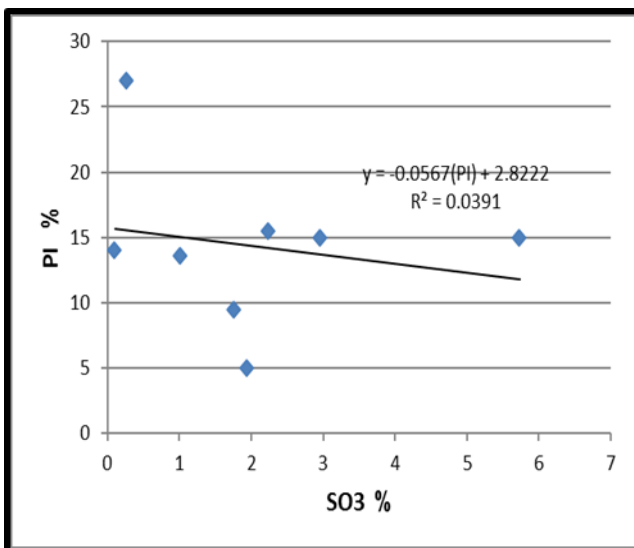


Fig. 23. Relationship between PI% vs. SO₃%.

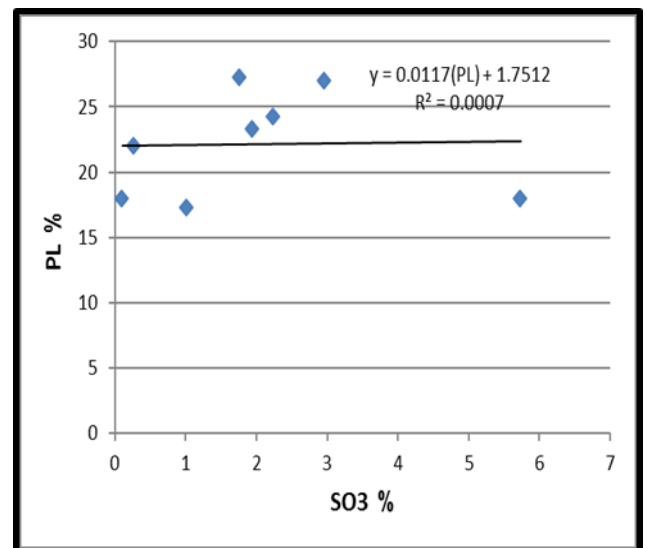


Fig. 24. Relationship between PL% vs. SO₃%.

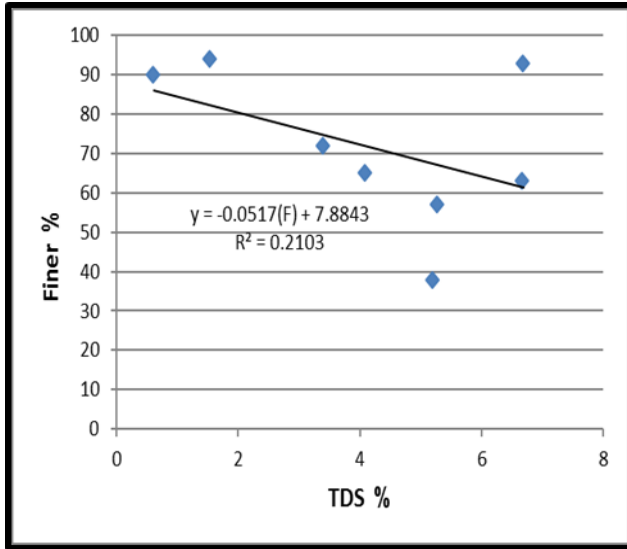


Fig. 25. Relationship between Finer% vs. TDS%.

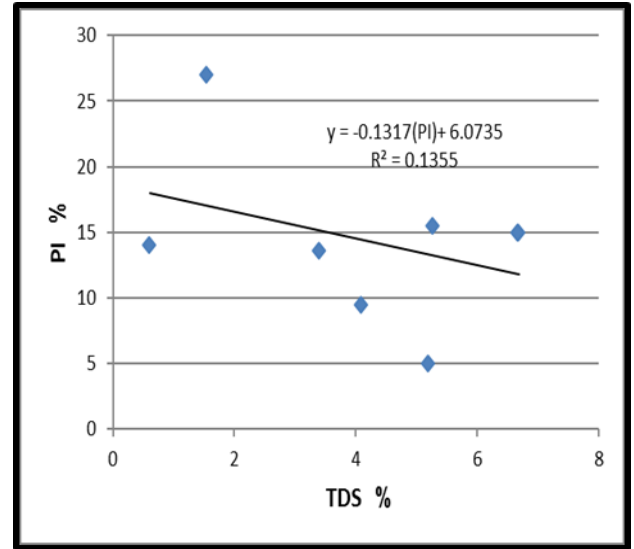


Fig. 26. Relationship between PI% vs. TDS%.

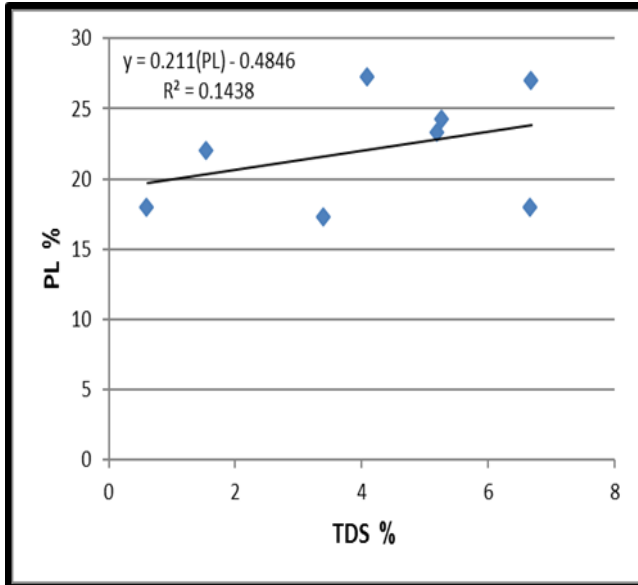


Fig. 27. Relationship between PL% vs. TDS%.

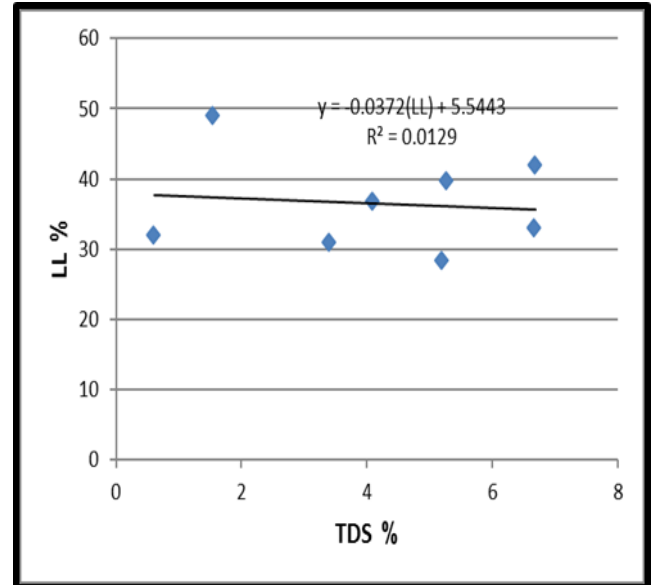


Fig. 28. Relationship between LL% vs. TDS%.

Table 5: Results of MLRA

Correlation	R ²
LL%=11.10 (TDS)-3.75 (Gyp)	0.8038
PI%=-1.14 (TDS)+2.67 (Gyp)-3.54 (SO ₃)+1.95 (pH)	0.8342
PI%=1.69 (pH) +0.35 (Gyp)	0.8271
PI%=0.59(OM) +3.62 (SO ₃)	0.4390
PL%=1.96 (SO ₃)+2.44 (pH)	0.9601
PL%=211.92 (Cl ⁻)+3.07 (OM)	0.8919
LL%=5.60 (pH) -77.66 (Cl ⁻)	0.9313
Finer%=400.05 (Cl ⁻) +6.43 (TDS)	0.7203
Finer%=8.52(pH)+1.65 (Gyp)	0.9034
LL%=1.77 (TDS)-31.26 (SO ₃) +3.75 (pH)+ 14.77(Gyp)	0.9513
PL%=2.87 (TDS)-1.63 (SO ₃) +1.80 (pH)	0.9810
PI%=1.52 (SO ₃)+3.40 (pH)-173.98 (Cl ⁻)	0.9423
Finer%=8.47 (pH)-22.16(OM) +6.63 (Gyp)	0.9136
Finer%=-537.60 (Cl ⁻)-30.01 (OM) +20.38 (SO ₃)+13.74 (pH)	0.7231
LL% =294.36 (Cl ⁻) -1.52 (OM) +4.48 (SO ₃)	0.8018
PI%=-2.86 (Gyp)+4.11 (TDS) +6.74 (OM)	0.6260
LL%=11.10 (TDS)-3.75 (Gyp)	0.8038
PL%=2.91 (TDS)+12.10 (Gyp) -27.71 (SO ₃)+1.80 (pH)	0.9810
Finer%=-537.60 (Cl ⁻)-30.01 (OM) +20.38 (SO ₃)+13.74 (pH)	0.9605
PI%=-1.14 (TDS)+2.67 (Gyp)-3.54 (SO ₃)+1.95 (pH)	0.8342
PI%=1.69 (pH) +0.35 (Gyp)	0.8271

PL%=-8.32 (OM)+10.50 (SO ₃)	0.5921
LL%=-7.72 (OM)+14.12 (SO ₃)	0.5488
Finer%=-27.87 (OM)+32.72 (SO ₃)	0.4885

Conclusions

Grain size analysis reveals a predominance of fine particles. Field density values varied, reflecting differences in soil composition and moisture content. Sandy soils, being less dense than clay soils, exhibit larger particle sizes and higher porosity. Standard Proctor test results indicated a relative consistency in maximum dry density and optimal moisture content, likely due to the presence of low-activity minerals like kaolinite, sample homogeneity, and higher salt concentrations. Chemical tests demonstrated that site T10 exhibits a significant increase in most measured properties.

Simple regression shows no strong relationships between the properties, except for a moderate correlation between chlorine and physical properties. However, multiple regression analysis improved the correlations, particularly between pH and chlorine. MLRA provides that suggested variations in pH could influence Atterberg limits. While relationships between physical properties and gypsum, TDS, organic matter, and sulfate percentages are observed, showing weaker R² values, likely due to the low concentrations of these properties in the study area's soil.

Acknowledgements

The authors would like to express their profound gratitude to everyone who contributed to this work, whether through guidance, insights, or valuable feedback.

References

- Abbas, Y.Y., 2002. Mechanism of penetration of sulfur salts into concrete, Unpublished Master's thesis, University of Technology, (in Arabic).
- Ahmed, A.M., Othman, B. S., and Ahmad, F. M., 2023. Production of geotechnical maps of the south-west of the city of Kirkuk using geographic information systems. *International Journal of Geography, Geology and Environment*, 5 (2), pp.181–191. <https://doi.org/10.22271/27067483.2023.v5.i2b.190>.
- Al-Abdullah, A.S., 2015. The effect of soil gypsum content on its compressibility and stabilization. *Al-Baath University Journal*, 37, 33-51 (In Arabic).
- Ali, A.R., Al-Mufti, T.M., and Taqi, C.M., 2021. Geochemical distribution of some heavy metals in agricultural soil and their environmental impacts in Kirkuk, Northern Iraq. *The Iraqi Geological Journal*, 54 (2), pp. 75-92. <https://doi.org/10.46717/igj.54.2A.6Ms-2021-07-27>.
- Aljuboori, N.S., and Çetin, H., 2019. Improvement of soil by using a structural repair mortar. *Journal of Science and Engineering*.
- Al-Kahdaar, R.M., and Al-Ameri, A.F.I., 2010. Correlations between physical and mechanical properties of Al-Ammarah soil in Messan Governorate. *Journal of Engineering*, 16(04), pp. 5946-5957.
- Al-Kasabi, A.A., 1993. *Soil Mechanics*, Dar Al-Kutub Al-Ilmiya Publishing, Cairo, Egypt, 7 P. (In Arabic).
- Al-Sultani, N.K., Al-Amar, H.A., and Al-Zubaydi, J.H., 2023. Geotechnical properties of soil slopes of the Great Musaiyab project, Babylon, Middle of Iraq. *The Iraqi Geological Journal*, 56(1), pp. 273-280. <https://doi.org/10.46717/igj.56.1B.20ms-2023-2-28>
- Arasan, S., and Yetimoğlu, T., 2008. Effect of Inorganic Salt Solutions on the Consistency Limits of Two Clays. *Turkish Journal of Engineering and Environmental Sciences*, 32(2).

- ASTM D2216-80, 2004. Standard test method for moisture content of soil. ASTM International.
- ASTM D854-14. 2014. Standard test method for specific gravity of soil solids by water pycnometer. ASTM International.
- ASTM, D 4318.14, 2004. Standard Test Methods for Liquid Limit, Plastic Limit and Plasticity Index of Soils.
- ASTM D - 698, 2004. Standard Test Methods for Laboratory Compaction Characteristics of Soil.
- ASTM D2937-10, 2016. Standard Test Method for Density of Soil in Place by the Drive-Cylinder Method.
- ASTM D-422, 2004. Standard Test Method for Particle-Size Analysis of Soils.
- B.S.1377-3, 1990. Methods Of Testing Soil for Civil Engineering Purposes, British Standards Institution, London.
- Barzanji, A.F., 1973. Gypsiferous soils of Iraq (Doctoral dissertation, Ghent University).
- Buday, T., and Jassim, S.Z., 1987. The regional geology of Iraq, vol 2: tectonism, magmatism and metamorphism, SE Geol. Surv. and Mineral Invest, Baghdad.
- Building Research Establishment (BRE), 2005. Concrete in Aggressive Ground (3rd ed., Special Digest 1). Building Research Establishment.
- Busch, W.H., and Keller, G.H., 1981. The physical properties of Peru-Chile continental margin sediments: the influence of coastal upwelling on sediment properties. *Journal of Sedimentary Research*, 51(3), 705-719.
- Certified M.T.P., 2024. Field Density Test Methods for Reliable Soil Analysis. Retrieved 23 January 2025, from <https://blog.certifiedmtp.com/field-density-test-methods-for-reliable-soil-analysis/>.
- Dewangan, S.K., Shrivastava, S., Kumari, L., Minj, P., Kumari, J., and Sahu, R., 2023. The effects of soil pH on soil health and environmental sustainability: A review. *Journal of Emerging Technologies and Innovative Research*, 10(6), 611-616.
- Fouad, S.F., 2015. Tectonic map of Iraq, scale 1: 1000 000, 2012. *Iraqi Bulletin of Geology and Mining*, 11(1), pp. 1-7.
- Gu, L., Zhang, J., Guo, L., and Lv, Q., 2022. Effect of Sulfate on the Aggregation of Clay Particles in Loess. *Front. Earth Sci.* 10:790882. DOI: [10.3389/feart.2022.790882](https://doi.org/10.3389/feart.2022.790882)
- Holtz, D.R. and Kovacs, D.W., 1981. *An Introduction to Geotechnical Engineering*. Prentice-Hall, Inc, 110 P.
- Ibrahim, R.A. and Tokmachy, A.A., 2023. Study of Geotechnical Properties of Clays in the Laylan Region and their Suitability in the Brick Industry in Northeastern Kirkuk, Northern Iraq. *The Iraqi Geological Journal*, 56(2), pp. 37-47. <https://doi.org/10.46717/igj.56.2E.3ms-2023-11-8>
- Karim, K.H., 2011. *The Geology of Iraq: Basic Principles*. Res Gate. <http://dx.doi.org/10.13140/2.1.3052.6245>
- Karira, H., Kumar, A., Raja, A., and Murtaza, A., 2018. Correlation between chemical and index properties of soils of the Hyderabad region. *Civil Engineering Journal*, 4(12), pp. 2821-2839. <https://doi.org/10.28991/cej-03091201>

- Khairul, N., Lee, C., Phuai, P., and Saiful, A., 2006. The Correlations Between Chemical and Index Properties for Soft Clay of Peninsular Malaysia. *Technology and Innovation for Sustainable Development Conference (TISD2006)*, January 2006, 152–161.
- Mahmoud, R.A. and Jaafar, I.M., 2017. Study of the proportions of sulphates, chlorides, and carbonates and their effect on engineering behavior in shallow loading layers in selected areas of the city of Basra / southern Iraq. *Journal of the University of Babylon*, 25 (1), 160–171 (In Arabic).
- Mahmood, R.A., 1997. Some geotechnical properties of recent Quaternary sediments in Basra city. Unpublished M. Sc. Thesis, College of Science, Basra University (In Arabic).
- Mohamed, A.I., Aljuboori, N.S., and Al-Jawadi, A.S. 2024a. Tracking Shaft Integrity of Jet Grouting Piles Injected in Soft Soil Layers Based on Sonic Integrity Test Method: A Case Study from Erdemli, Mersin Region, South Turkey. *The Iraqi Geological Journal*, 57 (2), pp. 54-66. <https://doi.org/10.46717/igj.57.2E.5ms-2024-11-14> .
- Mohamed, A.I., Saadi, S.W., Gart, I.H., and Mohammed, F.O., 2024b. Assessing the Improvement of Geotechnical Properties of Clayey Soil Using a Substrate Cement Mortar Material, from Ilgin, Konya City, Turkey. *The Iraqi Geological Journal*, 57 (2), pp. 162-176. <https://doi.org/10.46717/igj.57.2A.12ms-2024-7-22> .
- Moore, A.W., Anderson, B., Das, K., and Wong, W.K., 2007. Combining multiple signals for biosurveillance. *Handbook of Biosurveillance*, 235 P.
- NCCL (National Center of Construction Laboratories), 2001. *Materials and construction specifications*. Baghdad.
- Odell, R.T., Thornburn, T. H., and McKenzie, L. J. 1960. Relationships of Atterberg limits to some other properties of Illinois's soils. *Soil Science Society of America Journal*, 24(4), pp. 297-300.
- Raine, J., Stephan, G., and Rashid, A., 2003. *Laboratory Manual for Soil and Plant Analysis*, first edition in Arabic, jointly published by the International Center for Agricultural Research in the Dry Areas (ICARD) and the National Foundation for Agricultural Research. This manual is available at ICARD, Aleppo, Syria, 172 P.
- Roodposhti, H.R., Hafizi, M.K., Kermani, M.R.S., and Nik, M.R.G., 2019. Electrical resistivity method for water content and compaction evaluation, a laboratory test on construction material. *J Appl Geophys*, 168, pp. 49–58. <https://doi.org/10.1016/j.jappgeo.2019.05.015>
- Prakash, S., and Jain, P.K., 2002. *Engineering soil testing*. Roorkee: Nem Chand and Bros.
- Shikhil, N., Farid, A., and Thomas, N., 1999. *Chemistry handbook* (3rd ed.). National Center for Construction Laboratories, Performance Development Program (In Arabic).
- Sissakian, V.K., 2000. *Geological Map of Iraq*, 3rd Edition, scale 1:1000 000. GEOSURV, Baghdad, Iraq.
- Skalny, J., Marchand, J., and Odler, I., 2003. *Sulfate attack on concrete* (No. 15832). Taylor and Francis.
- Tanji, K.K., 2004. *Salinity in the Soil Environment*. Chapter 2 in *Salinity Environment- Plants Molecules*, A. Lauchli and L. Lutteg (eds.), Kluwer Academic Publishers, Dordrecht.
- Verma, S.K., Akhtar, S., and Shrivastava, S., 2017. Assessment of Particles of Varied Soil by Grain Size Analysis—A Case Study in Jabalpur, M.P., *International Journal of Engineering Research and Application*, 7(7), pp. 32-37. DOI:[10.9790/9622-0707093237](https://doi.org/10.9790/9622-0707093237)