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RELIABILITY OF VARIOUS SOIL CHARACTERISTICS RELATIONSHIPS FOR KIRKUK SOIL USING CONSISTENT UNDISTURBED FIELD SOILS SAMPLES WITH LINEAR REGRESSION MODELS

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EXTENDED ABSTRACT

La sempre crescente urbanizzazione ha comportato un aumento della costruzione di imponenti infrastrutture su superfici molto ridotte, per le quali è necessario valutare i rischi progettuali ed associare i relativi costi. Compito molto complesso potrebbe essere quello di ottenere un assestamento post-costruzione soddisfacente per le strutture realizzate su terreni soffici.

A tal riguardo, risulta importante valutare il modulo elastico e la resistenza di ogni tipo di terreno poiché le caratteristiche dei terreni hanno un'influenza sostanziale su diverse discipline, come la valutazione idrologica, il movimento dei contaminanti geoambientali, il controllo delle forniture agricole, i progetti di irrigazione e di dighe e la valutazione geotecnica per la progettazione stradale.

Per una grande varietà di terreni la curva sforzo-deformazione può essere prevista utilizzando le caratteristiche meccaniche oltre ai dati di letteratura combinati con le osservazioni sul campo, con i dati di laboratorio ottenuti da campioni sia disturbati che indisturbati.

Le proprietà ingegneristiche dei terreni sono importanti in molti casi: numerosi parametri geotecnici vengono calcolati empiricamente utilizzando le proprietà indice dei suoli come il limite plastico e il limite liquido. Inoltre, parametri del terreno, come l'indice di plasticità, possono essere utilizzati per stimare la resistenza al taglio non drenata, calcolare i parametri del modello del terreno Cam-Clay e valutare la relazione tra il numero di colpi nel test di penetrazione standard (*SPT*) e la resistenza del terreno.

La letteratura dispone di un'ampia gamma di relazioni statistiche e matematiche tra i diversi parametri dei terreni. Tali relazioni, tuttavia, sono basate su dati di sottosuolo provenienti da tutto il mondo e non includono valori affidabili e completi per i suoli della città di Kirkuk (Iraq).

Prelevare campioni di terreno affidabili e indisturbati da diverse parti di una singola città, in particolare Kirkuk City, rappresenta una difficoltà significativa: l'obiettivo principale di questo studio è quello di esaminare quanto siano affidabili le correlazioni per varie proprietà del suolo della città di Kirkuk, utilizzando diversi set di dati di terreno ottenuti da vari sondaggi, per creare relazioni matematiche precise utilizzando modelli di regressione lineare. Nello specifico, sono stati ricavati diversi dati di terreno da 40 sondaggi nella città di Kirkuk le cui proprietà includevano: contenuto di acqua (w%), limiti liquido e plastico (*LL* e *PL*), indici di plasticità e liquidità (*PI* e *LI*), resistenza a compressione semplice (*UCS*), peso per unità di volume totale e secco (γ_t e γ_d) e caratteristiche di consolidazione (rapporto dei vuoti iniziali "e_o", indice di compressione "C_c" e indice di ricompressione "C_r").

Per esaminare l'affidabilità delle relazioni tra le diverse caratteristiche del suolo sono state utilizzate le correlazioni di campo con modelli di regressione lineare che utilizzano la tecnica dei minimi quadrati. L'accuratezza dei modelli di regressione lineare proposti è stata valutata in base ai valori R^2, *R* multiplo e *RMSE*. I dati del suolo acquisiti sono stati valutati utilizzando modelli caratteristici pubblicati in precedenza. È stato dimostrato che *PI* e *LI* sono correlati positivamente mentre w% e γ_d sono correlati negativamente e il loro grado di correlazione è rispettivamente 0,878 e -0,573. Sono state trovate correlazioni lineari positive per le relazioni tra i valori di *LL*, *PL*, *PI*, *LI* e γ_t con un aumento del contenuto di acqua utilizzando il modello di regressione lineare suggerito per i suoli di Kirkuk, mentre sono state dimostrate correlazioni lineari negative per le relazioni tra i valori di *UCS*, γd, e_o, C_c e C_r con un aumento del contenuto di acqua.

È evidente che i dati di terreno sono al di sotto della linea normalizzata tracciata (C_u/σ_{vo} = 0.005**LL*), ad indicare che i terreni testati hanno una bassa resistenza al taglio non drenata. Si osserva, poi, che quasi tutti i dati di terreno si trovano al di sotto del modello non lineare disegnato ($\gamma = 42.42*w$-0.239) che può essere ottenuto a causa del basso contenuto di acqua naturale registrato.

La maggior parte dei dati elaborati si trovano evidentemente al di sotto del modello impostato ($C_c = 0.007*(LL\text{-}10)$), suggerendo che la compressione potrebbe essere sovrastimata se viene utilizzato il modello fornito. Infine, si dimostra che i suoli della città di Kirkuk (Iraq) hanno valori di C_c inferiori a quanto previsto dai modelli precedenti.

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ABSTRACT

Due to the new construction and development of massive geotechnical superstructures, as well as a limited budget and time frame, it is critical to assess the reliability of numerous correlations between different soil characteristics. Various field soil data from 40 boreholes across Kirkuk City (Iraq) were obtained and they include water content (w%), liquid and plastic limits (LL and PL), plasticity and liquidity indices (PI and LI), unconfined compressive strength (UCS), wet and dry densities (γ_t and γ_d), and consolidation characteristics (initial void ratio "e_o", compression index "C_c" and recompression index "C_r"). Field correlations with linear regression models were used to examine the reliability of relationships between different soil characteristics. The acquired soil data were evaluated using distinctive previous published models. It was demonstrated that the PI and LI are correlated positively whereas the w% and γ_d are correlated negatively and their degree of correlations are 0.878 and -0.573 respectively. It was proved that positive linear regression models can be obtained for the relations between the values of the LL, PL, PI, LI, and γ_t with the increase of the water content. Finally, it is demonstrated that the soils of Kirkuk City (Iraq) have Cc values less than the prediction of the previous models.

Keywords: *soil characteristics, reliability of soil relationships, parameters correlations, linear regression model*

INTRODUCTION

The land scarcities due to modern urbanization have caused an increase in contracting huge transportation infrastructures on the surface of minimal grounds. Specific confronts and concerns related to threats, costs, and extensive-term implementation of numerous engineering projects have been upraised (Feng *et alii* , 202; Pinghe *et alii*, 2020). Obtaining an acceptable post-construction settlement for many structures built over soft soils can be one of the extreme challenges. Evaluating soil strength and elastic modulus of any soil type is significant. Mechanical properties could be used to predict the load-deflection curve for various materials (Carey *et alii*, 2022). Countless relationships for different soil correlations have been provided in the literature to estimate various soil properties where undisturbed and disturbed soil data incorporated with laboratory and field measurements were used (Kasim *et alii*, 2021).

Several disciplines, including hydrological assessment, geoenvironmental contaminant movement, agricultural supply control, irrigation and dam projects, and geotechnical assessment for road building, are significantly impacted by soil characteristics (Fredlund *et alii*, 2009). The soil indices with engineering features are relevant in a variety of situations, such as ground contamination by industrial waste, where the leakage of any chemical might be the cause of the pollution (Naik *et alii*, 2019).

The soil indices such as liquid and plastic limits are empirically utilized to compute many geotechnical soil properties. It is feasible that the most famous correlation is Casagrande's A-line which categorized the soil into clays and silts depending on the correlation between soil type and the relationship between liquid limit and plasticity index. Moreover, soil factors such as the plasticity index may be utilized to estimate undrained shear strength, estimate Cam-Clay soil model parameters, and evaluate the ratio of soil strength to the number of blow counts on the standard penetration test (Vardanega *et alii*, 2014). Many different mathematical and statistical correlations between various soil properties are available in the literature. However, such correlations were made based on soil data distributed in different places around the world where no reliable extensive data for Iraqi soils from Kirkuk City have been used (Raheem *et alii*, 2021; Raheem *et alii*, 2023). In addition, it is a substantial challenge to collect undisturbed reliable field soil samples from various locations in one city specifically in Kirkuk City.

The main objective of this study is to investigate the reliability of correlations for different soil characteristics of Kirkuk City. The specific objective is concentrated on using various collected field soil data from different boreholes for Kirkuk City to obtain particular mathematical correlations using linear regression models. Additionally, Kirkuk City's soil properties have been assessed using earlier models from the available literature.

DESCRIPTION OF THE STUDIED AREA

The studied area is Kirkuk City, which is located in the middle northeastern zone of Iraq. The city's latitude and longitude are 35.478565 and 44.401932 respectively. The map of Kirkuk City with its administrative units is shown in Figure 1.

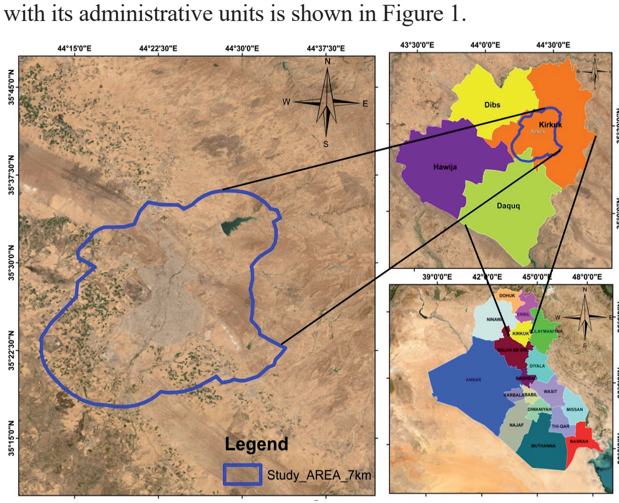

Fig. 1 - The map of Kirkuk City

It deserves to be emphasized that the surface morphology of Kirkuk City in Iraq is the plain twisted sector pattern expanded from the northern range of Iraq and it encompasses the segmentation of the Zagros Lithology Belt (Kent, 2010). Yet, the primary large-scale city constructions that contain hydrocarbon-providing sources are not the usual base formed from foreland basin deposits decollements. Although the city's folds modify and deform strata originating in the Zagros uplands and accumulating in the developing foreland basin, the generated faults are advanced from the pre-Zagros stratigraphy. The topographical changes and concomitant structural adjustments define Kirkuk City's limits. The Mountain Front Flexure establishes the boundary to the northeast and it is connected to imbricated attacks. The greater height of the City's folds toward the southeast of the Lurestan Salient might be the result of the neighboring gradient at the Khanaqin lineament. A full geological map for Iraq is presented in Figure 2 (Sissakian *et alii*, 2015).

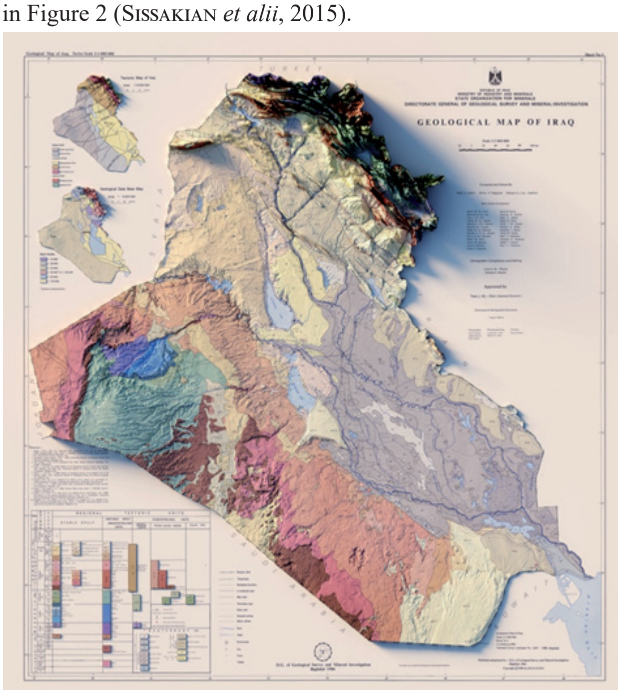

Fig. 2 - The geological map of Iraq (Sissakian & Fouad, 2015)

taken from shallow depths ranging from 1.5 m to 2.5 m. As a result, all of the soil samples came from the same area and contained an acceptable proportion of clay.

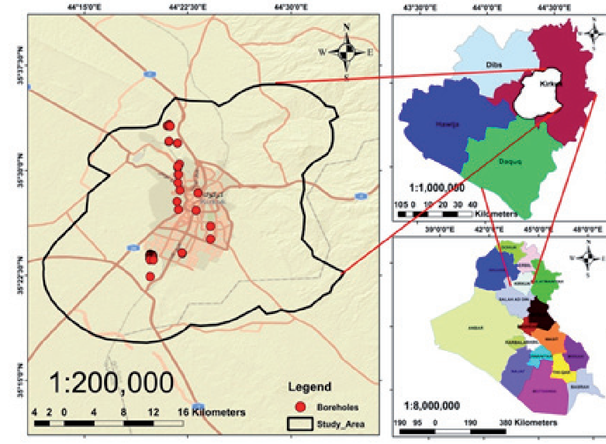

Fig. 3 - The borehole locations in Kirkuk City

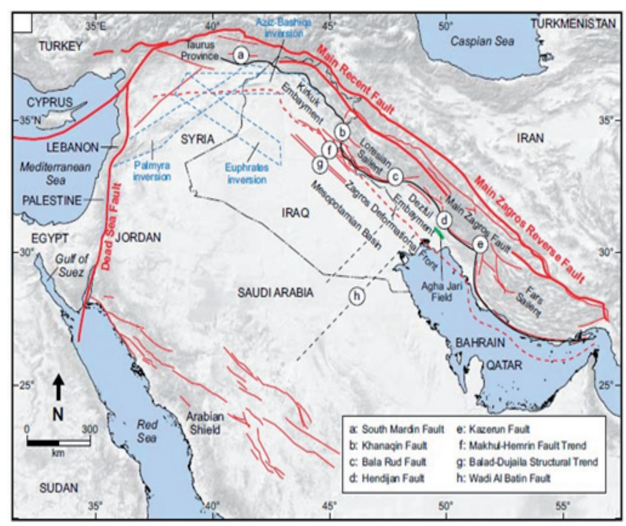

Fig. 4 - The geological layers for Kirkuk City (Kent, 2010)

DATA COLLECTION

A comprehensive list of field data has been obtained from 40 different boreholes in Kirkuk City. The borehole locations have been identified on Kirkuk map as shown in Figure 3. The geological layers for Kirkuk City have been presented in Figure 4 (Kent, 2010). The procedure for collecting the data is beneficial in terms of cost reduction and time savings for any upcoming projects that may be constructed in the city. Table 1 provides an overview of the boreholes' geotechnical parameters, including their natural water content, liquid and plastic limits, plasticity and liquidity indices, unconfined compressive strength, wet and dry densities, and consolidation properties. All soil samples were taken from shallow depths ranging from 1.5 m to 2.5 m.

RESULTS

Field soil correlation

The correlations between various soil characteristics for collected field soil data such as natural water content (*w*%), liquid and plastic limits (*LL* and *PL*), plasticity and liquidity indices (*PI* and *LI*), unconfined compressive strength (*UCS*), wet and dry densities (γ_t and γ_d), initial void ratio (e_o), compression index (C_c) and re-compression index (C_r) has been summarized in Table 2. It can be used to investigate the correlations for all the given soil characteristics with the simplest measured soil property which is the natural water content (*w%*). It is indicated that there are positive correlations between *w%* and *LL*, *PL*, *PI*, *LI*, and γ_t with

BH	w%	LL	PL	PI	LI	UCS (kN/m²)	γ_t (kN/m³)	γ_d (kN/m³)	e_o	C_c	C_r
1	12	32	8	24	0.167	31.142	2.02	1.804	0.91	0.027	0.062
2	15	32	27	5	-2.400	139.033	1.99	1.730	0.8	0.22	0.055
3	10	34	15	19	-0.263	37.880	1.92	1.745	1.061	0.339	0.166
4	11	32	13	19	-0.105	197.413	1.93	1.739	0.52	0.296	0.029
5	10.5	35	14	21	-0.167	190.010	2.03	1.837	0.53	0.339	0.04
6	11.5	35	15	20	-0.175	120.861	2.04	1.830	0.546	0.258	0.088
7	12	32	17	15	-0.333	167.097	2.05	1.830	0.649	0.169	0.038
8	10	28	20	8	-1.250	162.049	2.06	1.873	0.93	0.022	0.051
9	10.7	33	16	17	-0.312	49.748	2.07	1.870	0.62	0.16	0.023
10	10	34	16	18	-0.333	107.393	2.08	1.891	0.96	0.25	0.022
11	11.3	30	15	15	-0.247	156.004	2.09	1.878	0.5	0.043	0.03
12	18	27	21	6	-0.500	100.169	2.1	1.780	0.808	0.117	0.023
13	10.8	30	24	6	-2.200	168.453	2.11	1.904	0.845	0.124	0.096
14	11.7	34	24	10	-1.230	160.590	2.12	1.898	0.78	0.146	0.037
15	11.2	32	16	16	-0.300	47.801	2.13	1.915	0.555	0.03	0.04
16	10.3	24	8	16	0.144	31.142	1.94	1.759	0.92	0.27	0.05
17	10	32	17	15	-0.467	179.701	2.14	1.945	0.563	0.258	0.025
18	11	24	8	16	0.188	48.070	1.95	1.757	0.533	0.365	0.252
19	12	34	24	10	-1.200	170.397	2.025	1.808	0.78	0.125	0.25
20	14	49	14	35	0.000	190.010	2.035	1.785	0.536	0.336	0.04
21	18.4	37.5	8.63	28.87	0.338	47.151	1.945	1.643	0.62	0.119	0.026
22	22	40.2	21.1	19.1	0.047	8.905	1.965	1.611	0.62	0.113	0.025
23	11.65	51.1	20.3	30.8	-0.281	164.987	1.975	1.769	0.621	0.111	0.03
24	13.8	38.8	19.1	19.7	-0.269	110.070	1.985	1.744	0.52	0.122	0.043
25	14.8	48.2	16.6	31.6	-0.057	115.153	1.995	1.738	0.622	0.118	0.036
26	11.5	53.8	15.4	38.4	-0.102	45.494	1.99	1.785	0.64	0.116	0.04
27	19.6	49.8	25.6	24.2	-0.248	39.462	2.066	1.727	0.58	0.114	0.023
28	18.1	54.7	15.4	39.3	0.069	193.606	2.067	1.750	0.53	0.118	0.025
29	19.5	69	24.2	44.8	-0.105	67.905	2.068	1.731	0.65	0.117	0.023
30	17.2	49.6	13.1	36.5	0.112	201.397	2.07	1.766	0.56	0.236	0.0126
31	15.3	42.9	20.7	22.2	-0.243	59.931	2.08	1.804	0.566	0.123	0.036
32	17.6	61.3	25.9	35.4	-0.234	45.472	2.011	1.710	0.631	0.116	0.36
33	21.6	38	11.5	26.5	0.381	179.119	2.09	1.719	0.589	0.155	0.033
34	18.5	50.2	19.7	30.5	-0.039	116.778	2.1	1.772	0.52	0.114	0.022
35	16.76	62	29	33	-0.371	48.968	2.115	1.811	0.54	0.1	0.022
36	18.2	54.1	17.4	36.7	0.022	129.227	2.118	1.792	0.58	0.112	0.022
37	16.3	43.2	12.4	30.8	0.127	74.770	2.21	1.900	0.541	0.122	0.041
38	16.5	61.7	30	31.7	-0.426	49.714	2.13	1.828	0.524	0.113	0.014
39	18.22	57.9	14.9	43	0.077	64.127	2.14	1.810	0.522	0.111	0.033
40	15.6	50.6	18.2	32.4	-0.080	117.199	2.2	1.903	0.56	0.133	0.0333

Tab. 1 - Geotechnical properties for various soil characteristics for Kirkuk City

the highest degree of correlation of 0.597. However, negative correlations between *w%* and *UCS*, γ_d, e_o, C_c, and C_r have been noticed where the highest degree of correlation was -0.573. In addition, there are positive correlations between *LL* and *PL*, *PI*, *LI*, and γ_t with the highest degree of correlation of 0.878. Nevertheless, negative correlations between *LL* and *UCS*, γ_d, e_o, C_c, and C_r have been obtained. The *PL* has been correlated negatively with *PI*, *LI*, *UCS*, and C_c and positively with γ_t, γ_d, e_o, and C_r. Both *PI* and LI are correlated negatively with *UCS*, γ_d, e_o, and C_r. It is worthwhile to mention that *PI* is correlated positively with *LI*, and γ_t with a highest degree of correlation of 0.620. The *UCS* is correlated positively with γ_t, γ_d, and C_c and negatively with e_o and C_c. The γ_t and γ_d are correlated negatively with C_c and C_r. The eo is correlated positively with C_c and C_r and C_c is correlated positively with C_r. The highest positive correlation was 0.878 and it correlates *PI* with *LI* while the highest negative correlation was -0.573 and it correlates *w%* with γ_d.

Evaluated property	Given property	M	N	Equation	R^2	Multiple R	RMSE
LL	w%	1.943	13.559	LL = 1.943 * w(%) + 13.559	0.356	0.597	9.369
PL	w%	0.383	12.278	PL = 0.383 * w(%) + 12.278	0.060	0.245	5.439
PI	w%	1.559	1.281	PI = 1.559 * w(%) + 1.281	0.276	0.525	9.056
LI	w%	0.051	-1.035	LI = 0.051 * w(%) − 1.035	0.098	0.313	0.552
UCS (kN/m²)	w%	-3.273	155.340	UCS = −3.273 * w(%) + 155.340	0.040	0.200	57.777 (kN/m²)
γ_t (kN/m³)	w%	0.004	1.993	γ_t = 0.004 * w(%) + 1.993	0.045	0.212	0.069 (kN/m³)
γd (kN/m³)	w%	-0.012	1.967	γ_d = −0.012 * w(%) + 1.967	0.328	0.573	0.061 (kN/m³)
e_o	w%	-0.015	0.867	e_o = −0.015 * w(%) + 0.867	0.140	0.374	0.136
C_c	w%	-0.008	0.278	C_c = −0.008 * w(%) + 0.278	0.112	0.349	0.083
C_r	w%	-0.003	0.107	C_r = −0.003 * w(%) + 107	0.029	0.170	0.071

Tab. 2 - Correlation between various geotechnical characteristics for Kirkuk City

Linear regression model

Various soil characteristics are predicted using a proposed linear regression model depending on the measured water content as a single independent variable. The proposed linear regression model has the following form:

$$\text{Evaluated Soil Property} = M * \text{Independent Variable} + N \quad (1)$$

where *M* and *N* are model parameters.

All the details of the proposed model (Eq. 1) have been summarized in Table 3. The least square method has been utilized to obtain the linear regression model. In addition, Table 3 presents the model parameters (*M* and *N*), R^2, multiple *R*, and *RMSE* values. The range of the model parameters *M* and *N* are from -3.327 to 1.943 and -1.035 to 155.340 respectively. In addition, the R^2, multiple *R*, and *RMSE* values range from 0.029 to 0.365, 0.170 to 0.597, and 0.061 to 57.777. The variations of different soil characteristics with the natural water content have been shown in Figures 5 (a-e) and 6 (a-e). In Figure 5 (a-e), the variations of *LL*, *PL*, *PI*, *LI,* and *UCS* with the natural water content have been presented. Positive linear correlations are observed for the relationships between the values of *LL*, *PL*, *PI*, and *LI* with the increase of the natural water content, whereas negative linear correlation is noticed for the relationship between the values of *UCS* with the increase of the natural water content. In Figure 6 (a-e), the variations of γ_t, γ_d, e_o, C_c, and C_r with the natural water content have been introduced. Negative linear correlations are observed for the relationships between the values of γ_d, e_o, C_c, and C_r with the increase of the natural water content while a positive linear correlation is remarked for the relationship between the values of γ_t with the increase of the natural water content.

Evaluated property	Given property	M	N	Equation	R^2	Multiple R	RMSE
LL	w%	1.943	13.559	$LL = 1.943 * w(\%) + 13.559$	0.356	0.597	9.369
PL	w%	0.383	12.278	$PL = 0.383 * w(\%) + 12.278$	0.060	0.245	5.439
PI	w%	1.559	1.281	$PI = 1.559 * w(\%) + 1.281$	0.276	0.525	9.056
LI	w%	0.051	-1.035	$LI = 0.051 * w(\%) - 1.035$	0.098	0.313	0.552
UCS (kN/m^2)	w%	-3.273	155.340	$UCS = -3.273 * w(\%) + 155.340$	0.040	0.200	57.777 (kN/m^2)
γ_t (kN/m^3)	w%	0.004	1.993	$\gamma_t = 0.004 * w(\%) + 1.993$	0.045	0.212	0.069 (kN/m^3)
γd (kN/m^3)	w%	-0.012	1.967	$\gamma_d = -0.012 * w(\%) + 1.967$	0.328	0.573	0.061 (kN/m^3)
e_o	w%	-0.015	0.867	$e_o = -0.015 * w(\%) + 0.867$	0.140	0.374	0.136
C_c	w%	-0.008	0.278	$C_c = -0.008 * w(\%) + 0.278$	0.112	0.349	0.083
C_r	w%	-0.003	0.107	$C_r = -0.003 * w(\%) + 107$	0.029	0.170	0.071

Tab. 3 - Linear regression analysis for various soil characteristics for Kirkuk City

Soil characteristics evaluation

The collected field soil data for Kirkuk City have been evaluated depending on the conventional used methods. The variation of the plasticity index versus liquid limit for the field soil data has been shown in Figure 7(a). It is clearly shown that most of the soils lie between A-line (Ip = 0.73*(LL-20)) and U-line (Ip = 0.9*(LL-8)) starting from LL = 24 to LL = 69. In addition, most of the soils are CL soil with LL < 50. The variation of the undrained shear strength versus liquid limit for the field soil data has been shown in Figure 7(b). It can be noticed that the field soil data are located under the drawn normalized line (Cu/σ_{vo} = 0.005*LL), which indicates low observed undrained shear strength for the field soils. The variation of the wet soil density versus the natural moisture content for the field soil data has been shown in Figure 7(c). It is observed that almost all the field data are located below the nonlinear drawn model (γ = 42.42*w-0.239), which could be obtained due to low recorded natural water content. The variation of the compression index versus the initial void ratio for the field soil data is shown in Figure 7(d). It is noticed that most of the field data are distributed around the drawn model (C_c = 1.04*log(e_o)+0.357) and most of the data with e_o between 0.5 and 0.649 have compression index values compatible with model prediction evaluations.

A similar relationship between the variation of the compression index and initial void ratio has been shown in Figure 7(e) compatible with another drawn model (C_c = 0.575*(e_o)-0.241). It is also noticed that most of the field data are located around the drawn model for the e_o values in the range of 0.5 to 0.649. The variation of the compression index versus the natural water

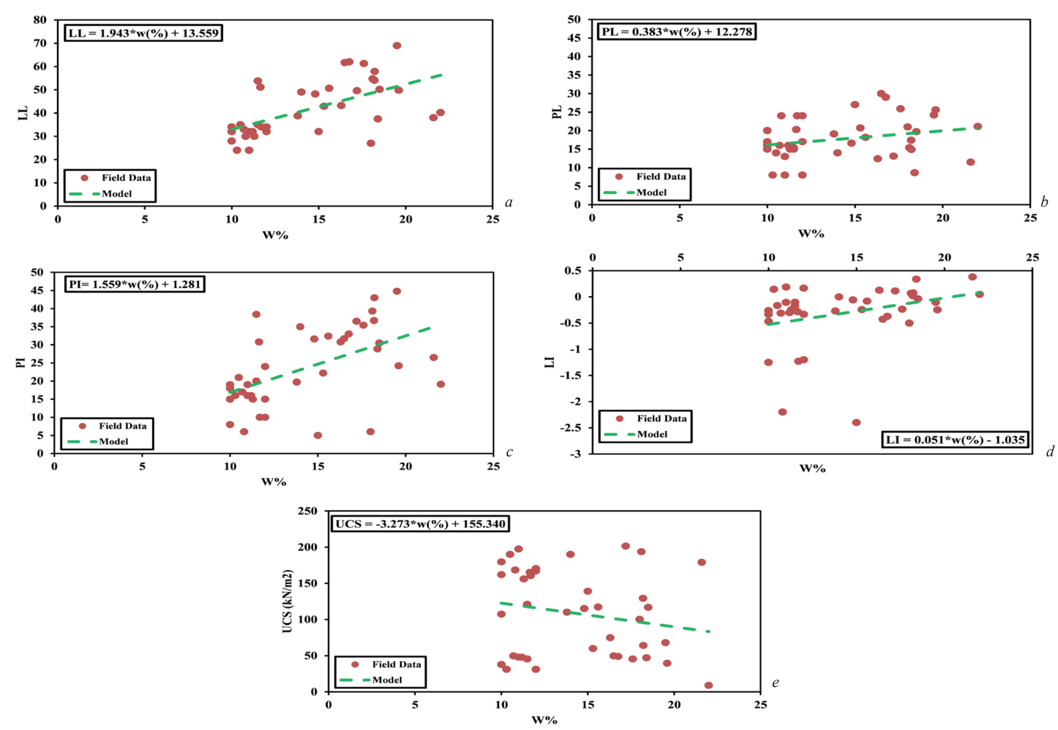

Fig. 5 - The variation of different soil characteristic with natural water content for Kirkuk City, (a) LL vs. W%, (b) PL vs. W%, (c) PI vs. W%, (d) LI vs. W%, and (e) UCS vs. W%

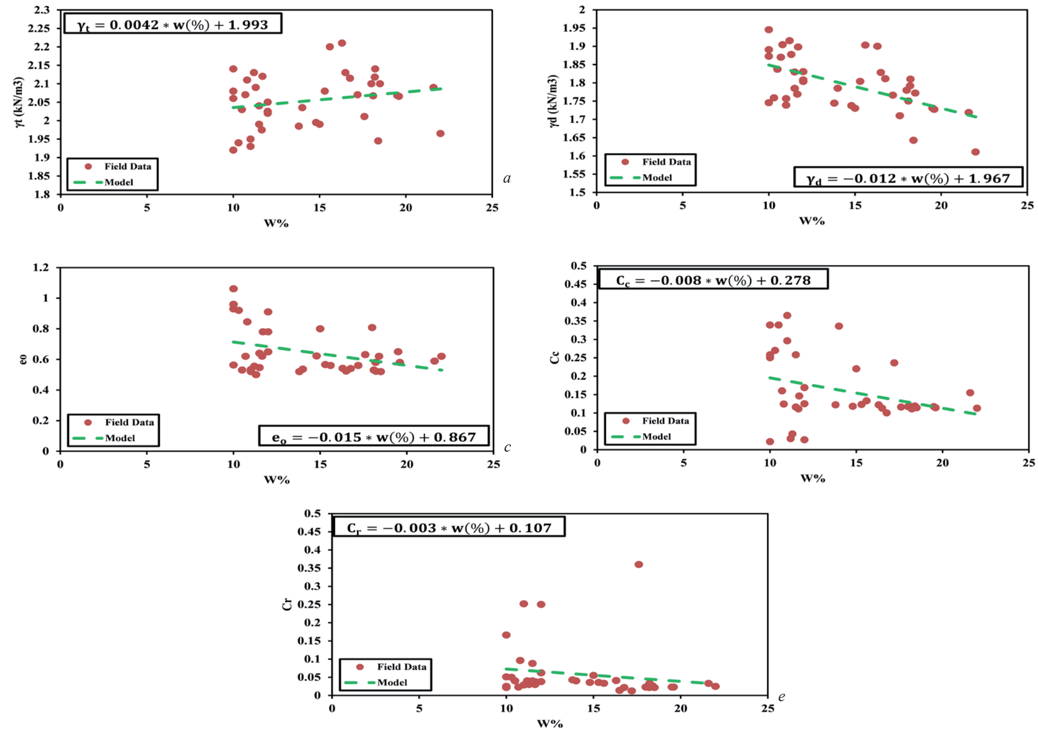

Fig. 6 - The variation of different soil characteristics with natural water content for Kirkuk City, (a) γ_t vs. W%, (b) γ_d vs. W%, (c) e_o vs. W%, (d) Cc vs. W%, and (e) C_r vs. W%

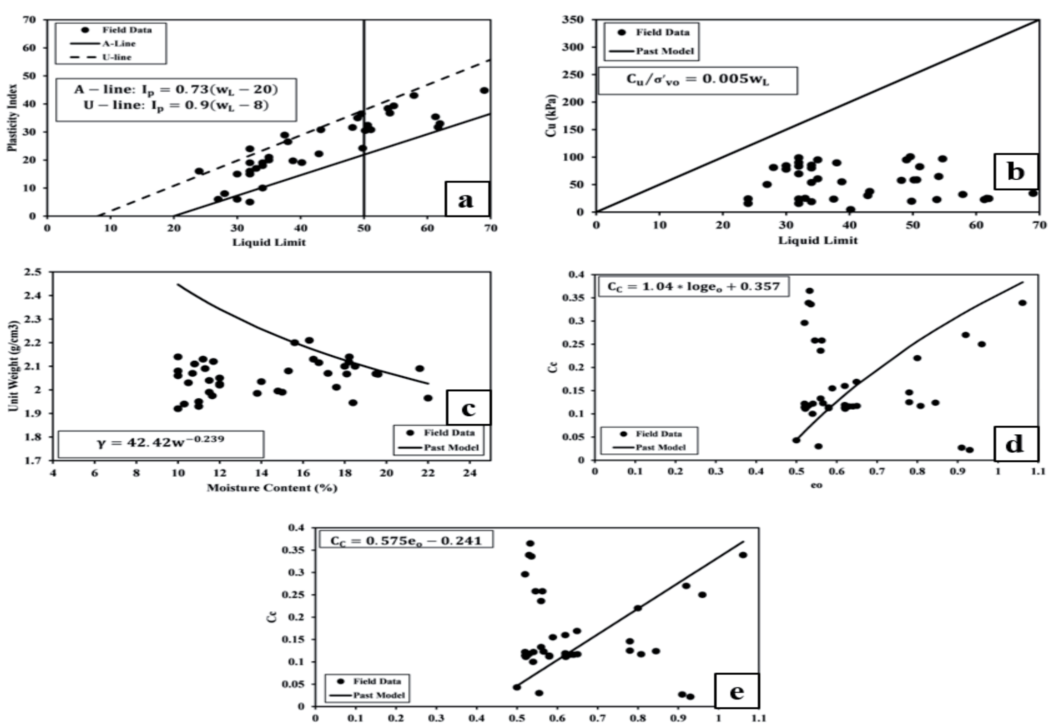

Fig. 7 - Evaluation of different soil characteristics using field soil data and various literature models for Kirkuk City, (a) PI vs. LL, (b) Cu vs. LL, (c) γ_t vs. W%, (d) C_c vs. e_o, and (e) C_c vs. e_o

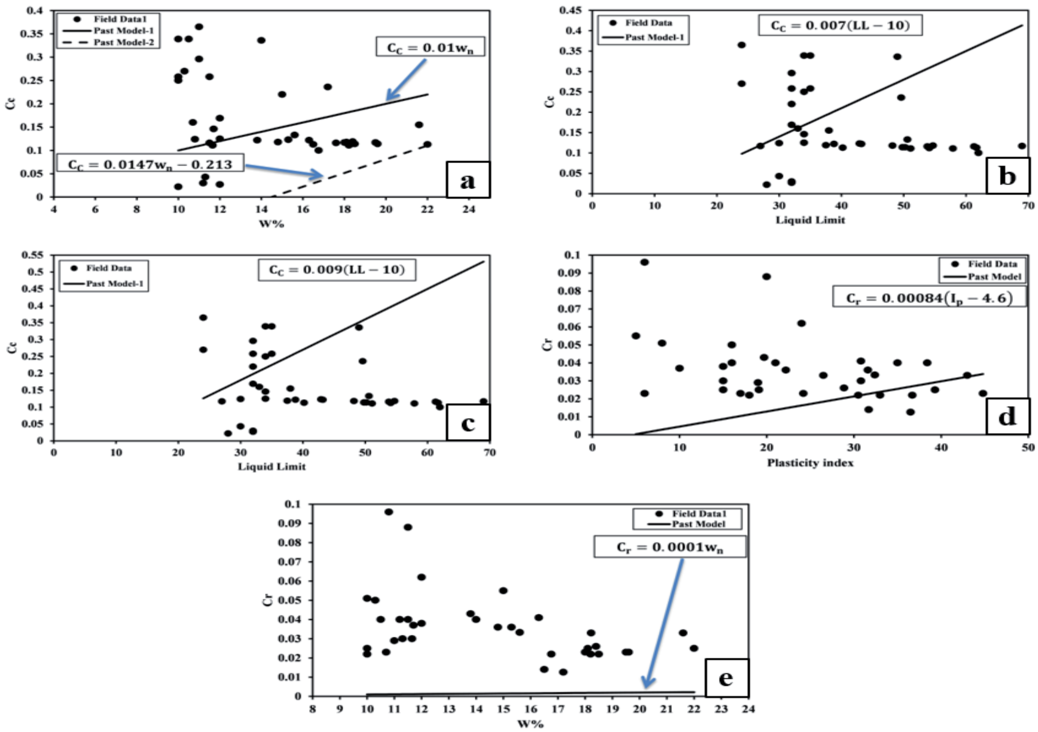

Fig. 8 - Evaluation of different soil characteristics using field soil data and various literature models for Kirkuk City, (a) PI vs. LL, (b) Cu vs. LL, (c) γ_t vs. W%, (d) C_c vs. e_o, and (e) C_c vs. e_o

content for the field soil data is shown in Figure 8(a). Almost half of the field soil data are located above the first model (C_c = 0.0147**w* – 0.213) and below the second model (C_c = 0.01**w*), which indicated that the compression index in this region could be predicted reasonably in the range of the two used models. The variation of the compression index versus liquid limit for the field soil data is shown in Figure 8(b). It is clearly shown that most of the field soil data are located below the drawn model (C_c = 0.007*(*LL*-10)), which indicated that the compression could be overpredicted as the given model is used. A similar relationship between the variation of the compression index and liquid limit has been shown in Figure 8(c) compatible with another drawn model (C_c = 0.009*(*LL*-10)). It is also noticed that most of the field data are located below the drawn model with a lower compression index than the predicted values. The variation of the re-compression index versus the plasticity index for the field soil data is shown in Figure 8(d). It is clearly shown that most of the field data are located above the drawn model (C_r = 0.00084*(*Ip*-4.6)), which means that the field data is underpredicted using the given model. The variation of the re-compression index versus the natural water content for the field soil data is shown in Figure 8(e). It is clearly shown that all the field data are located above the drawn model (C_r = 0.0001**w*), which means that the field data is underpredicted using the given model.

CONCLUSIONS

In this study, various field soil data from 40 boreholes in Kirkuk City have been collected. Numerous geotechnical properties for the boreholes including natural water content, liquid and plastic limits, plasticity and liquidity indices, unconfined compressive strength, wet and dry densities, and consolidation characteristics have been stated. Different relationships between various soil characteristics have been investigated using field soil correlation and linear regression models. In addition, various soil characteristics have been evaluated using field soil data and distinctive models from the literature. Based on the results of this study, the following conclusions can be illustrated:

1. Different positive and negative correlations are obtained between distinctive soil characteristics.
2. The highest positive correlation was noticed between PI and LI with a degree of correlation of 0.878 while the highest negative correlation was remarked between *w%* and γ_d with a degree of correlation of -0.573.
3. Using the proposed linear regression model for Kirkuk soils, positive linear correlations are obtained for the relations between the values of the *LL*, *PL*, *PI*, *LI*, and γ_t, with the increase of the water content, whereas negative linear correlations are proved for the relations between the values of the *UCS*, γ_d, e_o, C_c, and C_r with the increase

of the water content.

4. Based on the soil characteristics evaluation, it is proved that most of the soils in Kirkuk City are *CL* soil with *LL* < 50.
5. Using soil characteristics evaluation, it is demonstrated that Kirkuk City has soils with C_c values less than the previous models' prediction.

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