Research Article

Aram M. Raheem*, Najat Q. Omar, Ibrahim J. Naser and Mohammed O. Ibrahim

GIS implementation and statistical analysis for significant characteristics of Kirkuk soil

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Abstract: In the presence of harsh economic conditions, conducting laboratory experiments in a wide anticipated area to determine soil properties for any purpose or task within a city is unachievable. Hence, this work is focused on incorporating the existing record data of 56 distinct soil samples acquired from different pits of Kirkuk city utilizing spatial analysis described by inverse distance weighted (IDW) and Kriging methodologies. The incorporated constituents were principally categorized into basic soil characteristics such as clay, silt, sand, and gravel contents and various soil parameters such as initial void ratio (e_o), angle of internal friction (ϕ), cohesion (c), and optimum soil moisture content. Moreover, quantitative approaches such as geotechnical parameters association, linear single, and linear multi-regression models were used. Significant discrepancies in both approaches are readily obvious in the third to fifth zones, indicating that IDW and Kriging processes describe the distribution of sand in Kirkuk city differently. Furthermore, linear multi-regression model between basic and investigated soil parameters show good to excellent and very good to excellent degrees of correlation, with multiple R values in the range of (0.77–0.97) and (0.86–0.98), respectively.

Keywords: GIS, IDW and Kriging techniques, statistical and regression models

*** Corresponding author: Aram M. Raheem,** Department of Civil Engineering, University of Kirkuk, Kirkuk, Iraq, e-mail: aram_raheem@uokirkuk.edu.iq
Najat Q. Omar: Department of Civil Engineering, University of Kirkuk, Kirkuk, Iraq, e-mail: naj7engg@uokirkuk.edu.iq
Ibrahim J. Naser: Department of Civil Engineering, University of Kirkuk, Kirkuk, Iraq, e-mail: ibrahim.j.naser@uokirkuk.edu.iq
Mohammed O. Ibrahim: Department of Civil Engineering, University of Kirkuk, Kirkuk, Iraq, e-mail: m.o.ibrahim@uokirkuk.edu.iq

1 Introduction

At unsampled locations, geostatistical approaches might supply dependable approximations as the measurement scale eliminates the variance at the level of significance [1]. In contrast to traditional modeling methodologies, geographical expectation algorithms, commonly referred as spatial analytical models, integrate data from the physical position for the experimental data points [2]. In the presence of the complexity in soil characteristics, investigations utilizing spatial analysis are critical in enhancing soil planning and assessments, providing innovative information for accurate treatment, and growing fertilizer application in soils [3].

As is known, soil is an essential constituent in the urban environment that ensures an impression on the overall quality of life both directly and indirectly [4]. Planning and decision-making require an understanding of the geographical extent and recognition of contaminated municipal soils and topographical regions, as well as a clear understanding of the source of contamination [5,6]. Several studies have found that soils in metropolitan settings exhibit a lot of variation [7,8]. The non-homogeneity in soil properties, for instance, can affect the capability of the soil to absorb external pollutants depending on the various characteristics of density, texture, absorption, and humidity [9]. In addition, the soil non-homogeneity has resulted in the use of the concepts of probability in analyzing the load transfer to the foundation of submarine structures [10]. Furthermore, the standard penetration test is one of the soil field tests that can be utilized as an indicator for soil non-homogeneity since it provides various values for the soil density and shear strength parameters at different soil depths for the same examined site [11].

In geostatistical, the geographical interpolation method is becoming progressively important in understanding and solving urban soil contamination complications. The geostatistical methods depend on the minimum variance approximation and measurable diagramming of the contaminant spreading [12]. The quality of a map

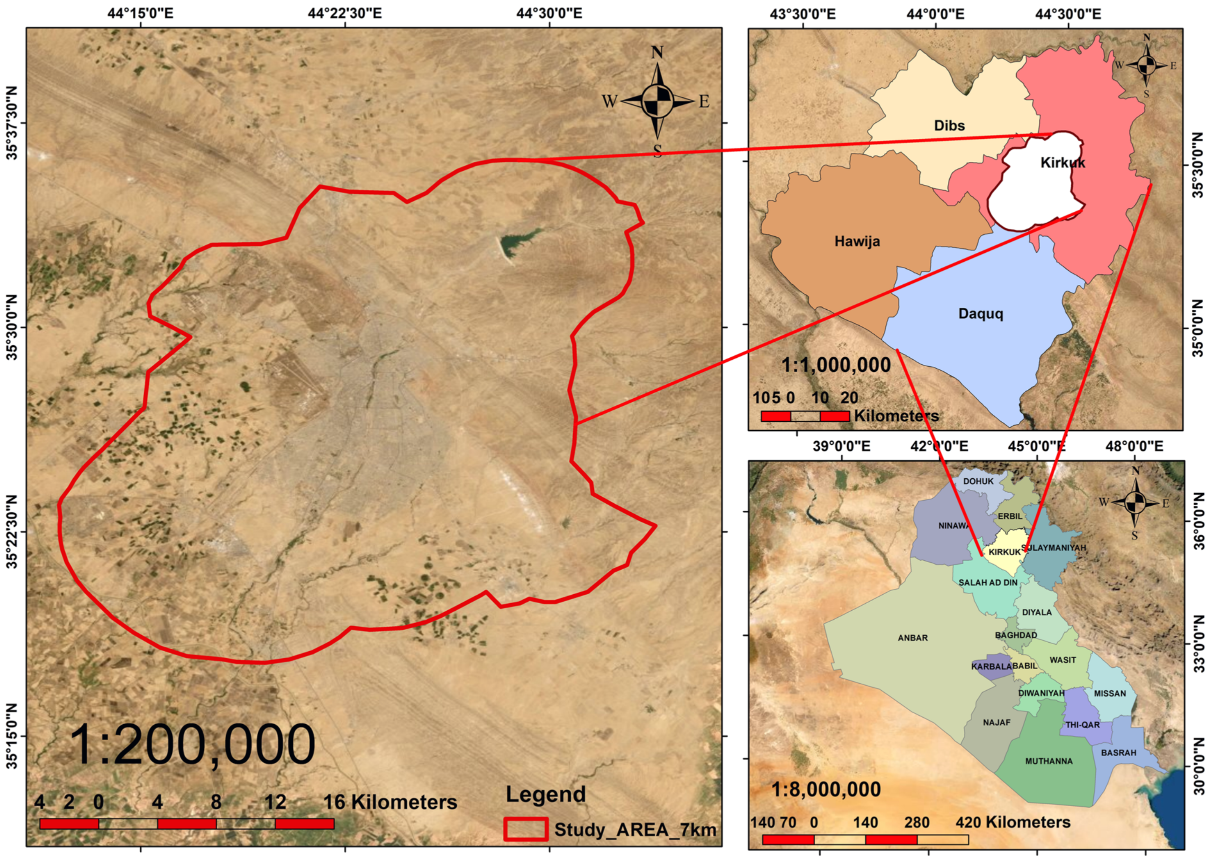

Figure 1: Localization of Kirkuk city using GIS technique.

obtained using such geostatistical techniques can be influenced by a variety of things such as sampling, interpolation technique, and soil heterogeneity [13]. Two different methods represented by inverse distance weighted (IDW) and Kriging are used as geographical techniques to create digital maps for distinctive soil properties [6,14]. Geostatistical approaches have extraordinary features in preparing accurate approximations in areas where no samples have been taken [15]. These approaches, known as spatial interpolation techniques, differ from conventional statistical methodologies in that they take into consideration the physical position of the sample data points. The most common interpolation approaches use a weighted average of surrounding data to quantify an assessment for a studied parameter on each and every possible position [16]. Because there are so many different interpolation methods, questions about their appropriateness have arisen. For soil quality measures, several comparison research works on comparative precision were carried out. Geostatistical Kriging-based approaches and the IDW scheme for reliable approximation were employed [17]. For constructing a surface value prediction, both approaches use the correspondence of neighboring sample positions. Interpolation in deterministic approaches is done with mathematical functions. Kriging is the best interpolation approach from a theoretical aspect [18]. The correct use of Kriging, on the other hand, necessitates a precise characterization of the spatial arrangement using semivariogram creation and fitting model consideration. Hence, the main goal of this research is to construct a thorough collection of soil profile data attained from 56 various soil samples for different pits in Kirkuk city, utilizing geographical examination techniques such as "IDW" and Kriging approaches. The specific goal might be represented by digital maps for categorizing basic and various soil properties such as the substances of gravel, sand, silt, and clay fractions and initial void ratio (e_o), angle of internal friction (ϕ), soil cohesion (c), and optimum moisture content (OMC). In addition, it was intended to use single and linear multi-regression models to investigate the relationships between basic and various soil properties. The obtained digital maps and the statistical models are constructive in terms of envisioning mechanical and agricultural soil properties in Kirkuk city in terms of identifying soil zones with various shear strength parameters and soil types.

2 Study area

One of the most important Iraqi ancient cities is Kirkuk city with buildings, antiquities, and monuments which more than 5,000 years old [19]. The position of the city on the map is specified on "latitude 35.46805556 north" and "longitude 44.39194444 east." Based on the "UTM" baseline reference region 38 N, the city is somewhere around 350 m above sea level. The Kirkuk territory is approximately "9,680 km^2" contributing over 2.2% of Iraq's total land area [3]. In the research area, groundwater is the primary source of agricultural and industrial usage. The city owns 13 government departments organized into 4 municipalities: Kirkuk, Al-Hawija, Daquq, and Dibs as described in Figure 1. The city is classified geologically as Pleistocene "Old Quaternary" formations, which are distinguished by layers of gravel and sand with high permeability.

3 Methodology

The technology of the geographical information system (GIS) is often compiling geographic data into a database to decrease the cost and time. The GIS technique is focused on relating and analyzing the collected data. The Kirkuk Constructional Laboratory for Material Testing is the principal supplier of the data. Moreover, fieldwork information for soil site examination has been attained. For exactly 56 distinct samples from various depths, substantial soil parameters with every point on the global latitude and longitude location scheme data *via* (GS 20 Leica) were retrieved. Examples of the studied soil properties for several pits have been summarized in Table 1. The collected data have been obtained from different areas of Kirkuk city where these soils are mainly tested for different projects in the city and hence, they can be used to represent the entire area sufficiently. Undisturbed field soil samples were obtained and tested using accurate measurements in the Kirkuk Constructional Laboratory; thus, all the used results are reliable with good accuracy.

The digital maps were created in GIS using both IDW and Kriging approaches based on the surface approximation algorithm for the input data. Specifically, the input data include the given soil properties at known points and the unknown points determined using IDW or Kriging techniques. The IDW approach is a precise computation strategy that estimates the essential soil parameter at unidentifiable places using a linear succession of evaluated adjacent points by an inverse function of the distance between the observed and sampled points [20]. The technique's hypothesis, on the other hand, is that the sampled and unsampled locations are equivalent in all measurable properties.

$$N_o = \sum_{i=1}^{i=k} \frac{N_i d_1^{-n}}{d_1^{-n}}, \quad (1)$$

where N_o = required unknown z (soil property) in any unknown point A; N_i = given unknown in the point A, d_1 = the distance between given unknown to the required unknown, k = coefficient of the weight depending on the distance, and n = inverse distance weighting power.

The Kriging approach, on the other hand, is among the best linear equitable predictors since it attempts to maintain the mean residual error to zero [21]. Furthermore, the Kriging methodology reduces the variation in the inaccuracies, providing a considerable benefit over the IDW technique. The traditional Kriging formula is represented as follows:

$$Z(P_o) = \sum_{i=1}^{k} \lambda_i Z(P_i), \quad (2)$$

Table 1: Examples of various soil properties for Kirkuk city

Pit no.	Depth (m)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	e_o	c (kg/cm^2)	ϕ	OMC (%)
1	1	31	35	26	8	0.91	0.18	34	12.5
2	1	53	23	18	6	0.363	0.33	22	11.36
3	1	68	20	6	6	0.25	0.15	36	12.6
4	1.5	52	15	22	11	0.28	0.25	24	8.5
5	1.5	0	8	72	20	0.8	1.3	30	11.5
6	1	2	11	47	40	1.061	0.32	18	9
7	1.5	3	14	57	26	0.52	1.9	29	8.11
8	2.5	0	12	45	43	0.33	1.8	34	11
9	3.0	0	7	40	43	0.365	1.1	33	11
10	1.5	0	12	46	42	0.649	1.6	27	10

where $Z(P_o)$ is the calculated value at a given position (ith), λ_i is the unknown weight for the required value at the location (ith), and P_o is the estimation position. P_i is the known soil property.

4 Results

4.1 Physical soil properties

4.1.1 IDW technique

The map of gravel distribution of Kirkuk city was examined depending on the IDW procedure as idealized in Figure 2(a). The distribution of gravel is clearly divided into five zones. The zones are very low, low, medium, high, and very high zones, where these zones start from 0.007 to 15.048, 15.048 to 30.089, 30.089 to 45.131, 45.131 to 60.172, and 60.172 to 75.213, respectively. These zones represent the gravel content all over the map where the fifth zone is identified by a tiny red spot at the center of the map as this high gravel percent is rare and existed in only this spot. In general, the highest gravel distribution is represented by yellow color and it is concentrated in both central and western zones of Kirkuk city. Similarly, the map of the sand distribution of Kirkuk city was evaluated by the same technique as shown in Figure 2(b). In a similar manner, the sand is divided into five zones where the highest sand distribution is identified by yellow color and it is spread in the central part from the east to the west zone of Kirkuk city. Additionally, the map of silt and clay distributions of Kirkuk city were examined by the IDW technique as identified in Figure 2(c) and (d), respectively. It is clearly shown that the silt and clay are separated into five zones with the maximum silt distribution in the entire southern portion, and maximum clay distribution in the northern to south eastern parts of Kirkuk city. As an overall evaluation, most of the zones in Kirkuk city are limited by very low to low gravel content, low to medium sand content, and medium silt and clay contents.

4.1.2 Kriging technique

The map of distribution of gravel of Kirkuk city was investigated using the Kriging procedure as shown in Figure 3(a). In comparison to the preceding technique, the gravel distribution is divided into five zones. The zones are very low, low, medium, high, and very high zones, where these zones start from 7.756 to 15.011, 15.011 to 22.267, 22.267 to 29.522, 29.522 to 36.777, and 36.777 to 44.033, respectively. Generally, the highest gravel distribution is represented by yellow color and it is spread in the northern and western parts of Kirkuk city. Correspondingly, the map of the sand, silt and clay distributions of Kirkuk city using the Kriging technique were identified as shown in Figure 3(b)–(d), respectively. The sand, silt, and clay are distributed into five zones where the highest zone for any type of soil is clearly identified. The highest soil distributions in Kirkuk city for sandy soils are spread from the north to the south of the eastern zone, silty soils are concentrated in the whole upper northern part and middle southern zone, and clayey soils are concentrated in the western part. Overall, the majority of zones of Kirkuk city are characterized by extremely low to low gravel content, medium sand content, medium to high silt content, and low to medium clay content.

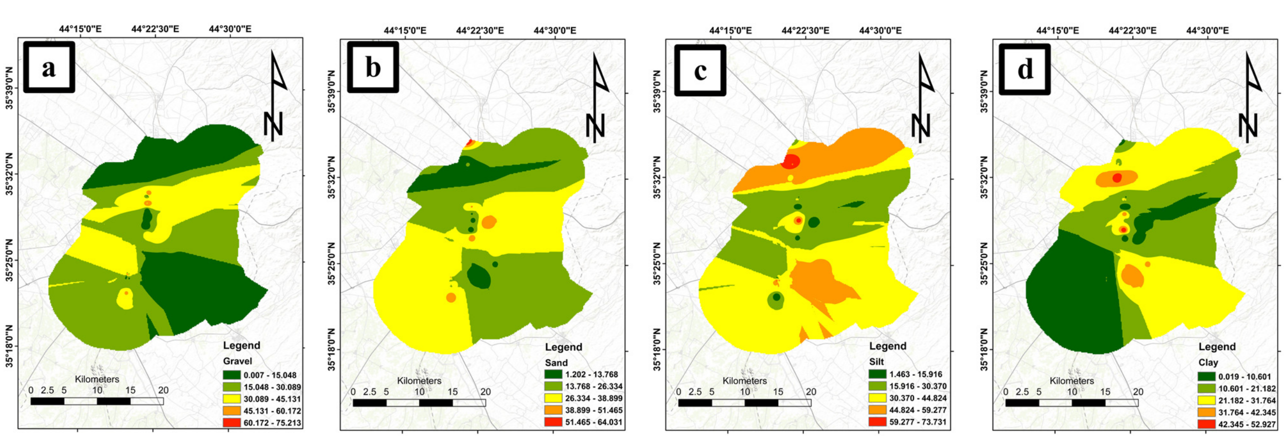

Figure 2: IDW representation of physical soil distribution in Kirkuk city: (a) gravel, (b) sand, (c) silt, and (d) clay.

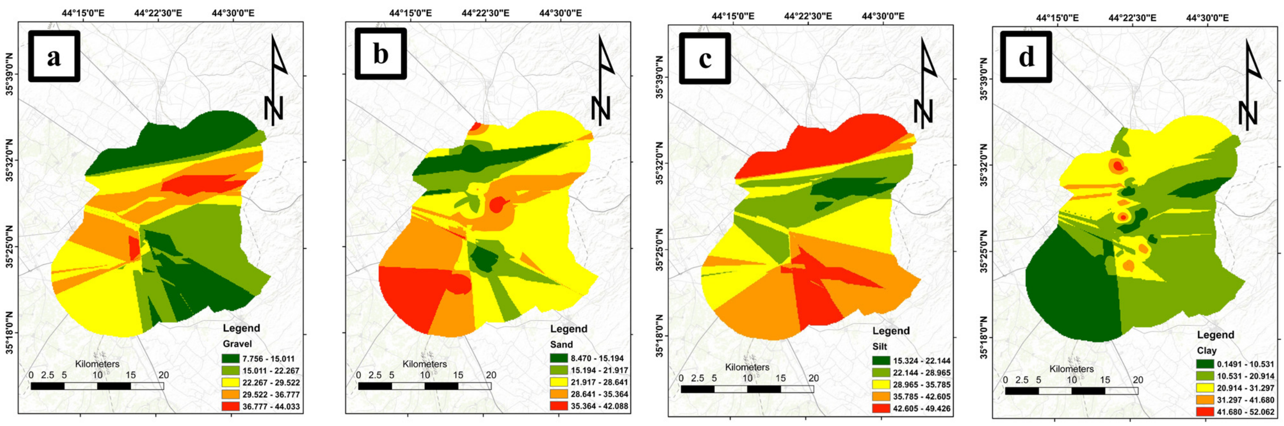

Figure 3: Kriging representation of physical soil distribution in Kirkuk city: (a) gravel, (b) sand, (c) silt, and (d) clay.

4.2 Various soil characteristics

4.2.1 IDW technique

The map of e_o distribution of Kirkuk city was studied utilizing the IDW procedure as shown in Figure 4(a). In a similar manner, the e_o distribution is clearly divided into five zones and these zones are very low, low, medium, high, and very high zones, where these zones start from 0.080 to 0.137, 0.137 to 0.194, 0.194 to 0.251, 0.251 to 0.307, and 0.307 to 0.364, respectively. In general, the highest e_o distribution is represented by yellow color and it is concentrated in both central and eastern zones of Kirkuk city. In addition, the maps of c, ϕ, and OMC distributions of Kirkuk city were considered with the use of the IDW procedure as shown in Figure 4(b)–(d), respectively. All the studied soil properties are divided into five zones where the highest zone for each property is obviously categorized. The highest soil properties distribution in Kirkuk city is for c, which is concentrated in both the middle-southern and northern zones, followed by ϕ, which is distributed in both the middle-northern and south-eastern zones, and OMC, which is distributed throughout the middle-northern and middle-southern zones. Overall, the majority of zones of Kirkuk city are characterized by low to medium e_o and c contents, and extremely low to low ϕ and OMC contents.

4.2.2 Kriging technique

The map of e_o, c, ϕ, and OMC distributions of Kirkuk city were evaluated utilizing the Kriging procedure as shown in Figure 5(a)–(d), respectively. All the investigated soil characteristics are divided into five zones where the highest zone for each property is noticeably classified. The highest soil properties distribution in Kirkuk city are for e_o, which is spread in the northern and western parts, followed by c, which is concentrated in the eastern and parts of the western zones, ϕ, which is distributed in the middle-northern and south-eastern zones, and OMC,

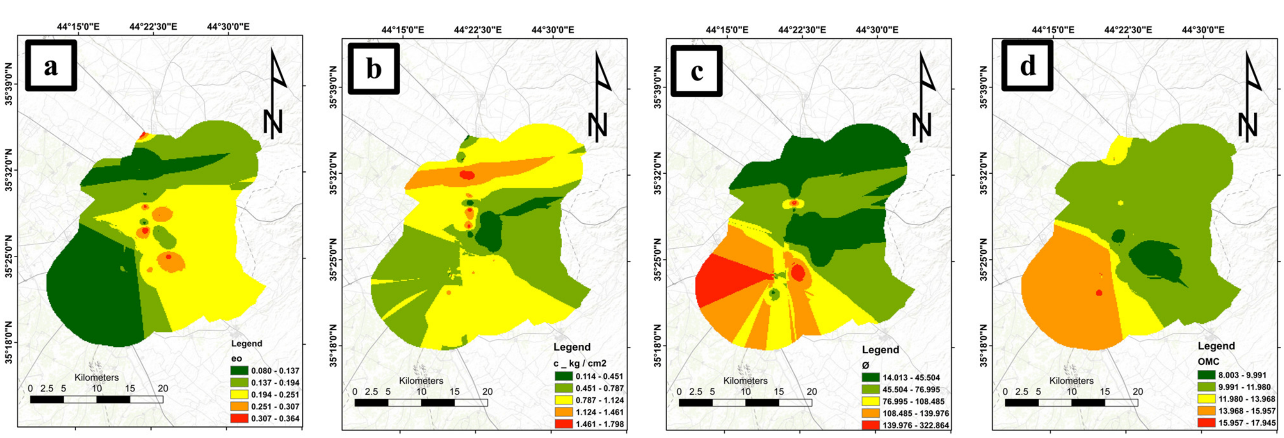

Figure 4: IDW representation of various soil characteristics distribution in Kirkuk city: (a) e_o, (b) c (kg/cm^2), (c) ϕ, and (d) OMC.

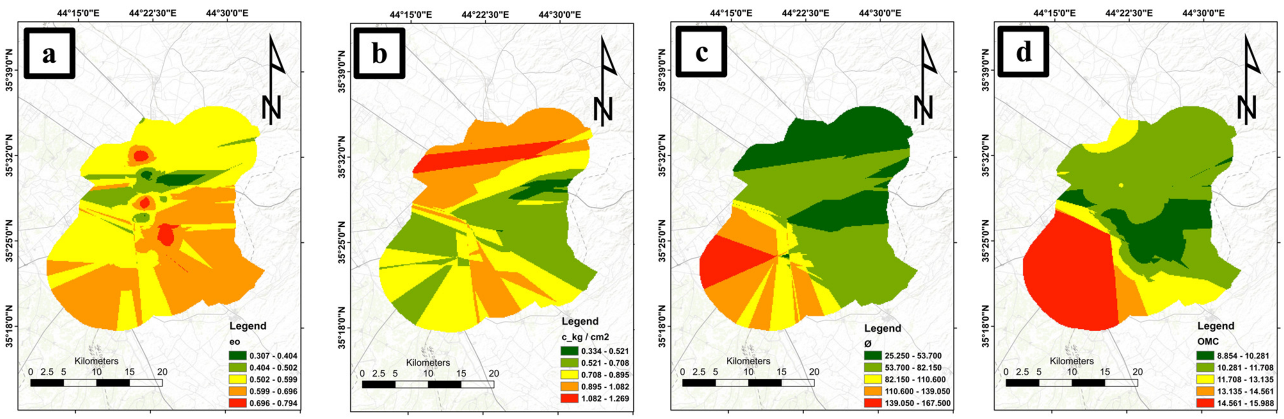

Figure 5: Kriging representation of various soil characteristics distribution in Kirkuk city: (a) e_o, (b) c (kg/cm^2), (c) ϕ, and (d) OMC.

which is distributed throughout the entire northern and south-eastern zones. Overall, the majority of zones of Kirkuk city are characterized by medium e_o content, low to medium c content, and extremely low to low ϕ and OMC contents. Due to the difference in the used algorithms for IDW and Kriging techniques, variations in soil properties distribution on the maps are expected. More field soil data are required to ensure the accuracy of any used technique.

4.3 Soil characteristics correlations

Table 2 summarizes the correlations between several soil parameters for the Kirkuk field soil data. Based on the collected field data, the soil characteristics were represented by gravel (%), sand (%), silt (%), clay (%), e_o, c, ϕ, and OMC (%). In general, considerable positive correlations have been noticed between all the investigated soil properties. Gravel had the highest and lowest positive correlations with sand and e_o, respectively, with degrees of correlation of 0.99 and 0.77. In addition, with degrees of correlation of 0.97 and 0.81, the highest and lowest positive correlations for sand were with clay and e_o, respectively. Moreover, the highest and lowest positive correlations for silt were with ϕ or OMC (%) and e_o with degrees of correlation of 0.96 and 0.84, respectively. Furthermore, the highest and lowest positive correlations for clay were with c and e_o with degrees of correlation of 0.95 and 0.79, respectively. Additionally, the highest and lowest positive correlations for e_o were with ϕ and c with degrees of correlation of 0.87 and 0.81, respectively. Besides, the highest and lowest positive correlations for c were with OMC (%) and ϕ with degrees of correlation of 0.96 and 0.91, respectively. Overall, all the soil characteristics have been associated with each other with good to excellent degrees of correlation.

4.4 Linear regression model

The evaluated soil properties represented by e_o, c, ϕ, and OMC (%) have been correlated with basic soil characteristics

Table 2: Correlation between various geotechnical characteristics for Kirkuk city

	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	e_o	c (kg/cm^2)	ϕ	OMC (%)
Gravel (%)	1.00							
Sand (%)	0.99	1.00						
Silt (%)	0.90	0.92	1.00					
Clay (%)	0.98	0.97	0.91	1.00				
e_o	0.77	0.81	0.84	0.79	1.00			
c (kg/cm^2)	0.97	0.97	0.94	0.95	0.81	1.00		
ϕ	0.87	0.90	0.96	0.90	0.87	0.91	1.00	
OMC (%)	0.92	0.94	0.96	0.93	0.83	0.96	0.96	1.00

Table 3: Linear regression details for various soil characteristic for Kirkuk city

Evaluated property	Basic property	*J*	*K*	Equation	R^2	Multiple *R*
e_o	Gravel (%)	0.01	0.45	e_o = 0.01 × Gravel(%) + 0.45	0.59	0.77
c (kg/cm^2)		0.02	0.33	c(kg/cm^2) = 0.02 × Gravel(%) + 0.33	0.93	0.97
ϕ		0.27	25.78	∅ = 0.27 × Gravel(%) + 25.78	0.76	0.87
OMC (%)		0.09	10.56	OMC(%) = 0.09 × Gravel(%) + 10.56	0.85	0.92
e_o	Sand (%)	0.01	0.41	e_o = 0.01 × Sand(%) + 0.41	0.65	0.81
c (kg/cm^2)		0.04	0.22	c(kg/cm^2) = 0.04 × Sand(%) + 0.22	0.94	0.97
ϕ		0.45	24.24	∅ = 0.45 × Sand(%) + 24.24	0.81	0.90
OMC (%)		0.15	10.07	OMC(%) = 0.15 × Sand(%) + 10.07	0.89	0.94
e_o	Silt (%)	0.01	0.32	e_o = 0.01 × Silt(%) + 0.32	0.71	0.84
c (kg/cm^2)		0.02	−0.06	c(kg/cm^2) = 0.02 × Silt(%) − 0.06	0.89	0.94
ϕ		0.34	19.58	∅ = 0.34 × Silt(%) + 19.58	0.92	0.96
OMC (%)		0.11	8.69	OMC(%) = 0.11 × Silt(%) + 8.69	0.93	0.96
e_o	Clay (%)	0.01	0.37	e_o = 0.01 × Clay(%) + 0.37	0.62	0.79
c (kg/cm^2)		0.03	0.07	c(kg/cm^2) = 0.03 × Clay(%) + 0.07	0.90	0.95
ϕ		0.40	22.07	∅ = 0.40 × Clay(%) + 22.07	0.81	0.90
OMC (%)		0.13	9.40	OMC(%) = 0.13 * Clay(%) + 9.40	0.86	0.93

using a linear regression model. The basic soil characteristics are the substances of gravel, sand, silt, and clay. The linear model has the following form:

$$\text{Evaluated property} = J \times \text{Basic property} + K, \quad (3)$$

where J and K are model parameters.

The details for the used linear regression model Eq. (3) are summarized in Table 3. The linear regression model is optimized using the least square procedure. In addition, Table 2 presents the evaluated and given soil properties with model parameters (J and K) and the values of both R^2 and multiple R. The ranges of J and K values are 0.01–0.45 and −0.06 to 25.78, respectively. Based on the R^2 values, the proposed regression models have acceptable to excellent relationships between the basic and evaluated soil properties as the R^2 values range from 0.59 to 0.94. In addition, based on multiple R values, the proposed regression models have good to excellent relationships between basic and evaluated soil properties as the multiple R values range from 0.77 to 0.97. The variations in the evaluated soil parameters with the gravel contents for Kirkuk city are shown in Figure 6(a)–(e). Positive linear correlations are remarked for the relationships between e_o, c, ϕ, and OMC (%) with the gravel content. In a similar manner, the variations in the evaluated soil parameters with the sand, silt, and clay substances for Kirkuk city are idealized in Figures 7(a)–(e), 8(a)–(e), and 9(a)–(e), respectively. It is noticed that all the remarked relationships for e_o, c, ϕ, and OMC (%) with the sand, silt, and gravel contents are positive.

4.5 Linear multi-regression model

Distinctive soil characteristics such as e_o, c, ϕ, and OMC (%) have been associated with basic soil characteristics using a linear multi-regression model. The input data are

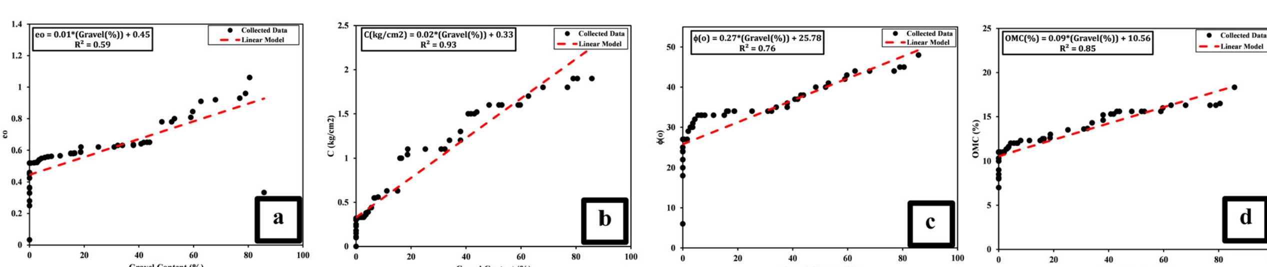

Figure 6: The variation in various soil characteristics *vs* gravel content for Kirkuk city: (a) e_o *vs* gravel content (%), (b) c (kg/cm^2) *vs* gravel content (%), (c) ϕ *vs* gravel content (%), and (d) OMC (%) *vs* gravel content (%).

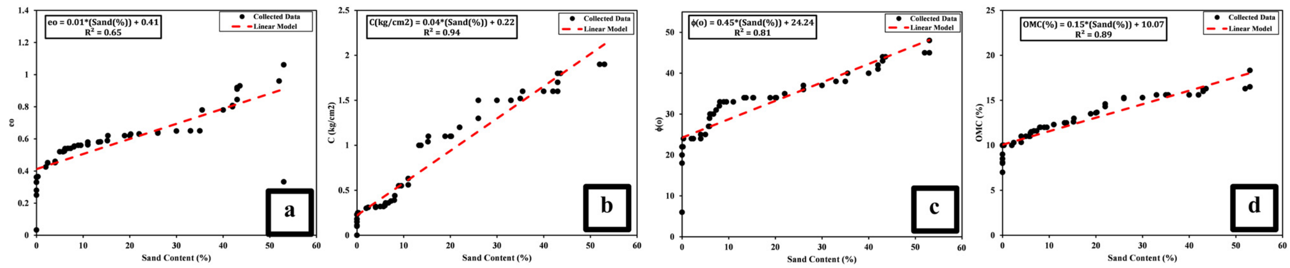

Figure 7: The variation in various soil characteristics *vs* sand content for Kirkuk city: (a) e_o *vs* sand content (%), (b) c (kg/cm^2) *vs* sand content (%), (c) ϕ *vs* sand content (%), and (d) OMC (%) *vs* sand content (%).

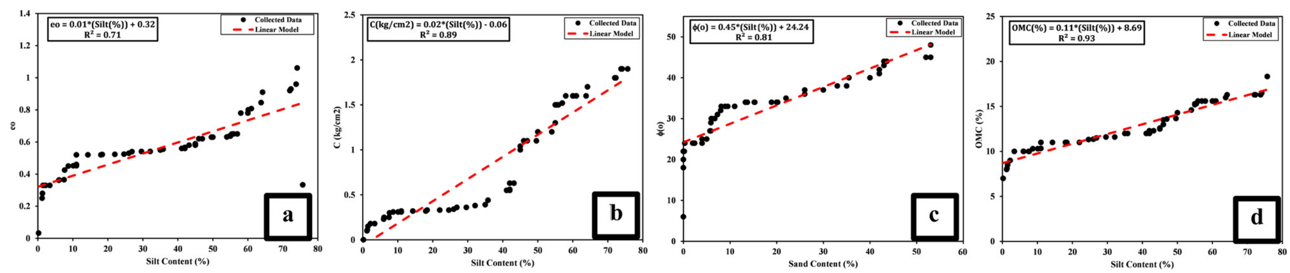

Figure 8: The variation in various soil characteristics *vs* silt content for Kirkuk city: (a) e_o *vs* silt content (%), (b) c (kg/cm^2) *vs* silt content (%), (c) ϕ *vs* silt content (%), and (d) OMC (%) *vs* silt content (%).

the basic soil properties that are the substances of gravel, sand, silt, and clay. The suggested linear multi-regression model is represented as follows:

$$\text{Evaluated property} = A \times \text{Gravel}\ (\%) + B \times \text{Sand}\ (\%) + C \times \text{Silt}\ (\%) + D \times \text{Clay}\ (\%) + E, \quad (4)$$

where A, B, C, D, and E are model parameters.

The model parameters' values of the proposed linear multi-regression model are summarized in Table 4. The suggested model is optimized using the least square technique. The model parameters (A, B, C, D, and E), R^2, and multiple R values are provided in Table 3. The range of the model parameters A, B, C, D, and E are −0.27370 to 0.01300, 0.01152–0.29395, 0.00434–0.26409, −0.00845 to 0.22109, and 0.29556–17.99133, respectively. Moreover, the ranges of the values for both R^2 and multiple R are between 0.74–0.97 and 0.86–0.98, respectively.

The variations in the evaluated and remarked distinctive soil parameters using the proposed linear multi-regression model are shown in Figure 10(a)–(d). The variations in the evaluated and remarked e_o values are shown in Figure 10(a) as the majority of the drawn data are close to the equality line with a good degree of prediction. In addition, the variations in the predicted and observed c (kg/cm^2) values have been idealized in Figure 10(b), where the majority of the data are close to the equality line with an excellent degree of prediction. Moreover, the variations in, the predicted and observed ϕ values have been shown in Figure 10(c) where the predominance of the data are close to the equality line with

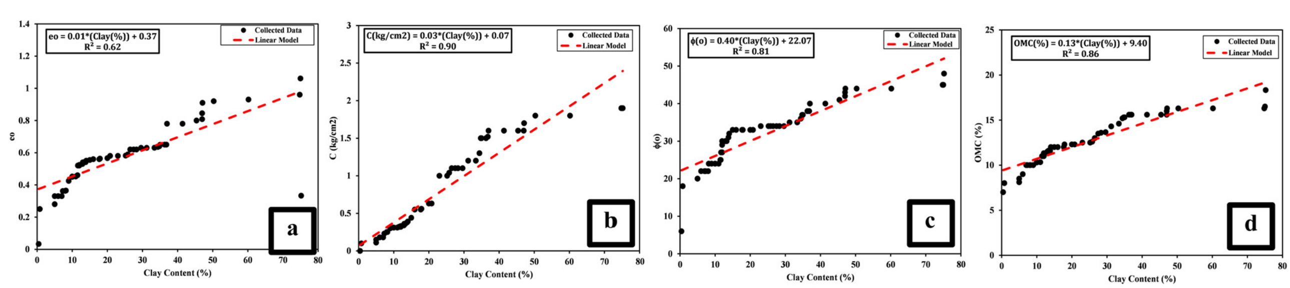

Figure 9: The variation in various soil characteristics *vs* clay content for Kirkuk city: (a) e_o *vs* clay content (%), (b) c (kg/cm^2) *vs* clay content (%), (c) ϕ *vs* clay content (%), and (d) OMC (%) *vs* clay content (%).

Table 4: Linear multi-regression idealization for various soil characteristic for Kirkuk city

Evaluated property	*A*	*B*	*C*	*D*	*E*	R^2	Multiple *R*
e_o	−0.00876	0.01437	0.00434	0.00285	0.29556	0.74	0.86
c (kg/cm^2)	0.01300	0.01152	0.01017	−0.00845	0.18410	0.97	0.98
ϕ	−0.27370	0.29395	0.26409	0.22109	17.99133	0.94	0.97
OMC (%)	−0.02208	0.09342	0.06650	0.00448	9.00116	0.95	0.98

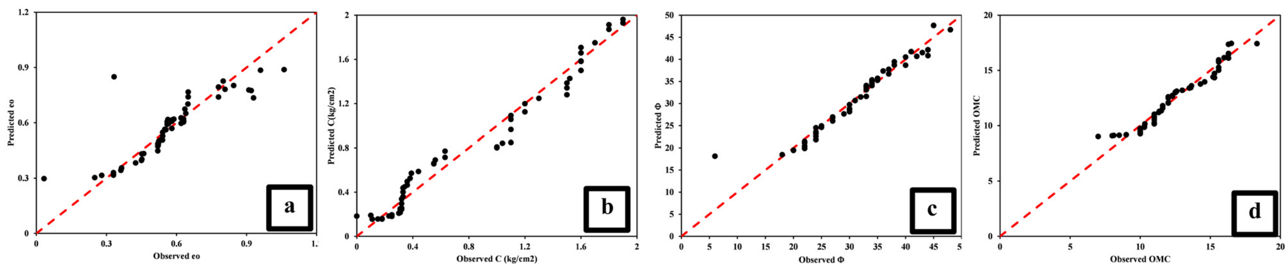

Figure 10: The variation between the predicted and observed soil properties for Kirkuk city: (a) e_o, (b) c (kg/cm^2), (c) ϕ, and (d) OMC (%).

an excellent degree of prediction. Furthermore, the variations in the predicted and observed OMC (%) values have been idealized in Figure 10(d). It should be noted that the majority of the data for OMC (%) are close to the equality lines with excellent degrees of predictions. Overall, the proposed linear multi-regression model has predicted distinctive soil properties with high degree of correlations.

5 Conclusion

The following conclusions have been drawn depending on the available data and the outcomes of this study:

1. According to an overall assessment utilizing the IDW approach, the majority of the zones in Kirkuk city have very low to low gravel content, low to medium sand content, and medium silt and clay contents.
2. Using the Kriging procedure, the majority of the zones of Kirkuk city are characterized by extremely low to low gravel content, medium sand content, medium to high silt content, and low to medium clay content.
3. Based on the geotechnical characteristics' correlation, the gravel had the highest and lowest positive correlations with sand and e_o, respectively, with degrees of correlation of 0.99 and 0.77.
4. Based on multiple *R* values, the proposed linear regression models have good to excellent relationships between basic and evaluated soil properties as the multiple *R* values range from 0.77 to 0.97.
5. Based on the results of the linear multi-regression model, the ranges of the values for both R^2 and multiple *R* for the evaluated soil parameters and the basic soil properties are between 0.74 and 0.97, and 0.86 and 0.98, respectively.
6. Practically, the obtained digital maps can be used for visualizing the various soil zones of Kirkuk city that are appropriate for civil and geotechnical projects or agricultural purposes based on the soil type and strength parameters.

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