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STATISTICAL METHOD FOR ESTIMATING SELECTED GEOTECHNICAL PROPERTIES OF QUATERNARY SEDIMENT

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Highlights

- Some geotechnical properties of Quaternary sediments have been presented.
- Data base for geotechnical properties of Quaternary sediments has been presented both statistically and graphically.
- Statistical correlations have been carried out with the assistance of regression analysis method by using a specialized and advanced software package in the statistical analysis.
- The geotechnical parameters of quaternary clay may be easily and rapidly estimated based on simple engineering test data, using one of the equations proposed in this paper.

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ABSTRACT: Quaternary sediments have characteristics that distinguish them from older soils. In engineering practice, these sediments are of particular interest to engineering geologists and geotechnical engineers because many engineering constructions have to be founded on, or in, them. This paper describes a method for rapidly estimating selected geotechnical properties of some Quaternary soil from the Mesopotamian Plain using statistical correlation equations. The paper explored an expedient statistical method to estimate some geotechnical properties (including total and dry unit weights, void ratio, porosity, Atterberg limits, and compression index) rapidly without running time-consuming and expensive laboratory tests. It was found that the selected properties showed a relatively moderate to high correlation with independent properties. Both the unit weight and void ratio depicted a high correlation with initial water content. while a moderate correlation existed between compression index and initial water content. Also, the plasticity index has a strong correlation with liquid limit values. The results of this study accord an additional usage as facultative engineering tools for geotechnical engineers to utilize for any preliminary engineering design.

Keywords: *Statistical method, Quaternary soil, Geotechnical properties*

1. INTRODUCTION

It is almost certain that the commonest materials (soil or rock), from the geological point of view, occurring closes to, or at, the earth's surface is of quaternary age. The characteristics of quaternary origin soils distinguish these soils from older soils [1], [2]. Geotechnical engineers, particularly, are interested in soils of the quaternary age. This particular interest is due to the that the quaternary soils are the foundation at which most of the engineering structures are founded. Also, some of these structures are founded in quaternary soils. Quaternary soils are of great significance for various activities, they form the founding materials for the major important parts of engineering construction. Almost a third of Iraq are quaternary deposits [3], [4], [5].

In the Mesopotamian Plain, the thickness of these sediments is more than 250m, Figure 1. In general, these sediments consist of levee silts and clays, flood plain clays and stacked river channel sand bodies with occasional marsh deposits [6], [7], [8]. Quaternary sediments are characterized by their physical and engineering properties; they are unconsolidated and usually finer grain than underlying formations [9], [10], [11], [12], [13]. Any development in Iraq may be affected by the existence of quaternary sediments, therefore, these important soils should be attained special interest and further detail is required to complete characterization for their geotechnical properties

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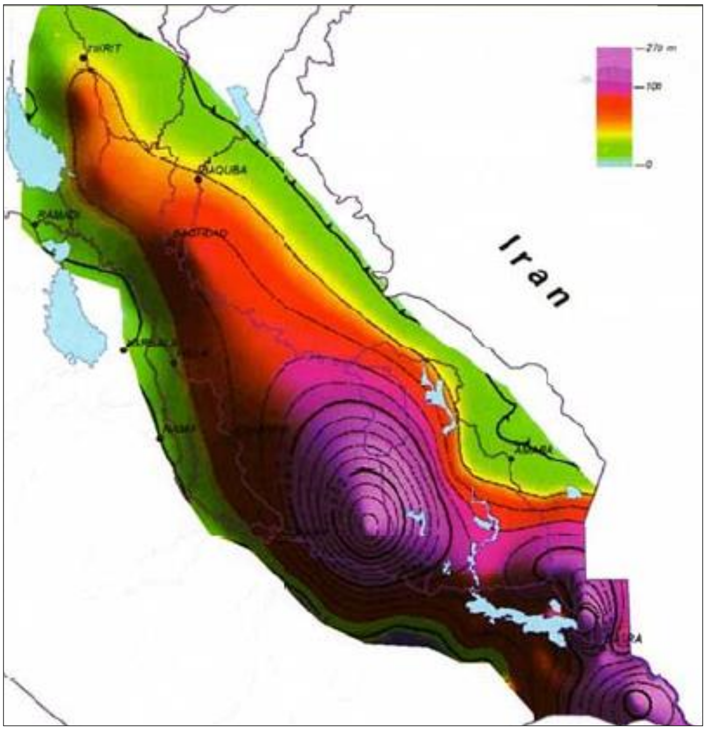


Figure 1. The thickness of Mesopotamian Plain's quaternary sediments [3].

During the last three decades, many constructions and engineering projects have been conducted in different areas of Iraq. A significant experience of geotechnical engineering data has been accumulated during this period, [14], [15], [16], [17], [18], [19], [20], [21], many empirical equations and relationships correlating quaternary soils' engineering properties can, therefore, be established in an accurate way. The development of such equations and correlations can accord an additional usage and as facultative engineering tools for geotechnical engineers to utilize for any preliminary engineering design. Furthermore, such equations and correlations allow fast and economical alternatives to design and construction in, or on, quaternary soils.

In the last decades, few researches were conducted to correlate the geotechnical properties of the Quaternary soil from the Mesopotamian Plain, essentially to evaluate the quaternary sediments. This paper investigates an expedient way to estimate (statistically) some index and engineering soil properties and parameters (including Atterberg limits, soil unit weights, moisture content, void ratio, porosity, and compression index) using basic soil properties (as water content, total unit weight, and specific gravity) without conducting (expensive and time-consuming) laboratory tests. Such statistical correlations have been carried out with the assistance of regression analysis method by using a specialized and advanced software package in the statistical analysis (Number-Cruncher-Statistical System (NCSS)).

2. THE DATA COMPILING AND DESCRIPTION

Numerous test results have been collected as the first stage of this study. These results included standard consolidation test and different physical tests. It should be mentioned that all these tests have been conducted in accordance with ASTM standards. Originally, a part of the result was compiled by [13] and the rest compiles (for the purpose of this study) from various geotechnical investigations located in Iraq. The results of sixty-three different locations were compiled, checked, tabulated. They are for quaternary soil samples obtained during site investigation for different engineering projects from the south part of Iraq. Such investigations were carried out by private companies and public agencies. The compiled data included initial void ratio (eo), total and dry unit weight (γt and γd), water content (w), liquid and plastic limits (LL and PL), plasticity index (PI), specific gravity (Gs), and compression index

(Cc). The investigated soils can be described as a cohesive fine-grained soil. They have low to high liquid limit values; they are mainly lean clay (CL) according to ASTM specifications (ASTM D2487) [22]. Also, the degree of compressibility of these soils can be described as a low to intermediate. Actually, they are a part of Mesopotamian Plain, Figure 2, which were resulted from interaction of Euphrates river and Tigris river, they are quaternary deposits [13].

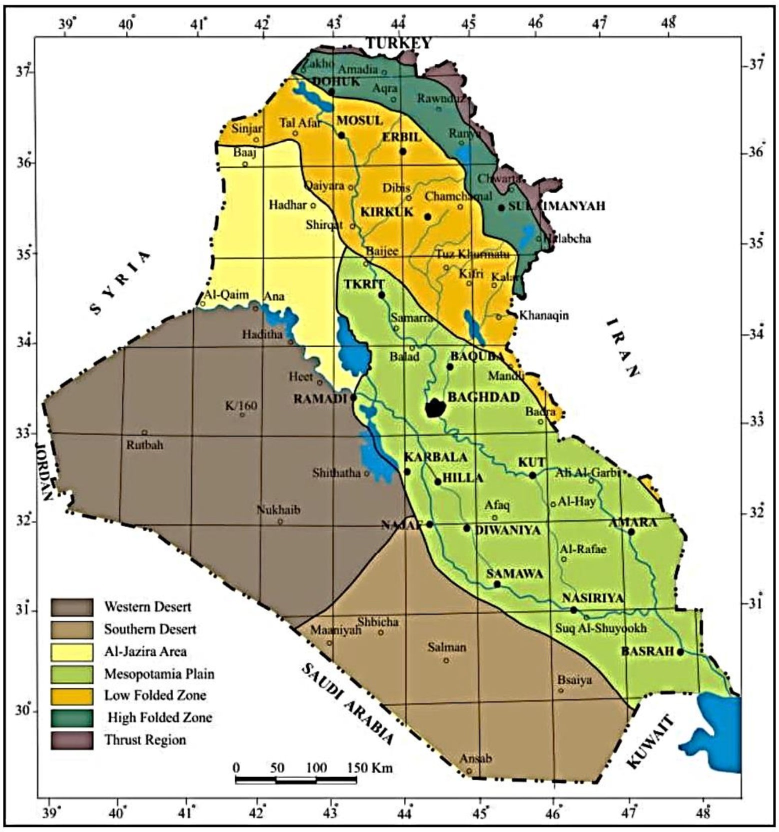
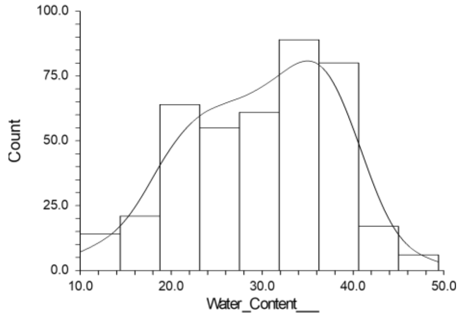


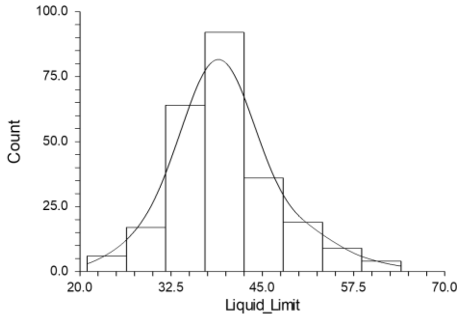
Figure 2. Location map of the Mesopotamia Plain [23]

3. DESCRIPTIVE STATISTICS FOR DATA USED

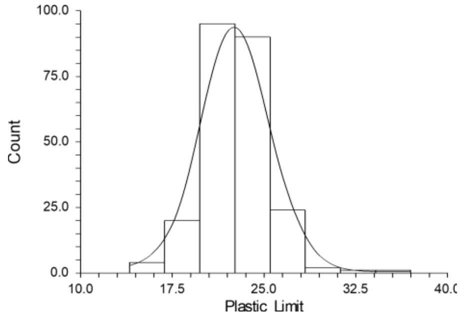
The results of the procedure used to describe the geotechnical parameters (of this paper) are shown in Figure 3 and Table 1. The variables were presented both statistically and graphically. For each single parameter, numerical descriptors (statistics) and statistical information about spread (variability), location (center), and distribution of data were provided. In this study, the location of variables (the center) on the number line was described by mean, median, and mode. As can be seen from Table 1, the values of mean and median of the geotechnical parameters are very close, thus, it is most unlikely there is an outlier in the soil parameters data, also, one can expect a slight skew in the distribution of data. The variability or dispersion of soil parameters, i.e. the pattern of these parameters' values around the location of variables (the center), was also studied by measuring the range and standard deviation. It should be mentioned that, to some degree, both of these dispersion measures are affected by outlier [24]. Due to a skewed distribution, the median has been adopted as a measure of central tendency in this study. Figure 3 presents histogram plots of the geotechnical parameters. It can be seen that the geotechnical data are generally bell shaped with nearly symmetric pattern of distribution. Approximately, these data appeared to have a single center. As it is appeared, the condition of normal distribution is generally satisfied for geotechnical paraments of this study.



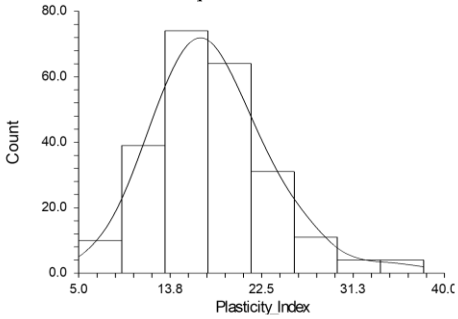
Water content



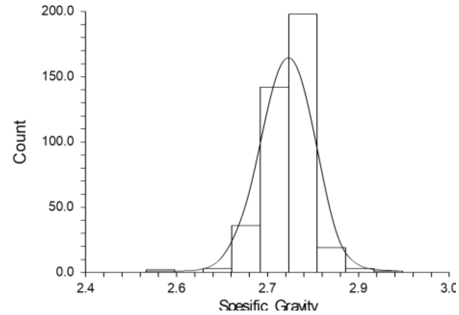
Liquid limit



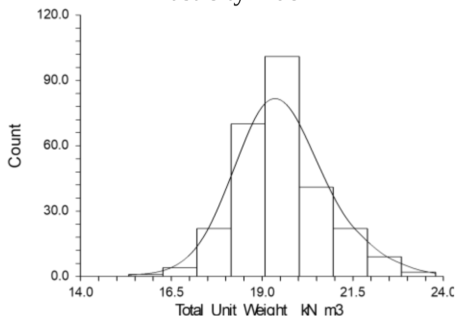
Plastic limit



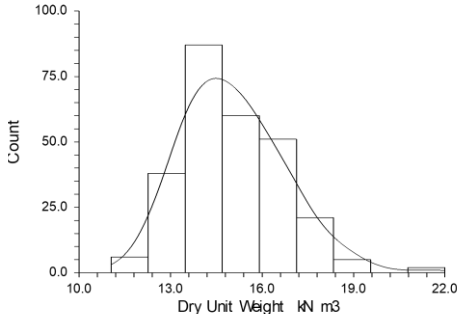
Plasticity index



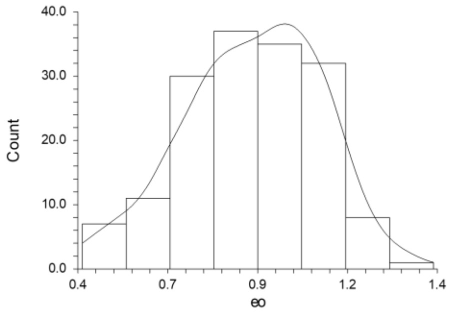
Specific gravity



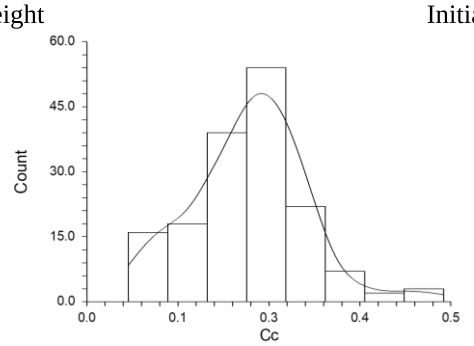
Total unit weight



Dry unit weight



Initial void ratio



Compression index

Figure 3. Histogram plots of the geotechnical parameters

Table 1. Descriptive statistics for data used

Parameters	Mean	Median	Mode	Standard Deviation	Standard Error	Minimum	Maximum	Range
w, %	29.92	30.55	22.00	8.01	0.40	10.00	49.40	39.40
LL, %	39.96	39.00	38.00	7.08	0.45	21.00	64.00	43.00
PL, %	22.68	22.00	22.00	2.78	0.18	14.00	37.00	23.00
PI, %	17.73	17.00	14.00	5.60	0.36	5.00	38.00	33.00
Gs	2.73	2.74	2.75	0.04	0.00	2.50	2.92	0.42
γ_t (kN/m^3)	19.56	19.54	0.00	1.21	0.07	15.33	23.78	8.45
γ_d (kN/m^3)	15.06	14.76	16.00	1.64	0.10	11.05	22.00	10.95
eo	0.886	0.885	0.720	0.190	0.015	0.412	1.390	0.978
Cc	0.223	0.230	0.270	0.080	0.006	0.057	0.490	0.433

4. RESULT AND DISCUSSION

4.1. Predicting unknown quaternary sediment geotechnical properties

Correlations were obtained from regression analysis of geotechnical data from Quaternary Sediment of Mesopotamian Plain. Such correlations may be useful for predicting some unknown soil properties including water content Atterberg limits, void ratio, porosity, unit weight, and compression index without carrying out expensive laboratory engineering tests. Also, these correlations, with other published correlations, enable the assessment of soil engineering properties without waiting for the prerequisite laboratory testing. To examine whenever the engineering properties of Quaternary sediment can be predicted from the knowledge of other soil properties, regression analysis performed using the database compiled in this paper. The analysis was carried out using an advanced statistical analysis software package named "Number Cruncher Statistical System" (NCSS). The improvement in developed correlations was examined with assistance of the correlation coefficient, (R). A correlation coefficient (R) with a value (R≥ |± 0.5|) was adopted in the current regression models. In fact, a quantitative measure of strength of variables relationships can be examine with assistance of this coefficient. According to Montgomery and Runger [25], correlation coefficient less than |0.5 | are, generally, considered weak, while R with values above |0.8| are, generally, considered strong. Also, another indicator has been used in the assessment of correlation, that the mean absolute error or (MAE). It should be mentioned that both R and MAE were calculated using the following expressions:

$$R = \frac{\sum_{i=1}^{n}(X_j-\bar{X})(Y_j-\bar{Y})}{\sqrt{\sum_{i=1}^{n}(X_j-\bar{X})^2\sum_{i=1}^{n}(Y_j-\bar{Y})^2}} \quad (1)$$

$$\mathrm{MAE} = \frac{1}{n}\sum_{1}^{n}\left|X_j - Y_j\right| \quad (2)$$

Where, Y_j is the predicted soil property; X_j is the measured soil property; and n is the number of datapoints used in the evaluation [21].

4.2. Prediction of water content

For a given quaternary clay, unknown water content (w, %) can be determined by measuring the wet unit weight (γ_t) using a standard method and apply the following equation (also shown in Figure 4):

$$w^2 = 4968 - 200\,\gamma_t \quad (3)$$

Where γ_t = total unit weight, kN/m^3. Eq. 3 is based on a non-linear regression of 258 data points with R = 0.535 and MAE = 6.1.

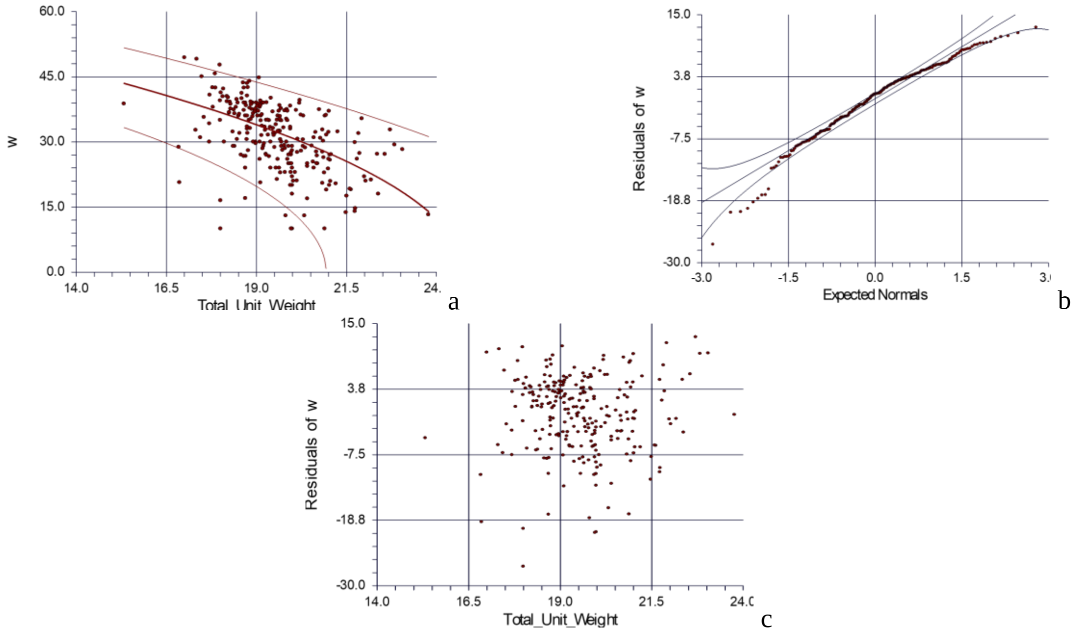


Figure 4. a, Correlation water content and total unit weight; b Probability plot of water content; c, Residual vs total unit weight

4.3. Predicting Atterberg limits

An expedient prediction method of Liquid limit (LL, %) is to conduct a plastic limit test and apply the following equations (Figure 5):

$$LL = 6.35 + 1.5\ PL \tag{4}$$

Where PL = plastic limit. Eq. 4 was experimentally obtained using non-linear regression of 237 data points from quaternary clay, R = 0.609, and MAE = 5.1.

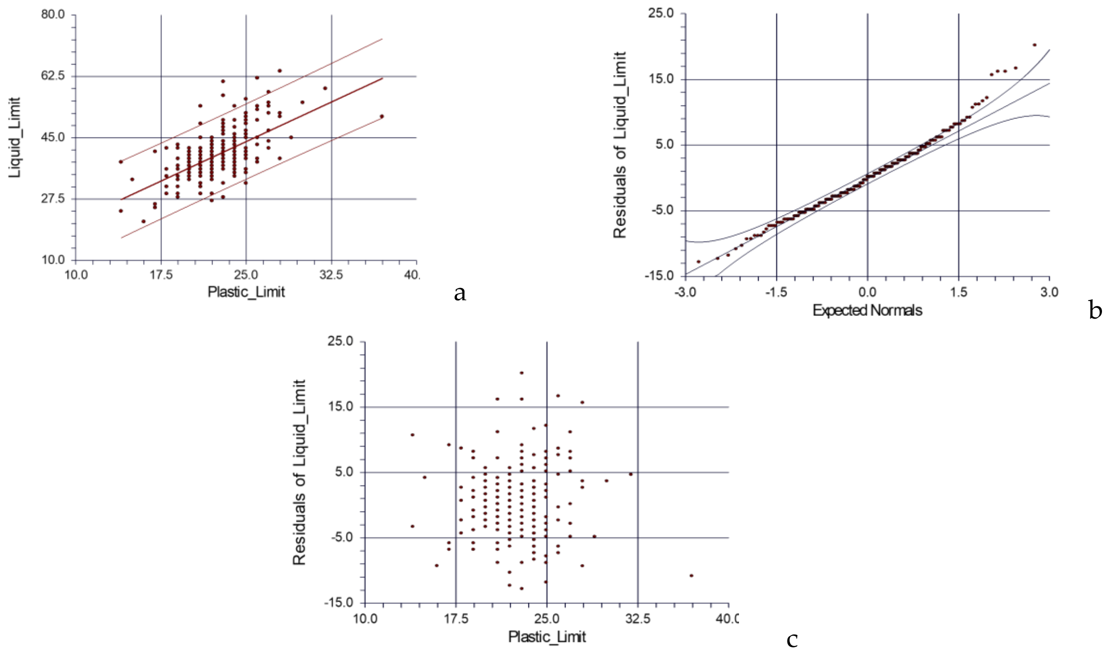


Figure 5. a, Correlation LL and PL; b Probability plot of LL; c, Residual vs PL

On the other hand, the plasticity index (PI, %) of the quaternary clay can be predicted from liquid limit value by using the following equation:

$$PI = 0.752\ LL - 12.67 \quad (5)$$

Eq. 3 is characterized by the correlation coefficient of (0.919) which reflects a high functional relation, and MAE = 4.3. As a result, the plasticity index of investigated soil can be directly obtained with sufficient accuracy from Eq. 5 or from graphical construction shown in Figure 6.

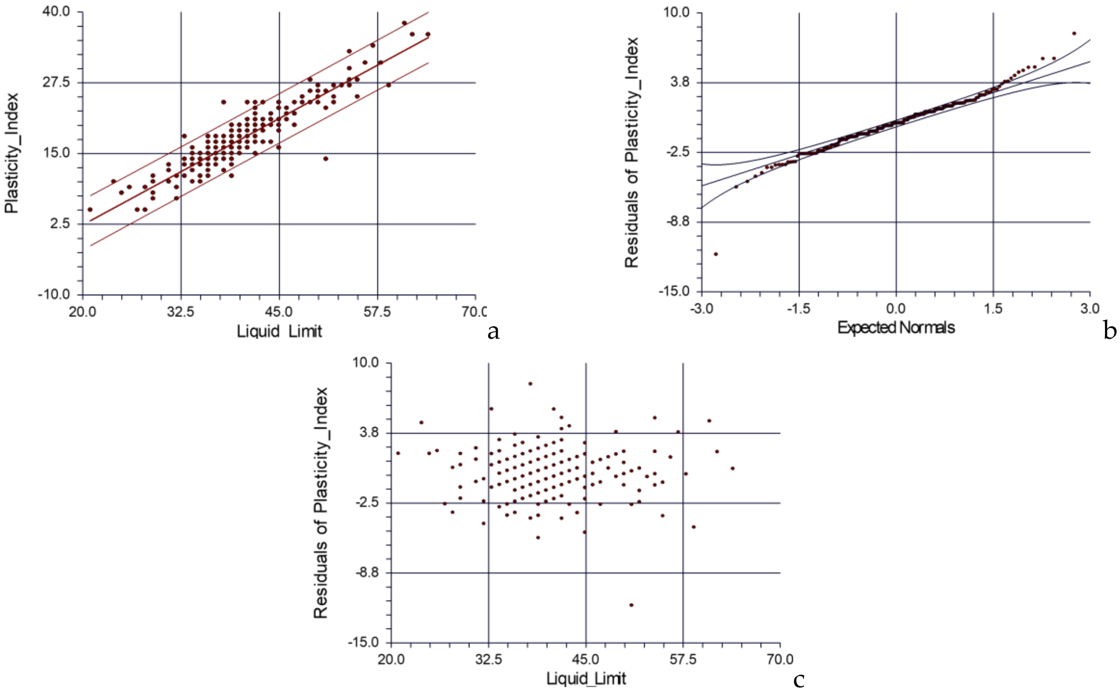


Figure 6. a, Correlation plasticity index and liquid limit; b Probability plot of plasticity index; c, Residual vs liquid limit

4.4. Predicting unit weights, void ratio, and porosity

It is well known in soil mechanics that void ratio, porosity, total unit weight and dry unit weight of soil are calculated from parameters such as water content, degree of saturation, and specific gravity. To predict the total unit weight of quaternary clay when only the water content is known, the following equation may be used or from graphical construction shown in Figure 7.

$$\gamma_t = 21.06 - 0.0014\ w^2 \quad (6)$$

Where

γ_t = total unit weight, kN/m^3
w = water content percent

Totally of 258 data points were used to obtain Eq. 6 by using non-linear regression analysis. The correlation coefficient of Eq. 4 is (R=0.536) while MAE is 1.0.

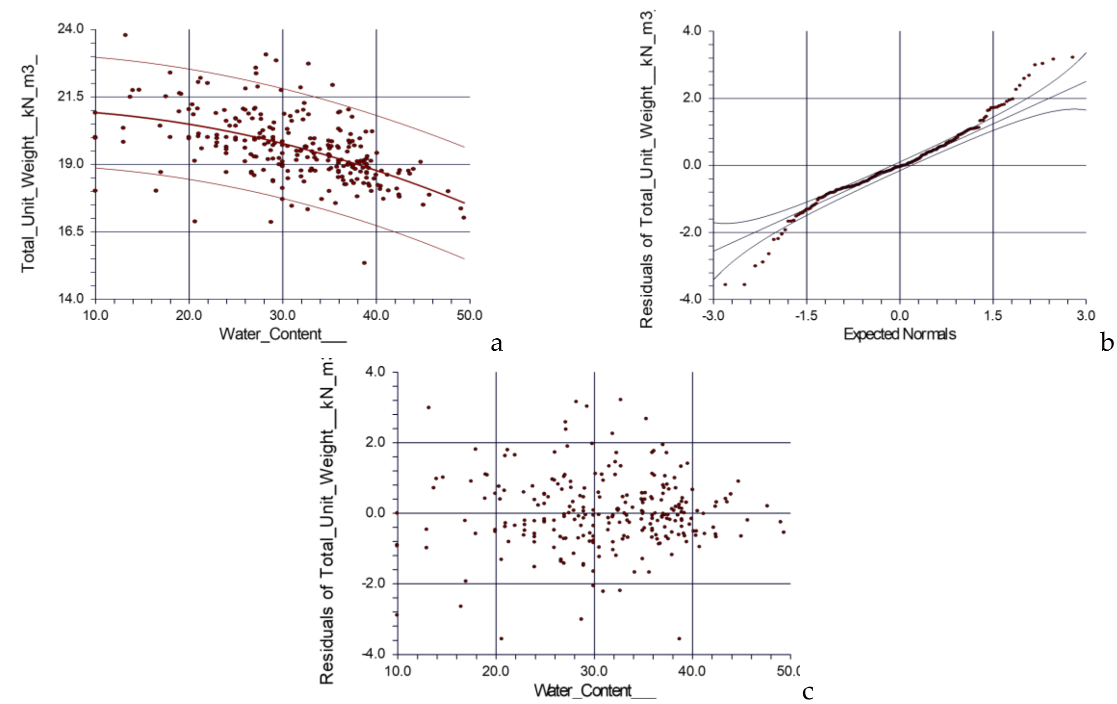


Figure 7. a, Correlation total unit weight and w; b Probability plot of total unit weight; c, Residual vs w

To predict the dry unit weight when the water content is known, but total unit weight is not, the following equation may be used:

$$1/{\gamma_d}^2 = 0.0028 - 0.00001\,w + 0.000002\,w^2 \qquad (7)$$

where

γ_d = dry unit weight, kN/m³

w = water content percent

According to regression analysis of 258 data points, Eq. 7 is obtained. This equation is characterized by the correlation coefficient of (0.860) which reflects a good functional relation and MAE is 1.3. As a result, the dry unit weight of investigated soil can be directly obtained with sufficient accuracy from Eq. 5 or from graphical construction shown in Figure 8.

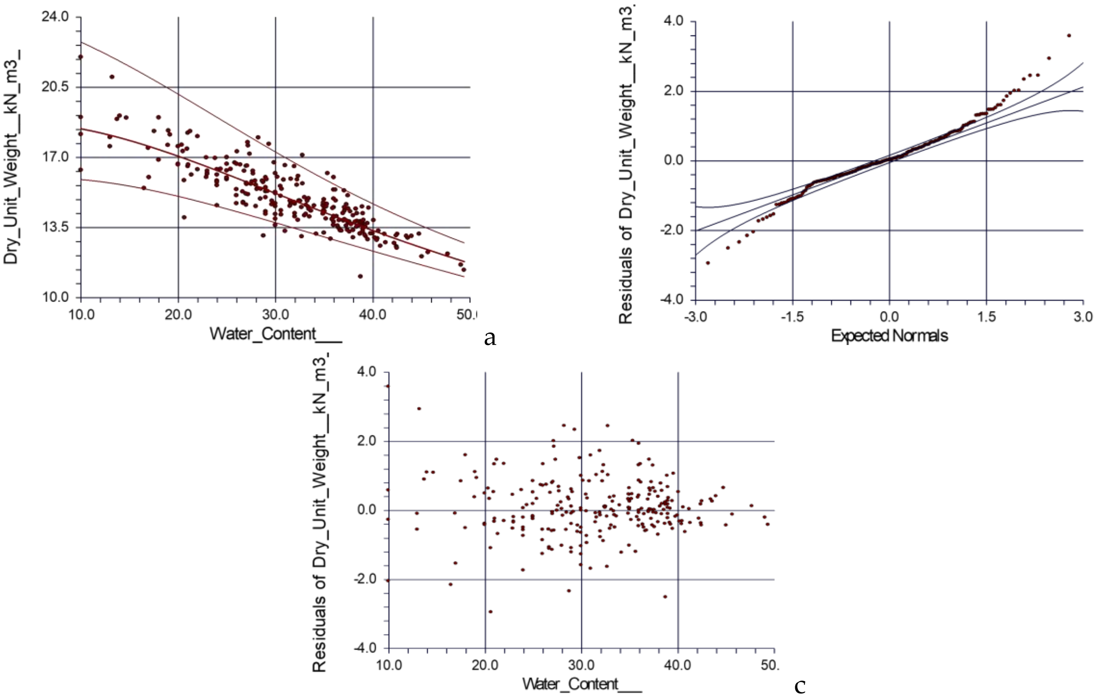


Figure 8 a, Correlation dry unit weight and w; b Probability plot of dry unit weight; c, Residual vs w

The ratio of the volume of voids (Vv) to the volume of soils (Vs) in a given volume is void ratio. It is usually expressed as a decimal. A useful relation for the void ratio in terms of degree of saturation (S), water content (w) and specific gravity (Gs) is shown below [26]:

$$e = Gs\, w/S \tag{8}$$

To predict the initial void ratio (eo) of the quaternary clay when the water content is known, but specific gravity and degree of saturation are not, the following equation, obtained from multiple regression analysis, can be used (Figure 9):

$$e_o{}^2 = 0.096 + 0.0007\, w^2 \tag{9}$$

where

e_o = initial void ratio

w = natural water content percent

Eq. 9 is based on 160 data points with correlation coefficient (R = 0.907), which is a good functional relation correlation, while MAE is 0.158.

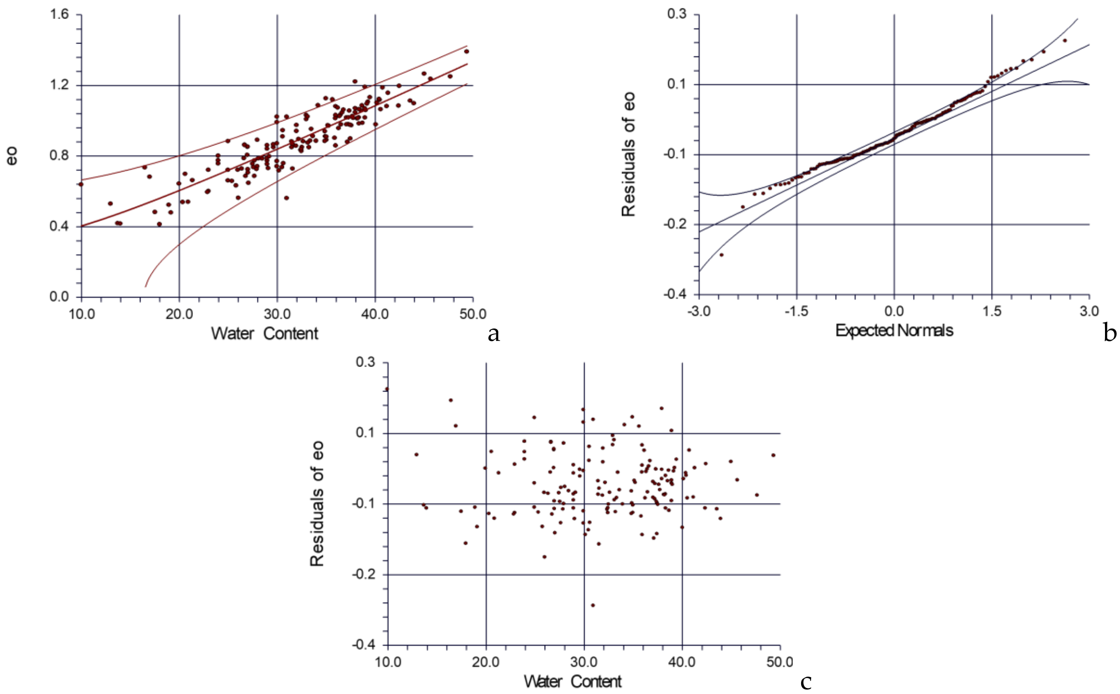


Figure 9. a, Correlation void ratio and water content; b Probability plot of void ratio; c, Residual vs water content

If water content and specific gravity are both known, but degree of saturation is not, the following equation can be used to predict the void ratio:

$$e_o{}^2 = 0.0735 + 0.00009\,(w\,Gs)^2 \quad (10)$$

where

w = water content percent

Gs = specific gravity of solids

A Good functional correlation coefficient (R=0.933) and MAE (0.161) obtained from nonlinear regression analysis based on 121 data points. The resulting functional relation (Eq. 10) is graphically illustrated on Figure 10 for more rapid determination of initial void ratio of the quaternary clay. It can be notes that the initial void ratio can be successfully estimated from the water content and specific gravity using Eq. 10.

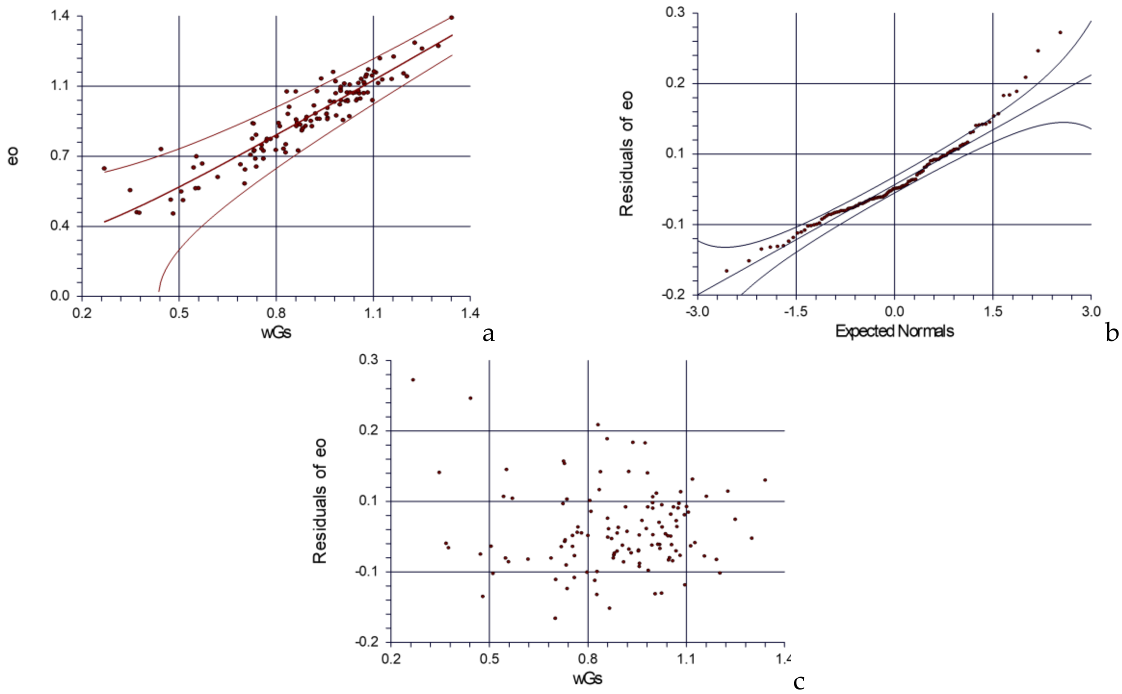


Figure 10. a, Correlation void ratio and water content and specific gravity; b Probability plot of void ratio; c, Residual vs water content and specific gravity

The Porosity (n) which is the ratio of the volume of voids to the total volume, [26], can be obtained from relationship with void ratio (e) as shown in the textbook Eq. 11:

$$n = e/(1 + e) \qquad (11)$$

Combining Equations 9 and 11 allows estimation of the porosity from the natural water content as shown in Eq. 12:

$$n = (0.096 + 0.0007\, w^2)^{1/2} / 1 + (0.096 + 0.0007\, w^2)^{1/2} \qquad (12)$$

4.5. Rapid estimation of consolidation properties

It is very important in geotechnical engineering to know the compressibility properties of the soils. These properties are used for the calculation of settlement of soil (consolidation). They are, conventionally, determined by time consuming laboratory oedometer test. For this reason, it is necessary to estimate such properties with reasonable accuracy for preliminary calculations and to control the validity of consolidation tests.

For determining compression index knowing only the water content of the quaternary soil, an approximate equation (Eq. 13) is obtained from the statistical analysis of 160 data points with correlation coefficient (R=0.784) and MAE (0.064).

$$\text{In}\,(Cc) = 1.277\ \text{In}\,(w) - 5.941 \qquad (13)$$

where:
Cc = compression index
w = water content percent

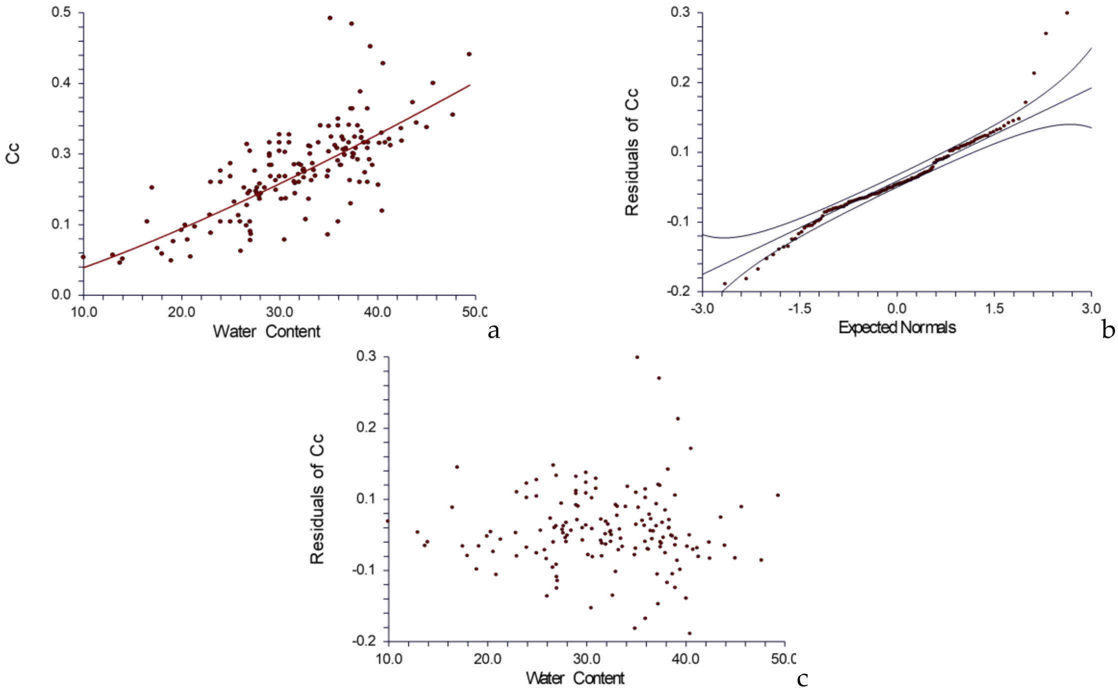


Figure 11. a, Correlation compression index and water content; b Probability plot of compression index; c, Residual vs water content

5. CONCLUSION

This paper investigates an expedient way to estimate (statistically) some index and engineering soil properties and parameters (including Atterberg limits, soil unit weights, moisture content, void ratio, porosity, and compression index) using basic soil properties (as water content and specific gravity) without conducting (expensive and time-consuming) laboratory tests. Such statistical correlations have been carried out with the assistance of regression analysis method by using a specialized and advanced software package in the statistical analysis (Number-Cruncher-Statistical System (NCSS)). According to the finding of this study, the above geotechnical parameters of quaternary clay may be easily and rapidly estimated based on simple engineering test data, using one of the following nine equations:

Estimating parameter	Equation
Water content (%) from total unit weight kN/m³	$w^2 = 4968 - 200\,\gamma_t$
Liquid limit (%) from plastic limit (%)	$LL = 6.35 + 1.5\,PL$
Plasticity index (%) from liquid limit (%)	$PI = 0.752\,LL - 12.67$
Total unit weight kN/m³ from water content (%)	$\gamma_t = 21.06 - 0.0014\,w^2$
Dry unit weight kN/m³ from water content (%)	$1/{\gamma_d}^2 = 0.0028 - 0.0001\,w + 0.000002\,w^2$
Initial void ratio from water content (%)	${e_o}^2 = 0.096 + 0.0007\,w^2$
Initial void ratio from water content (%) and Gs	${e_o}^2 = 0.0735 + 0.00009\,(w\,Gs)^2$
Initial porosity from water content (%)	$n = (0.096 + 0.0007\,w^2)^{1/2} / 1 + (0.096 + 0.0007\,w^2)^{1/2}$
Compression index from water content (%)	$\ln(Cc) = 1.277\,\ln(w) - 5.941$

It should be mentioned that the above equations do not substitute the standard laboratory tests. All these equations are aimed to be utilized as guidance for estimating purposes only.

Declaration of Ethical Standards

As the author of this study, I declare that all ethical standards have been complied with.

Credit Authorship Contribution Statement

In this study, the author contribution rate was determined as 100%.

Declaration of Competing Interest

As the author of this study, I declare that there are no declarations of conflict.

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Data Availability

The data that support the findings of this study are available from the corresponding author.

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