



Geotechnical Maps for Angle of Internal Friction of An-Najaf Soil-Iraq Using GIS

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Abstract

The angle of internal friction value (ϕ) is used to describe the soil resistance to shear failure. It is estimated experimentally either from Direct Shear Test or Triaxial Stress Tests. Because of the high cost needed for conducting field tests, it has become essential to find alternative and practical methods to predict soil characteristics for non-spatial data areas. The objective of this study is to specify the best interpolation method to predict the angle of internal friction and use it to produce geotechnical maps for parts of An-Najaf province-Iraq; these parts are the city centre An-Najaf and Kufa city. Furthermore, the study describes the strength and type of soil strata. The results show that the Local Polynomial Interpolation (LPI) is the ultimate and the most significant method to interpolate the angle of internal friction. Moreover, the angle of internal friction ϕ values is ranging between (20-46) degrees, which represent medium to dense soil resistance to shear, while the mean values of ϕ ranged between 34.3 - 36.18 and represent good resistance to shear failure. This indicates that the Density of Sand is medium to dense, and N60 values range from 10-50. This kind of map would ease the engineers and decision-makers to decide the suitability of the construction site to carry loads, and the selection the foundation type. The benefits also extend to selecting urban expansion alternatives and for the delimitation of future trends for land-use-development processes in the metropolitan area of An-Najaf city, mainly at local and regional scales.

Keywords: Geotechnical mapping, GIS, Angle of Internal Friction, An-Najaf.

الخلاصة: تستخدم زاوية قيمة الاحتكاك الداخلي (ϕ) لوصف مقاومة التربة لفشل القص. تحسب من المختبر من خلال اختبار القص المباشر أو اختبارات الإجهاد ثلاثي المحاور. بسبب التكلفة العالية اللازمة لإجراء الاختبارات الميدانية، أصبح من الضروري إيجاد طرق بديلة وعملية للتنبؤ بخصائص التربة لمناطق البيانات غير المكانية. تهدف هذه الدراسة إلى تحديد أفضل طريقة الاستكمال للتنبؤ بزاوية الاحتكاك الداخلي (ϕ) واستخدامها لإنتاج خرائط جيوتقنية لأجزاء من محافظة النجف - العراق. هذه الأجزاء هي مركز المدينة النجف ومدينة الكوفة. علاوة على ذلك، تصف الدراسة قوة ونوع طبقات التربة. أظهرت النتائج أن التكامل المحلي متعدد الحدود (LPI) هو الطريقة الأفضل والأكثر أهمية لاستيفاء زاوية الاحتكاك الداخلي. علاوة على ذلك، تتراوح زاوية قيم الاحتكاك الداخلي بين (20-46) درجة، والتي تمثل مقاومة التربة المتوسطة إلى الكثيفة للقص، في حين تراوحت القيم المتوسطة لـ ϕ بين 34,3 - 36,18 وتمثل مقاومة جيدة لفشل القص. يشير هذا إلى أن كثافة الرمال متوسطة إلى كثيفة، وتتراوح قيم N60 من 10 إلى 50. هذا النوع من الخرائط من شأنه أن يسهل على المهندسين وصناع القرار تحديد مدى ملاءمة موقع البناء لحمل الأحمال، واختيار نوع الأساس. تمتد الفوائد أيضاً إلى اختيار بدائل التوسع الحضري ولتحديد الاتجاهات المستقبلية لعمليات استخدام الأراضي وتطويرها في المنطقة الحضرية لمدينة النجف، خاصة على المستويات المحلية والإقليمية.

1. INTRODUCTION

Understanding the soil-foundation interaction is essential to engineers for appropriate foundation design and selection the better choice, and since the foundations are often located under the surface layers of soil, and their loads' effect extends to the underlying soil strata, this understanding would be through soil investigation tests. These tests require drilling boreholes and collecting samples for laboratory tests in addition to conducting field tests. In general, these tests are expensive and require time and effort. However, engineers are not always able to

conduct these tests, so they rely on the results of previous tests carried out by their peers for areas close to the project to estimate approximate values for some soil properties [1]. This procedure had been used by many scholars around the world, and with the development of science and technology, it has become easier to interpolate a set of data to find values for non-spatial data areas. One crucial software program used for this task is the Geographical information system (GIS), which represents a powerful tool to store, interpolate, retrieve, visualize, and display data [2]. GIS has been used for creating a geotechnical database of engineering soil properties for many countries and cities. W. Wan-Mohamad and A. Abdul-Ghani (2011) recommended the use of GIS tools to process and present the geotechnical data into more useful forms such as maps [3]. S. Al-mamoori et al. (2020) used GIS to classify soil according to USCS for An-Najaf city [4]. An analyses of Metro Manila soil bearing capacity in Philippine using the GIS have been performed [5]. The list extends to many different soil characteristics such as land suitability [6], seismic risk assessment [7-9], Landslide susceptibility [10], sulfate content [11, 12], the bearing capacity [13-15], and gypsum content [16]. However, there are few studies concerning the angle of internal friction, which is a shear strength parameter that is very significant in assessing the stability of soil and slopes as it reflects the soil shear resistance [17]. Soil angle of internal friction is the measure of the soil resistance to shear forces and represents the angle measured between the normal stresses [18] and the resultant force within the soil that is obtained just as the failure occurs due to a shear stresses [19, 20]. Roopnarine et al. (2012) point up to the significance of soil friction angle for soil and slope instability, and he classified the soils of Trinidad into friction angle categories for both peak and residual friction angle [18]. Mohammad Mehedi Hasan and Md. Abdur Rashid conducted an experimental study to determine the friction angle of soil through latterly developed double-punch test method [21].

This study aims to assess the best interpolation technique to create the angle of internal friction geotechnical maps for An-Najaf city soil. As well as describe the soil types and assessing its strength based on the angle of internal friction. The eventual maps will provide a preview of the proposed project sites and help designers, engineers, and decision-makers to determine the suitability of the site and the most appropriate type of foundations proposed in the preliminary studies.

2. MATERIALS AND DATA

GIS software was used to create the angle of internal friction of soil (ϕ) geotechnical maps. The data were collected first. Then the boreholes coordinates were designated using the GPS device. All data were sorted using the Excel software to match the GIS environment. Figure 1 shows the study methodology:

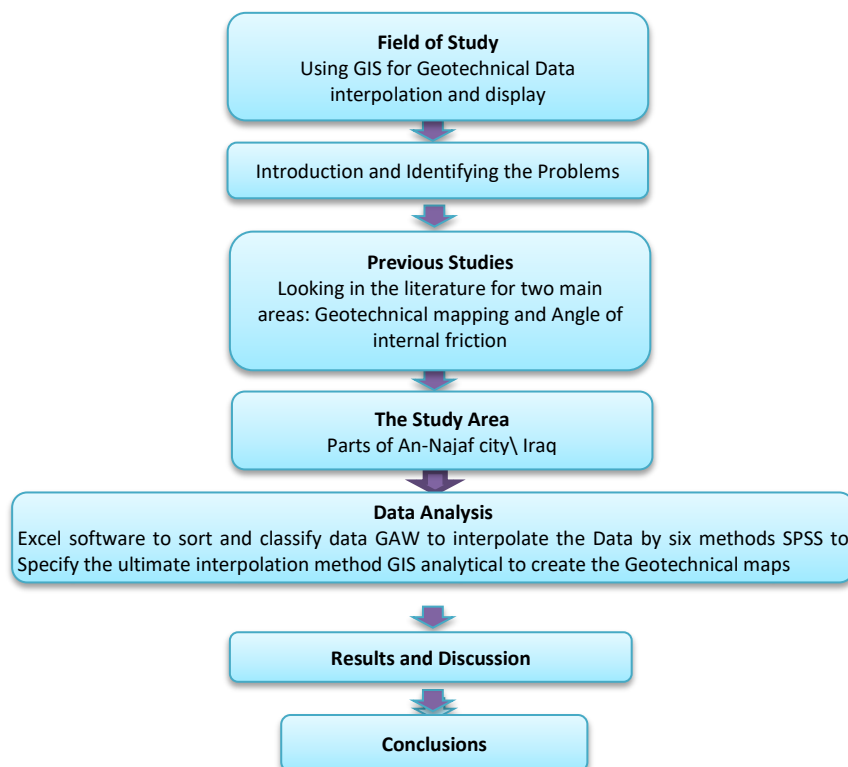


Figure 1 The flow chart of Study

2.1.The Location of Study

An-Najaf city (including Kufa) is bounded by 31.933 latitudes and 44.2833 longitudes. It covers an area of about 105.1 km² An-Najaf city has 81 neighbourhoods as shown in Fig. 2.

Arid and semi-arid are the main characteristics of An-Najaf climate city. The summer is hot and dry, with an average temperature of 45 °C [22]. The winter is short, cold [23], and wet, with an average temperature of 24 °C [24]. The average total annual rainfall is 100 mm in the wet period and 30 mm in the dry [11].

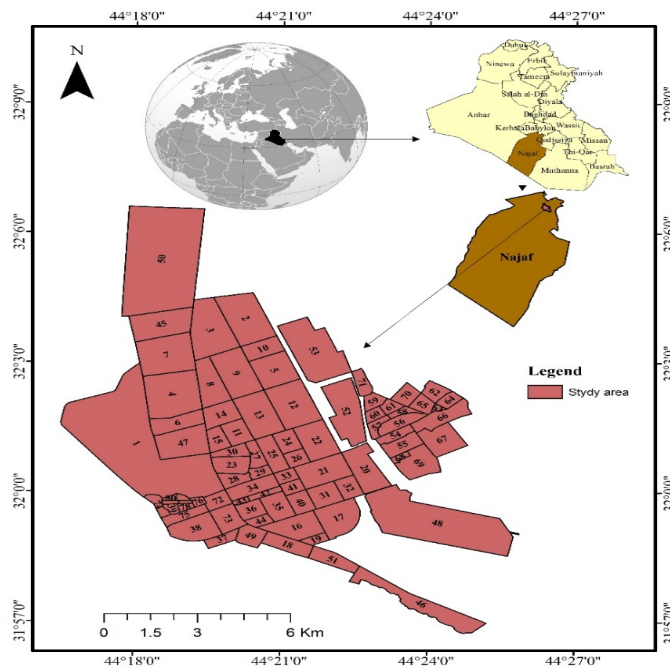


Figure 2 The map of location of study

2.2. Data

The study is dependent on data from soil samples, which collected from 464 sites in the study area. The utilized data were taken from the "National Center for Construction Laboratories and Researches (NCCLR)-Babylon" based on a cooperation memo. NCCLR- Babylon is a division of the "Iraqi National Center for Construction Laboratories and Research (NCCLR)". The site locations are shown in Figure 3. The sectors' numbers on the map refer to the neighbourhoods listed in table 1.

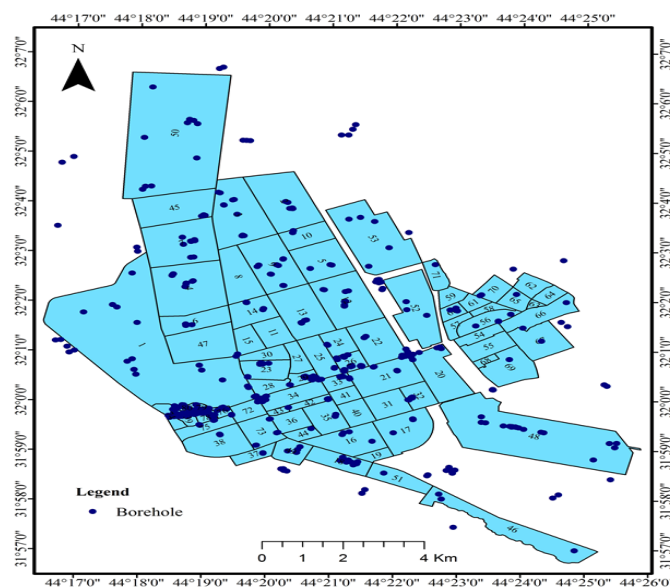


Figure 3 Soil Samples Locations

Table1. Neighbourhoods Numbers

Num	Neighborhood	Num	Neighborhood	Num	Neighborhood	Num	Neighborhood
1	Wadi Al Salam	22	Al Adala	43	Abu Khalid	64	Al Rashadica
2	Al Askari	23	Al Hussien	44	Al Mahdi	65	Al Jamhoorica
3	Al Makrama	24	Al Furat	45	Al Meelad Al Jadeed	66	Al Safeer
4	Al Nasr	25	Al Ghadeer	46	Al Radhawica	67	Al Furat
5	Al Wafa'a	26	Civil Offices	47	Al Rahma	68	Door Al Ma'amal
6	Abu Talib	27	Al Karama	48	Najaf National Airport	69	Al Sadr Al Thalith
7	Al Meelad	28	Al Sahha	49	Scientific City	70	Al Suhaylicia
8	Al Jam'ica	29	Al Ulama'a & Al Shuara'a	50	Al Nida'a	71	Al Sahla
9	Al Urooba	30	Al Zahra'a	51	Najaf Technical Institute	72	Al Jidayda 1
10	Al Indica	31	Al Qadissica	52	Kufa University	73	Al Jidayda 3
11	Al Ghari	32	Al Askan	53	Meesan	74	Tourism Zone
12	Al Jami'aa	33	Al Sa'ad	54	Kinda2	75	Al Jidayda 2
13	Al Salam	34		55	Maytham Al Tammar	76	Commercial Zone
14	Al Salam Al jadeed	35	Adan	56	Kinda 1	77	Imam Ali Shrine
15	Al Atibba'a	36	Al Mua'alimeen	57	Al Shurta	78	Al Buraq
16	Al Ansar	37	Al Shurta	58	Al Mua'alimeen	79	Al Mishraq
17	Al Harafieen	38	Al Jidayda 4	59	Al Askari	80	Al Emara
18	Al Quds2	39	Al Hwoayash	60	Al Mutanabbi	81	Al Sooq Al Kabeer
19	Al Quds1	40	Al Hawra'a	61	Al Jamia'a		
20	Al Sina'ei	41	Al Eshtiraki	62	Al Jedaydat		
21	Al Ameer	42	Al Muthanna	63	Al Waqf		

2.3. The angle of Internal Friction ϕ

The angle of Internal Friction (ϕ) is obtained mathematically by the graph (Mohr's Circle) of the shear stress and normal effective stresses at which the shear failure happened as illustrated in Figure 4. The combination of the friction angles with slope is based on the relationship established in the Mohr Columb failure criterion, which indicates that soil friction angle is a component of shear strength such that:

$$\tau_f = \sigma \tan \phi + c \tag{1}$$

Where:

τ_f : The shear strength

σ : The applied normal stress

(ϕ) : internal angle of friction soil

c: Cohesion of Soil.

Eq. 1 clarifies that the shear strength increases if the angle of internal friction increased, and the failure accure if the shear stress overcomes the shear strength.

The angle of internal friction (ϕ) of cohesionless soil is frequently estimated from field test results because of difficulty in obtaining undisturbed cohesionless soil samples for laboratory soil tests. It can be determined in the laboratory by the Direct Shear Test or the Triaxial Stress Test (TST) [1]. Typical values of (ϕ) for cohesionless soil range from 30-40 degrees. Friction angle increases with increasing particle angularity and with decreasing void ratio [2]. For this study, the angle of internal friction data was obtained by the Direct Shear Test. (ϕ) values can give an indication of the soil type and the soil relative density D_r as shown in table 2.

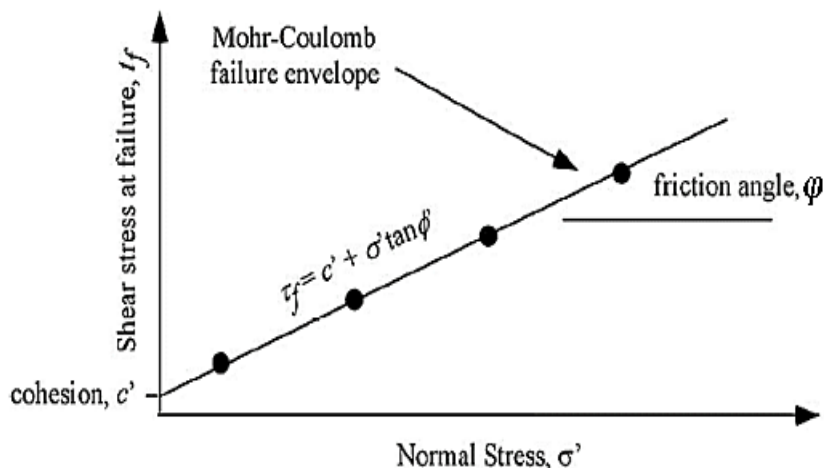


Figure 4 Mohr-Coulomb failure envelope [25]

Table 2. The angle of Internal Friction of Sands ϕ , and soil type [3].

Soil Type	Relative Density Dr, percent	Standard Penetration Resistance N60 (Terzaghi and Peck 1967) [25]	Meyrhof (1974)	Friction Angle ϕ , deg. Peck, Hanson and Thornburn (1974) [26]	Meyrhof (1974)
Very Loose	<20	<4	<30	<29	<30
Losse	20-40	4-10	30-35	29-30	30-35
Medium	40-60	10-30	35-38	30-36	35-40
Dense	60-80	30-50	38-41	36-41	40-45
Very Dense	>80	>50	41-44	>41	>45

The soil particle shape (rounded or angular) affects and would change the above angles by about four degrees [3].

3.METHOD

The maps of the angle of internal friction were performed by ArcGIS 10.7 using Geostatistical Analyst Wizard GAW. GAW has two types of interpolation techniques, which are deterministic and geostatistical, and each type has a group of interpolation methods [27]. Most of the methods depending on the resemblance of points to produce a surface or grid [28-30].

In this paper, both interpolation techniques were used. The deterministic interpolation techniques, including four methods (IDW, Local Polynomial Interpolation (LPI), Radial Basis Functions (RBF) and Global Polynomial Interpolation (GPI)), and the geostatistical interpolation techniques, has two methods (OK and Empirical Bayes Kriging (EBK)) were used for mapping the soil angle of internal friction.

4. RESULTS AND DISCUSSION

To create the angle of internal friction, geotechnical maps first, the best interpolation method that gives the most accurate results must be specified. Therefore; the data were imported to the GAW and interpolated by the six available methods, namely Inverse Distance Weighting IDW, Local Polynomial Interpolation (LPI), Radial Basis Functions (RBF), Global Polynomial Interpolation (GPI), Ordinary Kriging (OK), and Empirical Bayes Kriging (EBK). The interpolation results were then imported into the SPSS software to specify the optimum interpolation method by applying the Backward Elimination Regression. BER, as mentioned, is the best and simple statistical way to examine and specify the optimal interpolation method because it removes the least variable in the model each time and repeats the model again and again for the remaining variables until it reduces them to one most significant variable. BER has been applied to six interpolation methods (Table 3). The results of the BER test show that There are three optimal and most significant interpolation methods, namely IDW, RBF,

and LPI. However, since the LPI method has least Standardized error (0.158) comparing to the IDW and RBF, then it was used to produce the geotechnical maps.

Table 3. BER Results to specify the Ultimate Interpolation Method

Coefficients							
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Correlations
		B	Std. Error	Beta			Zero-order
1	[4]	4.892	4.239		1.154	.250	
	GPL	-.048	.192	-.010	-.252	.801	.201
	IDW	.972	.215	.761	4.516	.000	.939
	RBF	1.090	.496	.716	2.197	.029	.912
	EPK	.034	.203	.009	.169	.866	.396
	OK	-.183	.364	-.108	-.502	.617	.888
2	[4]	4.834	4.212		1.148	.253	
	GPL	-.025	.132	-.005	-.189	.850	.201
	IDW	.976	.214	.763	4.564	.000	.939
	RBF	1.059	.460	.695	2.303	.023	.912
	OK	-.157	.330	-.093	-.476	.635	.888
	LPI	-.988	.161	-.475	-6.147	.000	.753
3	[4]	4.141	2.074		1.997	.047	
	IDW	.980	.212	.767	4.625	.000	.939
	RBF	1.068	.457	.701	2.339	.021	.912
	OK	-.173	.317	-.103	-.547	.585	.888
	LPI	-.989	.160	-.476	-6.185	.000	.753
4	[4]	3.796	1.971		1.926	.056	
	IDW	1.008	.205	.789	4.916	.000	.939
	RBF	.888	.316	.583	2.810	.006	.912
	LPI	-1.001	.158	-.481	-6.327	.000	.753

ArcGIS 10.7 was used to produce the geotechnical maps for four depths up to 20 meters. The data were interpolated over the study area using the LPI interpolation method to characterize the spatial distribution of the soil internal friction angle. The statistical analyses are also performed, and the details were discussed for each depth.

4.1 Building the Model

Figure 5 presents the spatial distribution of the angle of internal friction for the study area and for four ranges of depths (i.e., 5, 10, 15, and 20 meters).

The study area was divided into four layers with a five meters depth for each layer then as shown in table 4. the statistical analysis of the results indicates the following:

- (Layer-1) has values ranging from 20°- 44 ° and Mean (μ) = 35.63.
- In (Layer-2) the values of ϕ range between 22 ° - 50 ° and mean (μ) = 36.18, which is the highest value among the layers, and this indicates the high roughness and shear resistance.
- (Layer-3), has the lowest values for ϕ , that ranged between 23 ° - 43 ° and mean (μ) = 34.63, which indicates low shear resistance.
- In (Layer-4), ϕ values ranged between 23 ° - 43 ° and mean (μ) = 35.91, where the values of the layers are medium.

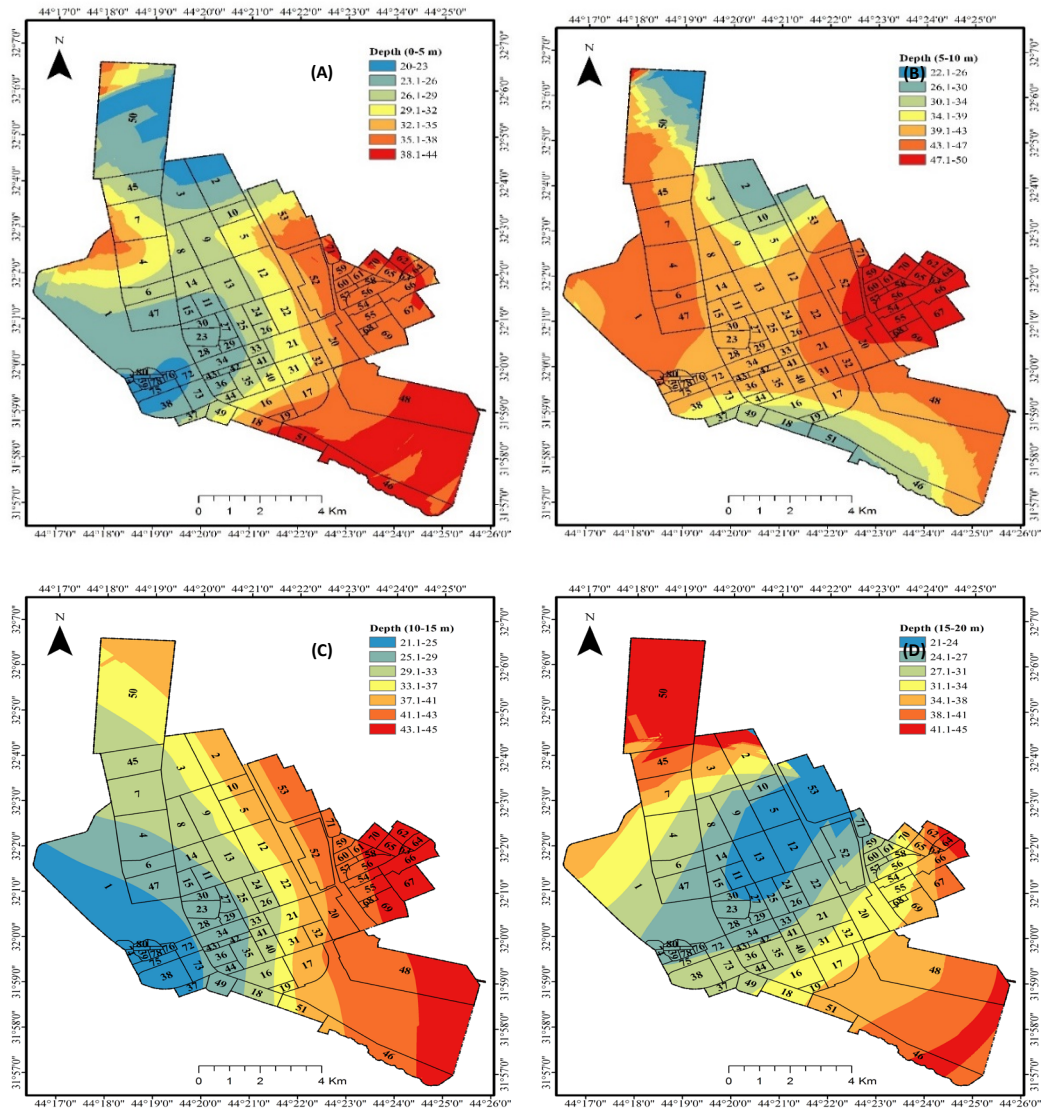


Figure 5 The Spatial Distribution of the Angle of Internal Friction for Depths: (A) 0-5 m, (B) 5-10 m, (C) 10-15m, and (D).

Table 4. Results of the statistical analysis of (ϕ) values with depth

Layers	Distribution ϕ° with depth	No. of Data	Mean (μ)	StDev (σ)	COV (%)	Range (ϕ) $^\circ$	Figure
Layer-1	ϕ° (0-5) m	196	35.63	4.288	0.12	20 $^\circ$ - 44 $^\circ$	Fig6-A & Fig7-A
Layer-2	ϕ° (5-10) m	228	36.18	4.181	0.11	22 $^\circ$ - 50 $^\circ$	Fig6-B & Fig7-B
Layer-3	ϕ° (10-15) m	196	34.63	4.559	0.13	23 $^\circ$ - 43 $^\circ$	Fig6-C & Fig7-C
Layer-4	ϕ° (15-20) m	152	35.91	5.53	0.154	21 $^\circ$ - 46 $^\circ$	Fig6-D & Fig7-D

On the other hand, the values of the angle of internal friction in the soil of An-Najaf city are considered high and give a clear indication of its cohesion and resistance to shear failure, as mean values (μ) range from 34.63-36.18. Moreover, depending on Table 2, this indicates that the Density of Sand is medium to dense and the values of N_{60} are ranging from 10-50. To determine the exact values of ϕ for any point at any depth, maps in Figure 5, will be used. The results in table 4 were also plotted in Figures 6 & 7.

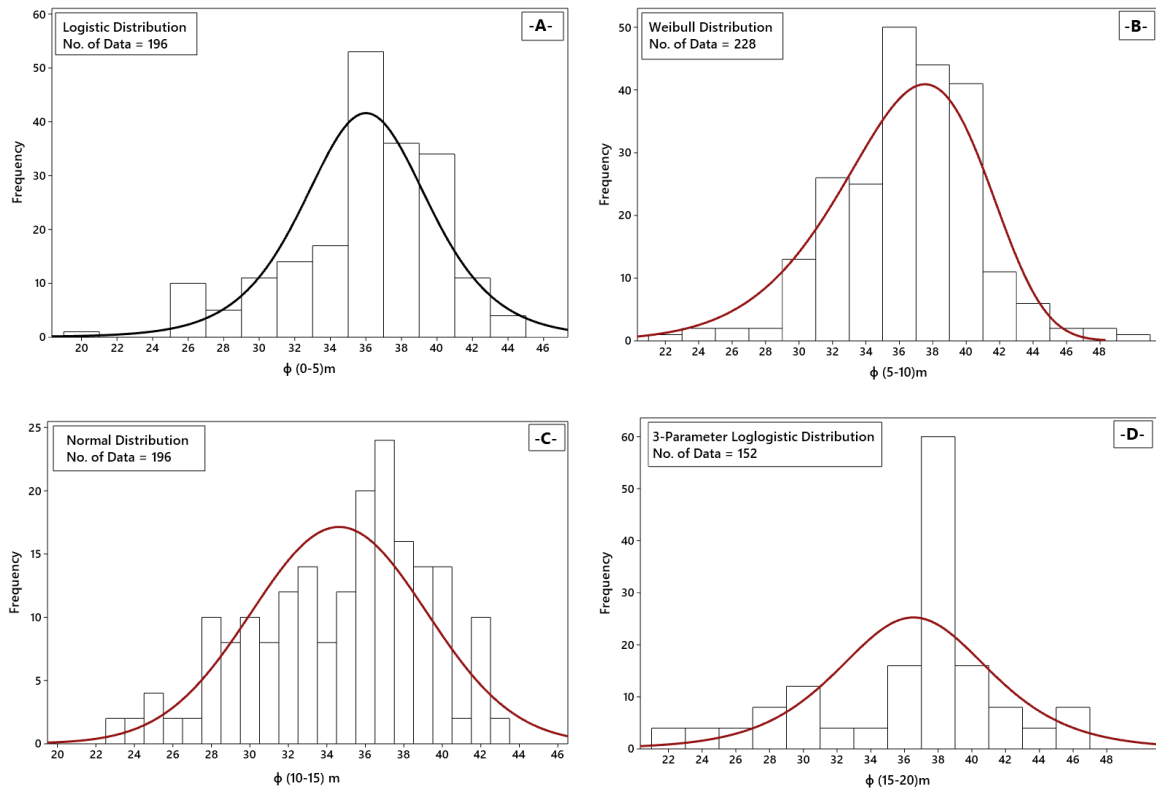


Figure 6 Histogram and Distribution function for the angle of internal friction for depths: (A) (0-5) m (B) (5-10) m, (C) (10-15) m, (D) (15-20) m. The mean value of each depth is presented in Figure 7, along with the standard deviation

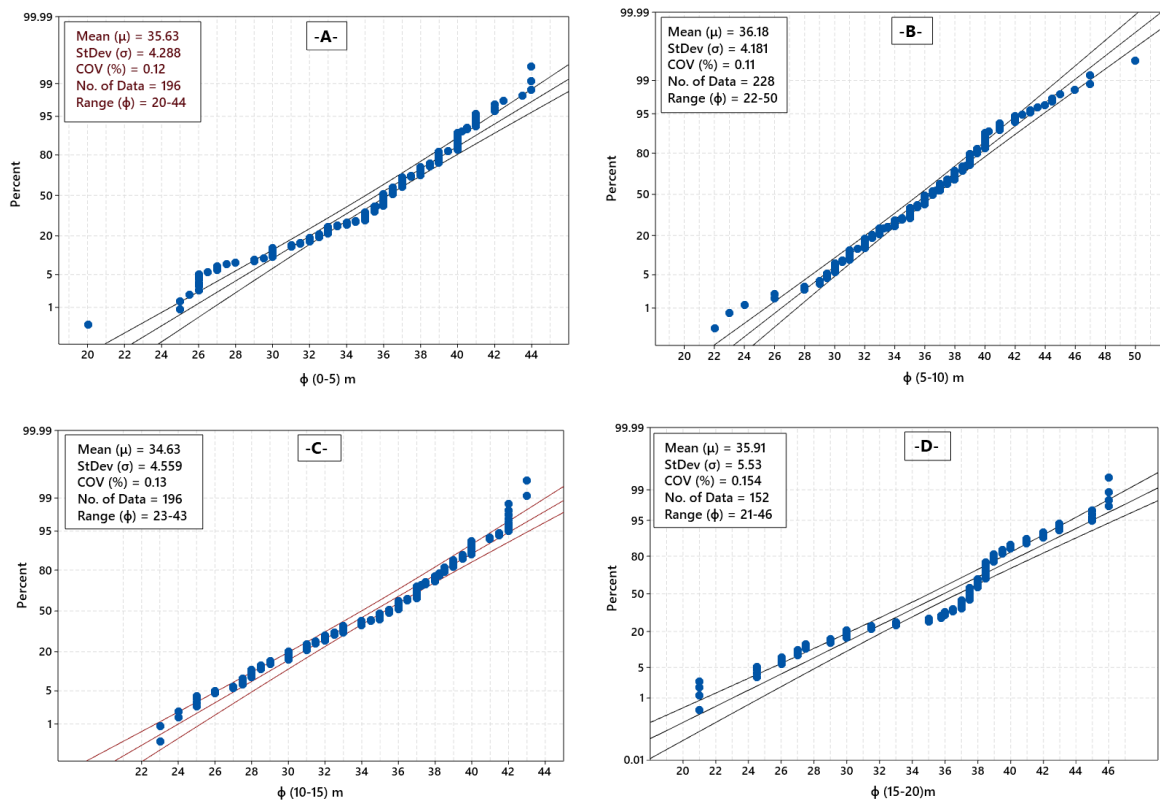


Figure 7 Probability function of the An-Najaf City soil for the angle of internal friction for depths: (A) (0-5) m (B) (5-10) m, (C) (10-15) m, (D) (15-20) m.

5. CONCLUSIONS

With economic development and population growth in An-Najaf city, the need for a large number of new buildings is arises, most of which are constructed in new areas where there is a lack of information about the soil layers properties. Therefore, the presence of an economical solution to predict soil behaviour is essential. In this research, the angle of internal friction has been interpolated by six different methods to determine the ultimate one using the Backward elimination regression. The results indicate that the EBK, IDW, and LPI were the most significant methods. Moreover, the spatial distribution was presented by the GIS software using the LPI interpolation method because it has the least standard error. However, the angle of internal friction values for depths 0-10m range (35-41) degree, while for 10-15 m were (28-43) degree, and for 15-20m were (37-39) degree. These values give an indication for the soil type and can be used for estimating other soil properties as well as estimating soil bearing capacity.

This kind of map proposes a vigorous database for the study area; also, they ease understanding the data visually. As well, using these maps will help saving expenses along with time and effort. As well, using these maps will help saving expenses along with time and effort. Another advantage for producing geotechnical maps for soil bearing capacity is to be used as a guide for engineers and decision-makers to decide the best choice for any construction design, the most suitable foundation design, and the appropriate treatment needed. Finally, the results of this paper might be used for Laying the foundations of smart cities.

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