International Journal on
"Technical and Physical Problems of Engineering"
(IJTPE)
Published by International Organization of IOTPE

ISSN 2077-3528
IJTPE Journal
www.iotpe.com
ijtpe@iotpe.com

March 2023 | Issue 54 | Volume 15 | Number 1 | Pages 204-211

# PRODUCE REFERENCE MAPS OF INTERNAL FRICTION ANGLE FOR SOIL USING GIS

**H.M. Ali [1] J.K. Thajeel [1] A.R. Al Adhadh [2]**

*1. Department of Civil Engineering, College of Engineering, University of Thi-Qar, Thi-Qar, Iraq*
*haneen1994@utq.edu.iq, jawad.thajeel@utq.edu.iq*
*2. Department of Civil Engineering, College of Engineering, Al-Muthanna University, Samawah, Iraq*
*ahmad_al_iraqi2000@mu.edu.iq*

**Abstract**- The internal friction angle ($\varphi°$) is one of the essential geotechnical parameters that are included in theories and studies to calculate the permissible bearing capacity of soil for the design of foundations. For the preliminary design of any structure, soil character maps are a crucial resource. The application of the inverse distance weighting (IDW) and ordinary Kriging (OK) approach to extend knowledge of a specific geotechnical attribute from a few sites to a larger geographical area is investigated in this paper, with a focus on the Karbala region. The accuracy of various methods was assessed using cross-validation, and the interpolation techniques were compared using the mean error (ME) and the root mean squared error (RMSE), two indices. OK is the best technique for interpolating ($\varphi°$) in this area, according to a comparison of interpolated values with observed values: The root mean squire standardized estimation errors were the lowest, and 45% was the smallest. In this article, ordinary analysis statistics are combined with geostatistical methods to infer spatial variance for data analysis. This kind of map simplifies making the decision of choosing the best foundation design. The advantages also apply to deciding on options for urban growth and defining future trends for land-use-development procedures in the metropolitan area of Karbala City, mostly at local and regional scales.

**Keywords:** Geographical Information System (GIS), Inverse Distance Weighting (IDW), Ordinary Kriging (OK), Geotechnical Design, Karbala Soil.

## 1. INTRODUCTION

In GIS, maps hold a special place. GIS-based map creation offers a significant deal more flexibility than manual or automated cartography methods. Database creation is the first step existing paper maps can be digitalized, and data that is computer-compatible can be converted into the GIS. One of the most essential elements in defining the flow characteristics and behavior of granular materials is internal friction angle ($\varphi°$), which specifies the failure characteristics of particle assemblage under normal load [1]. Meanwhile, internal friction angle is mostly caused by mechanical interlocking forces between particles because of their huge aspect ratio. The frictional coefficient during the shear process is calculated as the ratio of the shear and normal stresses [2]. The angle of internal friction value measures the soil's resistance to shear failure. Either the Direct Shear Test or the Triaxle Stress Tests are used to estimate it experimentally. Acquiring geotechnical data through on-site investigations and field and laboratory tests is essential for site design and development. Field and laboratory tests provide the data to show the soil type, strength, and behavior. Engineers must consider the effect of soil on the foundations design [3]. Engineers, however, are not always in a position to perform these tests, so they rely on the outcomes of earlier tests performed by their peers for areas close to the project to estimate approximations for some soil attributes.

Valuable data is often left scattered in its original reports in engineering offices and laboratories after projects are completed despite its importance in obtaining safe and economical designs. It is a reliable and practical method for conducting such analysis quickly and efficiently across extremely broad areas for geotechnical assessments on vast amounts of data [4].

Many academics worldwide have employed this method, and as science and technology advanced, it became simpler to interpolate a set of data to obtain values for non-spatial data areas. Emphasize that the technical environment in which the tool is used allows for the creation of new systems and applications in addition to the collecting and processing of spatial information. The geographic information system One of the greatest programs to make an accurate map and allow ease of use is GIS [5]. It allows for creating dependable databases for any attribute [6]. ArcGIS zonation maps depending on soil type are shown, along with statistical studies; these data are quickly available, useful, and able to offer planners and engineers advice [7]. GIS maps are used in decision-making concerning spatial data in areas most vulnerable to risks and damage. Maps help better understand the soil layers' behavior beneath the earth's surface [8].

Creating generalized soil profiles and geotechnical zonation maps can help with subsoil profiling and determining the hydrological and engineering qualities of soil [9]. The preliminary design of foundations, feasibility analysis, and planning of a comprehensive geotechnical site investigation will be aided by the geotechnical zonation maps and sub-soil profiling. Two case studies in semi-arid regions, the coastal province of Valencia and the island of Gran Canaria in Spain have been examined using a method of integrated environmental mapping and evaluation [10].

Al Ani relied on GIS to produce twenty-six maps on Gold Coast in Queensland, Australia, and at different depths using IDW method in data analysis [11]. W.N.S. Wan Mohamad Provided practical formats for planning engineers and land development specialists using GIS [12]. Kriging is a geostatistical interpolation method that comes in a variety of forms, with ordinary kriging (OK), co-kriging, stratified kriging, and non-linear kriging being the most popular. Groundwater variability in Turkey's Bafra Plain was analyzed using ordinary kriging (OK) [13]. OK was used to map the salinity of a source of groundwater used for irrigation in China [14].

The purpose of this project is to create geotechnical zone maps for the soil in Karbala. There is a need for the development of subsoil stratigraphy and average shear strength that may be used for preliminary planning of structures as there are more and more large projects on the horizon. As a result, this work is more pertinent and has many real-world applications. The cartographic database built using GIS can be continuous and scale-free. Then, map products can be made that are scaled to any size, centered on any location, and show selected information effectively symbolized to highlight particular characteristics.

### 1.2. Study Area

Karbala city, located in the central part of Iraq, is experiencing rapid population growth and development Figure 1. It is located about 100 km southwest of Baghdad or approximately 62 miles and a few miles east of Salt Lake, known as Lake Al Razzaza [15]. Karbala represents the capital of Karbala Governorate, which had an estimated population of about (700,000 people) in 2015 and is constantly growing and developing. The most widely used classification system is "The Koppen climate classification" Karbala's climate is classified as Karbala is characterized by a hot desert climate, with hot, dry summers and mild winters [16]. It rains annually between November and April and lacks moisture throughout the year [17].

The primary soil types in the study region are sedimentations of sand, gravel, and gravelly sand with clayey lenses, which often take the shape of compacted clayey balls interspersed with tiny amounts of sand and gypsum acting as agent material.

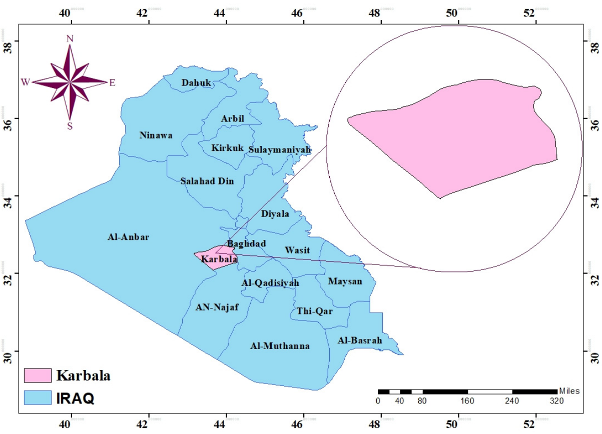



Figure 1. A window represents Karbala Governorate's location from Iraq map

## 2. MATERIALS AND METHODS

GIS provides a means for integrating different types of data into one system and allows the ability to interrogate, query, and overlay data in the form of charts and maps. GIS is well suited for projects that need to analyze large amounts of data, as it offers multiple functions and saves costs. It opens opportunities for project architects and improves their ability to view and analyze data. The GIS automated repetitious search processes and quickly became the instrument of choice [8]. Karbala city has a higher concentration of borehole locations, as shown in Figure 2. The angle of internal friction served as the main determinant. In addition, studies on the spatial changes of the angle of internal friction were carried out at a depth of 20 meters.

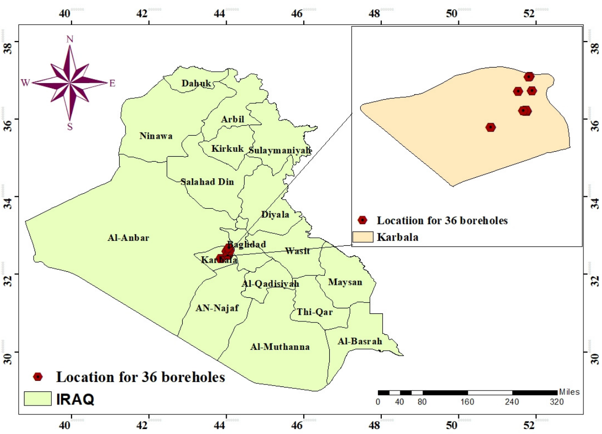



Figure 2. Distribution of soil data in Karbala province

### 2.1. Geotechnical Data

In order to create a generalized soil profile for this study, information from 39 geotechnical site investigations at various sites dispersed throughout the study area was gathered. Using the coordinates of a specific borehole, each data point was marked using an earth point on a Google map. A benchmark of a minimum of five data points was established for the selection of a zone fit for profiling. Sectors with fewer than five data points were discarded; if more data become available, they may be included in a future study.

### 2.2. Input of Data

Data must be transformed into an appropriate digital format before it can be used in a GIS. Digitizing describes the process of transferring information from paper maps or aerial photos into digital files. For major projects, modern GIS technology can fully automate this procedure utilizing scanning technology; for smaller works, manual digitizing using a digitizing table may be necessary. Many different kinds of geographic data are currently available in GIS-compatible formats today. Direct loading of these data into a GIS is possible.

### 2.3. Data Integration

The study depends on information from soil samples taken at 39 different study sites. The maps showing the angle of internal friction were created by ArcGIS 10.7 using the Geostatistical Analyst Wizard. This tool contains two sorts of interpolation techniques: deterministic and geostatistical and each type have a set of interpolation methods. Most techniques for creating a surface or grid rely on the similarity of points [18].

### 2.4. Data Visualization

Checking points were used to validate the current study's findings. The interpolation process did not include these points. The methods utilized for validation were the Root Mean Square Error (*RMSE*) and Coefficient of Determinacy ($R^2$) with zero interception. The standard deviation of the predicted errors, or *RMSE*, is defined in Equation (1) and illustrates how dispersed the prediction errors are from the regression line. According to Equation 2, $R^2$ is the square of the correlation between the predicted and measured variables.

$$RMSR = \sqrt{\frac{\sum_{i=1}^{n} \check{Z}(x_i) - z(x_i)}{n}} \tag{1}$$

$$R^2 = 1 - \left( \frac{\sum \check{Z}(x_i) - z(x_i)}{\sum \check{Z}(x_i) - \mu} \right)^2 \tag{2}$$

$$ME = \frac{\sum_{i=1}^{n} \check{Z}(x_i) - z(x_i)}{n} \tag{3}$$

where, $\check{Z}(x_i)$ is collected data, is predictions $z(x_i)$ derived from the maps, $\mu$ is the mean of the data, and $n$ is number of data [19].

## 3. DESCRIPTIVE ANALYTICS

Descriptive statistics were utilized to examine and report the study's data. A summary of the researched data will be presented during the first step of data analysis, known as descriptive analytics. The initial phase of data analysis is descriptive analytics. It gives a summary of past data that might point to the need for more preprocessing to make the data more suitable for predictive modeling. For instance, to create a more accurate model, a highly skewed variable might need to be normalized. A data collection that can be a sampling of the complete population or a representation of it is summarized by descriptive analytics. This article discusses two important statistical methods, the IDW method and Ordinary Kriging (OK), and compares the results. Consequently, our data are better understood [20]. Table.1 displays the findings of the descriptive statistics of the information used in this investigation. The scientific literature has more recently included spatial statistical models [21].

Table 1. Descriptive statistics for the internal friction angle ($\varphi$°) soil data

| Statistic | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Layers of Soil | Minimum | Maximum | Mean | Standard deviation (s.d) | COV (%) | Skewness | Kurtosis | Median |
| Layer 1 | 25 | 33 | 27.29 | 2.26 | 8 | 2.13 | 3.94 | 27 |
| Layer 2 | 26 | 34 | 27.72 | 2.32 | 8 | 1.93 | 3.28 | 27 |
| Layer 3 | 24 | 32 | 28 | 2.94 | 11 | 0.55 | -0.60 | 27 |
| Layer 4 | 25 | 33 | 28 | 3.58 | 13 | 0.83 | -1.72 | 26.5 |
| Layer 5 | 31 | 35 | 33 | 1.83 | 6 | 0 | -3.3 | 33 |
| Layer 6 | 27 | 35 | 32.25 | 3.59 | 11 | -1.69 | 3.01 | 33.5 |

### 3.1. Inverse Distance Weighted (IDW)

Earth scientists frequently employ IDW interpolation [22]. Inverse distance weighted interpolation's general equation is:

$$Z_{x,y} = \frac{\sum_{i=1}^{n} Z_i w_i}{\sum_{i=1}^{n} w_i} \tag{4}$$

where, $Z_{x,y}$ is the point that needs estimation, $Z_i$ symbolize the control value for the $i^{th}$ sample point, $w_i$ is a weight used in the interpolation process to establish the relative relevance of each particular control point $Z_i$ [23]. Based on the inverse of distance to power, a different weighting method that gives near locations comparatively more weight than distant points are as follows:

$$w_i = d_{x,y,i}^{-\beta} \tag{5}$$

where, $d_{x,y,i}$ represents the distance between $Z_i$ and $Z_{x,y}$, $\beta$ is an exponent that the user defines. Equation (4) can be rewritten as follows:

$$Z_{x,y} = \frac{\sum_{i=1}^{n} Z_i d_{x,y,i}^{-\beta}}{\sum_{i=1}^{n} d_{x,y,i}^{-\beta}} \tag{6}$$

Although [24, 25] have developed interpolation versions that will create new highs and lows, these algorithms based on Equation (6) will not infer surface highs and lows beyond those defined by existing control points, and the interpolation process will not guarantee that the reconstructed surface will pass exactly through all control points.

$$Z_{x,y} = Z_i \text{ for all } Z_i \tag{7}$$

According to [22], the univariate IDW methodology also presupposes that the surface between any two locations is smooth but not differentiable, which means that this interpolation method (in its simplest form) does not support rapid changes in height.

### 3.2. Ordinary Kriging (OK)

The term "Kriging" is a catch-all term used by geo-statisticians to refer to a group of minimum error-variance estimation techniques. Ordinary kriging (OK), one of the many types of kriging, has gained popularity as a trustworthy estimation technique [26]. In recent years, there have been more and more problems, as well as a wider range of functions using the data [19]. Functions that vary over space are used to represent properties in many scientific fields. The most popular kriging technique is standard kriging. Utilizing information from the area around the estimation location, it serves to estimate a value at a point within a region for which a variogram is known [27]. In this article, a method is presented to make spatial predictions at locations without data when the data values are functions. Clarification of the (OK) strategy by examining actual data based on soil friction angle. The pre-processing of the curves involves a non-parametric fitting in which the smoothing parameters are selected using cross-validation. When data near the location being estimated screen outlying data, negative weights in ordinary kriging (OK) result [28]. OK is estimated by the Equation (8) [19].

$$z(u)_{OK} = \sum_{\alpha=1}^{n} \lambda_\alpha (u).z(u_\alpha) \tag{8}$$

where, $z(u_\alpha)$ represent adjacent data values, $z(u)_{OK}$ is unspecified value's best guess, $\lambda_\alpha(u)$ is the weights, under the unbiasedness constraint, are chosen to minimize the error variance, $\alpha = 1,...,n$ .

In the particular case, where all data values are equal to one constant, the estimated value should also be equal to this constant. Therefore, it is obvious that we must constrain the weights to add up to one.

## 4. INTERNAL FRICTION ANGLE ($\varphi$°)

The internal friction angle ($\varphi$°) measures the resistance between particle interlocks. The soil is capable of withstanding the shear stress caused by applied loads from the structures. This resistance is described in terms of any soil shear strength parameters [29]. There are numerous ways to calculate the shear strength parameters, including the triaxle test and the direct shear torsional direct shear test. The direct shear test is the easiest way to calculate the shear strength parameters. In this paper, the direct shear test methods are used to generate the collected data and used as input into the GIS software.

## 5. RESULTS AND DISCUSSION

This part focuses on explaining the outcomes discovered and briefly discussed above. The validation procedure was reliant on the root mean square error (*RMSE*) and mean error values (*ME*) for each method. Results according to the method of IDW of the *RMSE* for the $\varphi$° were (0.6427, 0.9128, 1.1990, 1.414, 2.4498, 3.7099) for the layers (0 to 3, 3 to 6, 6 to 14, 14 to 18, and 18 to 24) meter, respectively. The mean error (*ME*) for the six layers is additionally (0.0545, -0.1766, 0.4522, -0.00108, -0.4590, 0.83155), respectively. While the results of the OK approach showed the average RMSE for the six layers (0.730, 1.707, 1.405, 1.3109, 2.0194, 4.34159), respectively.

Results of *ME* for the $\varphi$° were (-0.0713, -0.0601, 0.529, -0.0122, -0.3036, 0.51127) for each layer, respectively. The angle of internal friction *ME* was close to zero (between 0.4522 and -0.4590), and *RMSE* ranged from 0.6427 to 3.7099, according to the IDW method (Table. 2), indicating that predictions were accurate. According to the OK approach, the *ME* of the soil friction angle is also close to zero between -0.3036 and 0.529, and *RMSE* values range between 0.730 to 4.34159, which results indicate the accuracy of the predictions in the OK approach is more accurate than IDW [30]. Figure 3 shows the limits of Standardized Errors according to OK. Approach each soil layer in the vertical and horizontal direction Based on the total of 39 boreholes for the average internal friction angle between a standard deviation of 3.1 and a coefficient of variation of 11% as shown in Figure 4.

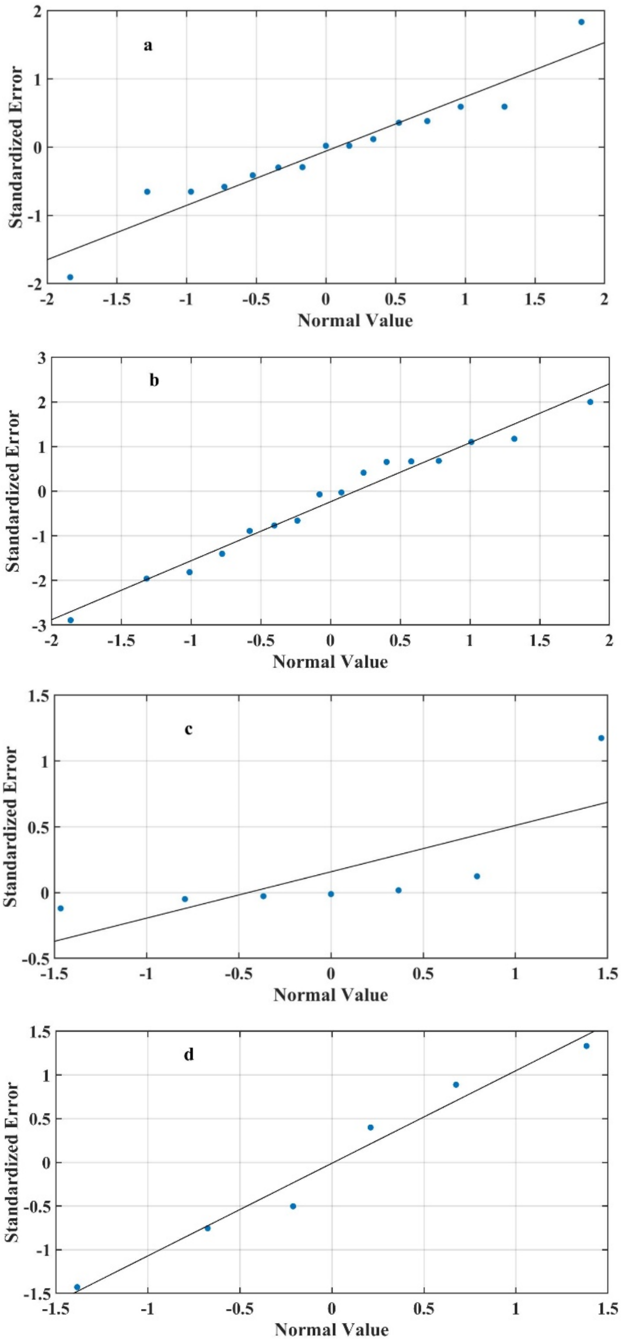
Table 2. Cross-validation of measured and estimated ($\varphi^\circ$) values using IDW and OK

| Prediction errors | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Layers of Soil | Depths | IDW | | OK | | | | |
| | | *ME* | *RMSE* | *ME* | *RMSE* | *MSE* | *RMSSE* | *ASE* |
| Layer 1 | (0-3) m | 0.0545 | 0.6427 | -0.0713 | 0.730 | -0.0574 | 0.797 | 1.0481 |
| Layer 2 | (3-6) m | -0.1766 | 0.9128 | -0.0601 | 1.707 | -0.0419 | 0.965 | 1.795 |
| Layer 3 | (6-14) m | 0.4522 | 1.1990 | 0.529 | 1.405 | 0.159 | 0.449 | 1.2124 |
| Layer 4 | (14-18) m | -0.00108 | 1.414 | -0.0122 | 1.3109 | -0.0109 | 0.9645 | 1.4423 |
| Layer 5 | (18-24) m | -0.4590 | 2.4498 | -0.3036 | 2.0194 | -0.0686 | 0.9793 | 2.0797 |
| Layer 6 | (24-26) m | 0.83155 | 3.7099 | 0.51127 | 4.34159 | 0.0522 | 0.8989 | 3.9223 |

Note: *ME* is Mean Error, *RMSE* is Root Mean Squire Errors, *MSE* is Mean Standardized Error, *RMSSE* is Root Mean Squire Standardized Errors, *ASE* is Average Standard Error.

Figure 5 presents the objective maps to predict $\varphi$° according to the OK method in the city of Karbala, central Iraq, at a depth of (0-26) meters and in the form of layers. The first layer represents soil data at a depth of (0-3) m. The layer shows the value of $\varphi$° ranging 28-33° and shown in red. The value of $\varphi$° increases in layer 2, which represents the depth (3-6) m, as its value ranges from 29-34°. Layer 3 and Layer 4 represent the depth (6-14) m and

(14-18) m, respectively. The value of $\varphi°$ appears from 28° to 33° approximately, with a decrease in the value of $\varphi°$ in the west for the aforementioned four layers. The lowest value of phi appears on the maps in blue, ranging between 24-26°. Layer 5 and Layer 6, which represent the depths 18-24° m and 24-26° m, respectively. An increase in the angle of friction with depth was observed, as the angle of friction ranged from 31 to 35 throughout each layer. The soil layers' predominant formation is the sandy silty soil. The maximum angle of friction is 35°, according to the shear strength digital maps of the parameter $\varphi°$.



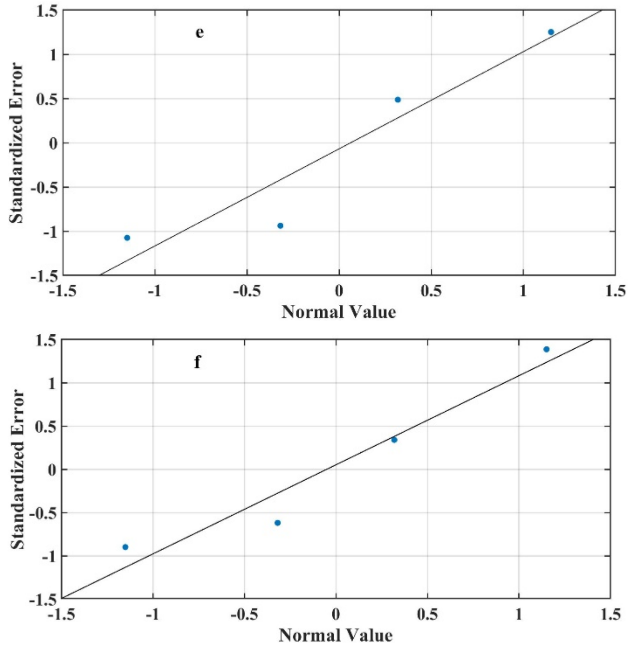




Figure 3. Correlation between normal value and Standardized Errors according to OK approach for; a: For layer 1, b: For layer 2, c: For layer 3, d: For layer 4, e: For layer 5, f: For layer 6

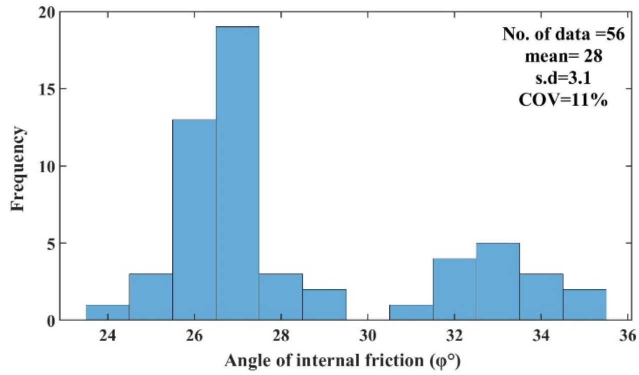
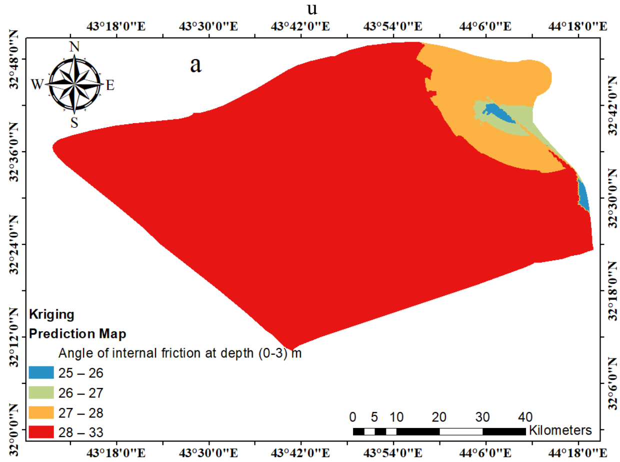
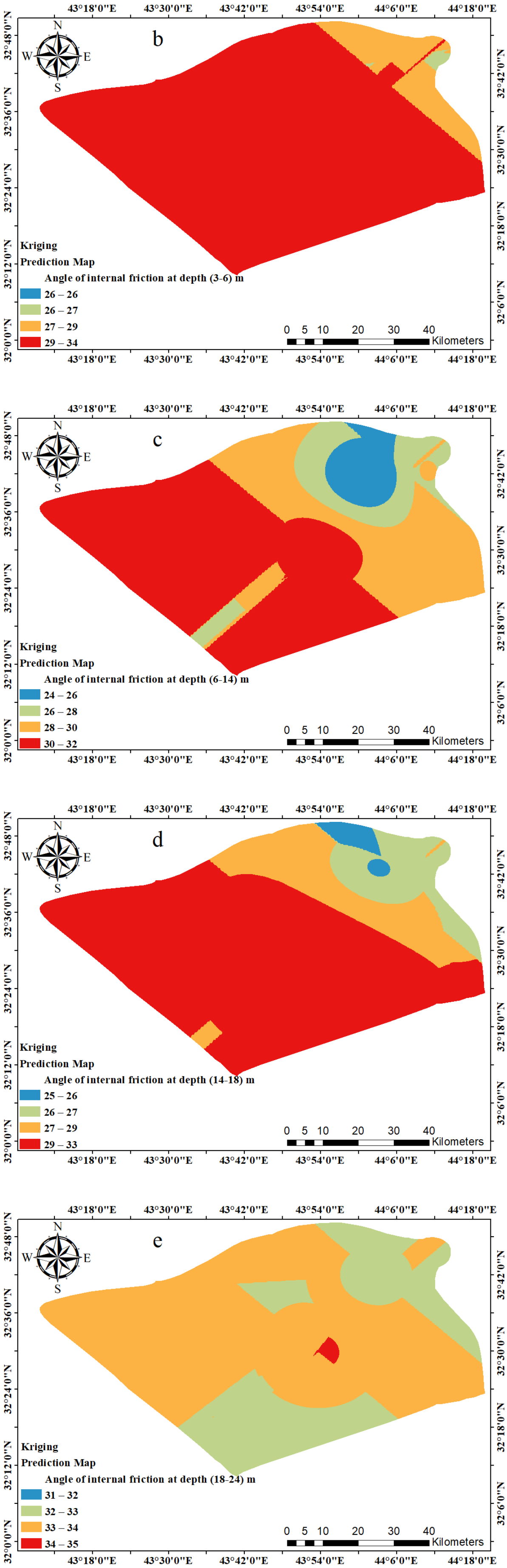



Figure 4. Histogram for $\varphi°$ in the city of Karbala

u





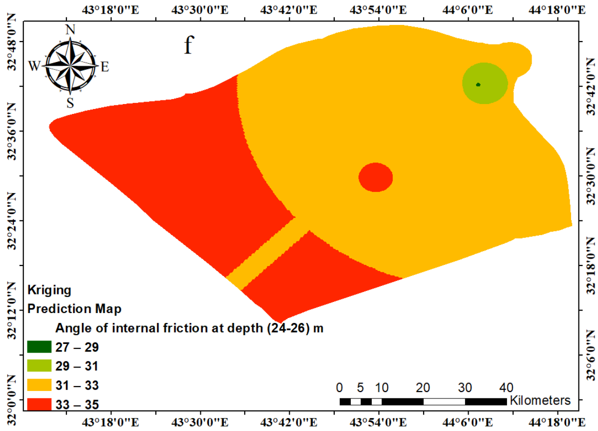




Figure 5. Soil friction angle prediction maps according to OK method for the depths: a: (0-3) m, b: (3-6) m, c: (6-14) m, d: (14-18) m, e: (18-24) m, f: (24-26) m

## 6. CONCLUSION

This study focuses on the creation of digital geotechnical maps for the key properties of geotechnical systems that geotechnical engineers frequently use in the design of footings and foundations. The boreholes data was collected to bring the total to 39 sites throughout the Karbala governorate. Additionally, maps displaying the locations of the gathered boreholes across Karbala were produced. Different geotechnical characteristics of the gathered boreholes were estimated using a spreadsheet application. The angle of internal friction is one example of this, and the article is an extension of other articles concerned with the soil of Karbala Governorate. Maps of the contours, there were also measurements and analyses of the angle of internal friction at each depth. All Ministries, institutions, and engineering firms that work with a significant amount of geotechnical data are advised to implement GIS technology. To map the spatial of $\varphi^{\circ}$ this study used IDW and OK. The OK is a practical method for tracking, assessing, and managing the geotechnical characteristics of soils. According to the root mean squared errors and correlation coefficients between interpolated values and observed values, ordinary kriging is the best method for extrapolating $\varphi^{\circ}$ in this region. Measures of uncertainty show that the standard deviation of estimation errors for OK was the smallest.

## REFERENCES

[1] Z. Guo, X. Chen, Y. Xu, H. Liu, "Effect of Granular Shape on Angle of Internal Friction of Binary Granular System", Fuel, Vol. 150, pp. 298-304, 2015.

[2] J. Zegzulka, J. Necas, J. Rozbroj, D. Gelnar, A. Ramirez Gomez, L. Jezerska, "Internal Friction Angle Model of Particles", Sci. Rep., Vol. 12, No. 1, pp. 1-9, 2022.

[3] J.R. Dungca, I. Concepcion, M.C.M. Limyuen, T.O. See, M.R. Vicencio, "Soil Bearing Capacity Reference for Metro Manila, Philippines", Int. J. GEOMATE, Vol. 12, No. 32, pp. 5-11, 2017.

[4] S. Kareem, A.L.A. Jasem, K.E. Hussain, M.H. Nadhir, "Horizontal and Vertical Geotechnical Variations of Soils

According to USCS Classification for the City of An-Najaf, Iraq Using GIS", Geotech. Geol. Eng., Vol. 38, No. 2, pp. 1919-1938, 2020.
[5] K. Hariri Asli, "GIS and Nonlinear Dynamics Model: Some Computational Aspects and Practical Hints", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 5, Vol. 2, No. 4, pp. 1-5, December 2010.
[6] A. Zarekar, H. Vahidi, B. Kazemi, Z. S. Ghorbani, H. Jafari, "Forest Fire Hazard Mapping Using Fuzzy AHP and GIS Study Area: Gilan Province of Iran", International Journal on Technical and Physical Problems on Engineering (IJTPE), Issue 12, Vol. 4, No. 3, pp. 47-55, September 2012.
[7] C. Ahmed, A. Mohammed, A. Tahir, "Geostatistics of Strength, Modeling and GIS Mapping of Soil Properties for Residential Purpose for Sulaimani City Soils, Kurdistan Region, Iraq", Model. Earth Syst. Environ., Vol. 6, No. 2, pp. 879-893, 2020.
[8] K.A. Rashed, A.A. Hussein, "GIS as A Tool for Expansive Soil Detection at Sulaymaniyah City", J. Eng., Vol. 26, No. 6, pp. 152-171, 2020.
[9] M. Din, J. Ali, A.Q. Khan, F. Sami, "Geotechnical Characteristics of Subsoil for Different Sectors of Islamabad", NUST J. Eng. Sci., Vol. 11, No. 1, pp. 33-40, 2019.
[10] A. Cendrero, et al., "Geoscientific Maps for Planning in Semi-Arid Regions: Valencia and Gran Canaria, Spain", Eng. Geol., Vol. 29, No. 4, pp. 291-319, 1990.
[11] H. Al Ani, L. Eslami Andargoli, E. Oh, G. Chai, "Categorising Geotechnical Properties of Surfers Paradise Soil Using Geographic Information System (GIS)", Int. J. GEOMATE, Vol. 5, No. 2, pp. 690-695, 2013.
[12] W.N.S. Wan Mohamad, A.N. Abdul Ghani, "The Use of Geographic Information System (GIS) for Geotechnical Data Processing and Presentation", Procedia Eng., Vol. 20, pp. 397-406, 2011.
[13] H. Arslan, "Spatial and Temporal Mapping of Groundwater Salinity Using Ordinary Kriging and Indicator Kriging: The Case of Bafra Plain, Turkey", Agric. Water Manag., Vol. 113, pp. 57-63, 2012.
[14] B. Cemek, M. GuLer, K. Kilic, Y. Demir, H. Arslan, "Assessment of Spatial Variability in Some Soil Properties as Related to Soil Salinity and Alkalinity in Bafra Plain in Northern Turkey", Environ. Monit. Assess., Vol. 124, No. 1-3, pp. 223-234, 2007.
[15] A. Parkes, "The Ashura Assemblage: Karbala's Religious Urban Fabric and Reproduction of Collective Shi'i Identity", Religions, Vol. 12, No. 10, 2021.
[16] R.D. Ward, J. Hann, "Handbuch der Klimatologie", Bull. Am. Geogr. Soc., Vol. 43, No. 12, p. 935, 1911.
[17] M. Kottek, J. Grieser, C. Beck, B. Rudolf, F. Rubel, "World Map of the Koppen-Geiger Climate Classification Updated", Meteorol. Zeitschrift, Vol. 15, No. 3, pp. 259-263, 2006.
[18] M. Wach, "The Application of Predictive Analysis in the Management of Investment Project Portfolios", Inform. Ekon., Vol. 2021, No. 4, pp. 51-61, 2021.
[19] R. Giraldo, P. Delicado, J. Mateu, "Ordinary Kriging for Function-Valued Spatial Data", Environ. Ecol. Stat., Vol. 18, No. 3, pp. 411-426, 2011.
[20] R.V. McCarthy, M.M. McCarthy, W. Ceccucci, L. Halawi, Applying Predictive Analytics, 2019.
[21] C.A. Gotway, R.B. Ferguson, G.W. Hergert, T.A. Peterson, "Comparison of Kriging and Inverse Distance Methods for Mapping Soil Parameters", J. Soil Sci. Soc. Am. Jour., Issue 60, pp. 1237-1247, 1992.
[22] C. Ware, W. Knight, D. Wells, "Memory Intensive Statistical Algorithms for Multibeam Bathymetric Data", Comput. Geosci., Vol. 17, No. 7, pp. 985-993, 1991.
[23] F.W. Chen, C.W. Liu, "Estimation of the Spatial Rainfall Distribution Using Inverse Distance Weighting (IDW) in the Middle of Taiwan", Paddy Water Environ., Vol. 10, No. 3, pp. 209-222, 2012.
[24] M.J. McCullagh, "Terrain and Surface Modelling Systems: Theory and Practice", Photogramm. Rec., Vol. 12, No. 72, pp. 747-779, 1988.
[25] S. Shahbeik, P. Afzal, P. Moarefvand, M. Qumarsy, "Comparison between Ordinary Kriging (OK) and Inverse Distance Weighted (IDW) Based on Estimation Error. Case Study: Dardevey Iron Ore Deposit, NE Iran," Arab. J. Geosci., Vol. 7, No. 9, pp. 3693-3704, 2014.
[26] J.K. Yamamoto, "An Alternative Measure of the Reliability of Ordinary Kriging Estimates", Math. Geol., Vol. 32, No. 4, pp. 489-509, 2000.
[27] Q. Zhu, H.S. Lin, "Comparing Ordinary Kriging and Regression Kriging for Soil Properties in Contrasting Landscapes", Pedosphere, Vol. 20, No. 5, pp. 594-606, 2010.
[28] C.V. Deutsch, "Correcting for Negative Weights in Ordinary Kriging", Comput. Geosci., Vol. 22, No. 7, pp. 765-773, 1996.
[29] K. Thermann, C. Gau, J. Tiedemann, "Shear Strength Parameters from Direct Shear Tests - Influencing Factors and Their Significance", Geol. Soc., Vol. 1, No. 484, pp. 1-12, London, UK, 2006.
[30] Y. Sun, S. Kang, F. Li, L. Zhang, "Comparison of Interpolation Methods for Depth to Groundwater and its Temporal and Spatial Variations in the Minqin Oasis of Northwest China", Environ. Model. Softw., Vol. 24, No. 10, pp. 1163-1170, 2009.

## BIOGRAPHIES

Name: **Haneen**
Middle Name: **Mohammed**
Surname: **Ali**
Birthday: 02.11.1996
Birth Place: Thi-Qar, Iraq
Bachelor: Engineering Civil, Engineering Faculty, University of Thi-Qar, Thi-Qar, Iraq, 2018
Master: Engineering, Civil, Geotechnical Engineering, University of Thi-Qar, Thi-Qar, Iraq, 2022
Research Interests: GIS, Spatial Statistics, Bayesian Approach, Geotechnical Properties
Scientific Publications: 6 Papers only, 1 Project

Name: **Jawad**
Middle Name: **Kadhim**
Surname: **Thajeel**
Birthday: 25.08.1974
Birth Place: Babylon, Iraq
Bachelor: Civil Engineering, Engineering Faculty, University of Technology, Bagdad, Iraq, 1997
Master: Geotechnical Engineering, Civil Engineering, Engineering Faculty, University of Technology, Bagdad, Iraq, 2001
Doctorate: Geotechnical Engineering, Civil Engineering, Engineering Faculty, University of Nantes, France, 2017
The Last Scientific Position: Assist. Prof., Head of Department of Civil Engineering, College of Engineering, University of Thi-Qar, Thi-Qar, Iraq, Since 2021
Research Interests: Geotechnical Risk, Reliability, Spatial Variability, Random Fields, Probabilistic Soil Properties, Probabilistic Site Characterization, Improvement of Soil Properties
Scientific Publications: 14 Papers, 2 Projects, 3 Theses
Scientific Memberships: Iraqi Engineers Association (IEA) (Consultant), Iraqi Society of Soil Mechanics and Foundation Engineering (MISSMGE)

Name: **Ahmed**
Middle Name: **Raad**
Surname: **Al Adhadh**
Birthday: 01.01.1988
Birth Place: Thi-Qar, Iraq
Bachelor: Civil Engineering, Engineering Faculty, University of Thi Qar, Thi qar, Iraq, 2008
Master: Geotechnical Engineering, Civil Engineering, Geotechnical Engineering, Engineering Faculty, California State University, Fullerton, USA, 2013
Research Interests: Foundations, Piles Design, GIS, Geotechnical Properties
Scientific Publications: 10 Papers