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Geo-statistics Modeling of Shallow Soil and Rock Stratum Layers based on Geotechnical Data Field using GIS Tool : A case study of Al Kharj Region - Saudi Arabia

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Abstract— During the last decade, the continued demand to build heavy buildings in Al Kharj city requires more attention by doing a geotechnical investigation in order to design an optimized foundations based on geo-database and mapping that have been indexed in neighboring buildings for future projects. However, to design the foundations of heavy buildings we need to explore the shallow soil and rock stratum layers using boreholes up to 20 meters in order to know the thickness of each layer and its geotechnical proprieties before designing any foundations type. For this reason, the owner of each building must be chosen an appropriate foundations according to the civil engineering specifications. According to the field investigation and the geotechnical data from the boreholes which were included in various corners of the site, we observe that there are a difference in the geotechnical proprieties from one borehole to another concerning the thickness of layer and also the mineralogical composition of these layers as well as its geotechnical characteristics, that why we intend to apply a new tool such as GIS application in order to predict the 3D distribution of the soil and rock stratum layers thickness based on the geo-statistics modeling implemented within the GIS software. As an important results involved within this paper, we note the randomly distribution of the soil and rock stratum layers thickness which have no conformity of geotechnical proprieties with the best choice of heavy buildings foundations which were adopted by the designer, however, it is necessary to look for a new methods allow to develop and support geotechnical investigations, including the indirect applied geophysics methods. In addition, referring to the randomly geotechnical proprieties distribution of the soil and rock stratum layers thickness, it is necessary to build a geo-database using GIS software taking into account many sources of geospatial data (Satellite images, GPS, field surveying, and so on…) which help public and private companies that are active in the construction field to help to take decision for better designing the heavy buildings foundations and to avoid many reasons of foundations failure after construction phases. Finally, we recommend to complete these findings involved in this paper by taking into account the groundwater phenomenon at shallow depth where the reinforcement foundations can be affected by salts or any other chemical elements associated with groundwater surface. As well as the need to be in the short term to review and develop the required geotechnical investigations which can be integrated with the spatial database in order to help to take better decisions when we design the heavy buildings foundations in Al Kharj city and where else in Kingdom of Saudi Arabia.

Index Terms— Soil and rock stratum, Boreholes, Geotechnical data, Geospatial data, Geo-statistics modeling.

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2 INTRODUCTION

Geotechnical study is an important task needed for all planning and construction of Civil Engineering projects. For any Civil Engineering project, a preliminary site investigation work has to be conducted and a site investigation report has to be submitted to the owner of the project. The report must show information about the subsurface stratification condition of the site. Conventionally, the site investigation is conducted by drilling a number of boreholes up to specified depths to check the soil and rock stratum layers in the site.

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The site investigation report would usually contain some recommendation for the foundation system that can be used for the new building. It is always the case that such report is based on extrapolating the data that was obtained from the individual boreholes to cover the total area of the site. The extrapolation is conducted mainly based on the experience of the geotechnical engineer in charge. However, there is always the question of how many boreholes are enough? and up to what depth? The answer to these questions is always a controversial issue and at the end, other factors (such as financial ones) may end up controlling the decision on how many boreholes and how deep each borehole should be. An experienced geotechnical engineer will definitely take enough precautions in his report to cover this work from future liabilities due to missing some important information in the report. Therefore a general trend of constructing expert systems for

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geotechnical engineering purposes has started decades ago. During the past two or three decades, the expert systems are of the major targets in all fields of science. Using the advantage of computers, all necessary data about a subject is stored and reformed using the concerning knowledge of its characteristics for future use. Expert systems have been developed during that period for many of geotechnical applications such as site investigation planning, soil classification parameter assessment, choice of type of foundation, and many others. Some of these systems aimed to develop inference of the deposition patterns for subsurface layers by means of interpreting the field and laboratory data such as Rehak, et al. (1985), Lok (1987) and Adams et al. (1989) which provides two dimensional subsurface profiles. Also a knowledge based system developed by Olephant et al (1996) provides two dimensional interpretations of the ground conditions. An integrated GIS and knowledge based geo-statistical system is developed by Adams and Bosscher (1995) enables to view and retrieve the subsurface data. The system can provide inference of soil and rock formation and properties at any location within the area of data. "Geotechnical Expert System for the Arab Republic of Egypt" GES-ARE is developed jointly by the General Authority for Educational Buildings and the Soil Mechanics and Foundations Research Laboratory of Cairo University, includes three modules : soil matching, site wide interpretation, and the proximity modules. It is mainly relying on similarity numbers between soil layer for each of the soil features : type, consistency, and color, (Youssef and Elkhouly, 2000). With 3D interpolation such as ArcGIS10 software , a more realistic approach for the extrapolation of a preliminary geotechnical report can be conducted. Such computer programs provide spatial continuity of the data, which eventually will enhance the quality of the recommendations of the geotechnical engineer. The enhancement may result from the followings : 1 - Human errors are minimized in extrapolating the point–to–point data coming from the borehole readings. 2 - The ability to verify the reliability of the obtained extrapolated results will be enhanced and can be conducted at any point in the site. 3 - The engineering decisions may be easier since the overall picture of the site is available. Geographic Information System (GIS) has been widely used recently in the field of geotechnical engineering. The capability of the GIS system and its main advantage of dealing with database of spatially distributed points meet the characteristics of soil boring logs information. GIS has been defined as "a fundamental and universally applicable set of value-added tools for capturing, transforming, managing, analyzing, and presenting information that are geographically referenced (Tim, 1995)." In preliminary geotechnical site evaluations, GIS can be used in four ways : 1 - data integration, 2 - data visualization and analysis, 3 - planning and summarizing site activities, and 4 - data presentation. GIS can be employed in this field to create a model of the geotechnical conditions and consideration facing a project through preliminary geotechnical site investigation. The model is then used to analyze the project from the geotechnical point of view and decisions are made to prevent foundation problems (Player, 2000). For example In Saudi Arabia many of contractors claims in projects are due to soil and rock problems appeared at time of foundation constructions (Hesham, 2003). A successful preliminary investigation may result in significant cost savings in design, construction, and longevity of the project (Player, 2000). New Jersey Department of Transportation (NJDOT) Bureau of Geotechnical Engineering maintains a large database of boring location plans and corresponding test boring logs. They conducted a successful pilot study to investigate the development of a GIS to better manage and disseminate soils and rocks information, as developed from test boring results (Williams, et al. 2002). That makes it easier to obtain information regarding soil types at a specific project location. The main procedure used in expert geotechnical system is to benefit from the extended soil and rock data available at different points spatially distributed to interpolate or extrapolate the subsurface soil and rock layers in regard of type and characteristic. One of the important parameters in the knowledge base that used in such system is the depth distribution of different soil and rock stratum layers. Previous application was made by (Bahr and Aguib 2003), considered the distribution of two layer types along a study area for Riyadh city in Saudi Arabia. Depths distribution among the boring points as processed by 3D Analyst (an ArcGIS10 extension) depended on the TIN network. However, modeling complex subsurface data as 3-dimentional body, merely surfaces are not supported by 3D Analyst of the GIS software ArcGIS10 (Rush, 1999). That was a limitation to that procedure. In addition this method considers soil and rock types characteristic changes gradually from a type to another, which is not the case spatially wise. Therefore methods of interpolations for soil and rock types may not give good results**.**

Study area : The site chosen for this application is the North western area of Al Kharj city. The general layout of the site is shown in Fig. 1. Its area is about 40000 square meters. The site is covered by about 30 boreholes with depths varies between 10 and 20 meters distributed in the area as shown in the Fig. 3. The spatial distribution of the boreholes locations in the site was transferred to a digital plan by means of scanning the general layout. Then each borehole location were digitized in a point data layer within the GIS

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software ArcGIS10. Boreholes layers description were collected from the geotechnical report and summarized. In order to facilitate the analysis of the soil and rock type layer distribution, the detailed soil and rock description is reduced to 5 main types (coded as 1, 2, 3, 4, and 5) that are common in most of soil and rock logs. They are : Sand, gravel, clay, limestone, and mixture of limestone sand & clay. Tab. 1, Tab. 2 and Tab. 3 show the reduced layers description for each borehole. The database table to be used for the analysis is constructed from : Borehole ID, layer type, depth of layer, elevation of layer, and borehole description. The number of layers was limited to 5 layers along the borehole depth. The elevation of the upper surface of the top layer for each borehole was taken from the geotechnical report and the elevation of subsurface layers is calculated accordingly using the depth of each layer. Tab. 2 and Tab. 3 show the data after editing through the ArcGIS10 software as attribute file.

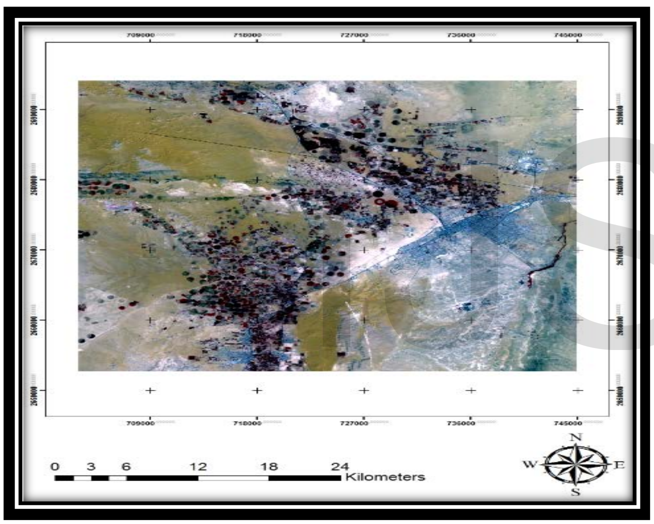

Fig. 1. Study area of Al Kharj.

(LandSat7 Image from RSI-KACST*, 2014).

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2 Materiels and Methods

There are two main groupings of interpolation techniques : deterministic and geo-statistical. Deterministic interpolation techniques create surfaces from measured points, based on either the extent of similarity (e.g., Inverse Distance Weighted (IDW)) or the degree of smoothing (e.g., Radial Basis Functions (RBF)). Geo-statistical interpolation techniques (e.g., Kriging) utilize the statistical properties of the measured points. The geo-statistical techniques quantify the spatial autocorrelation among measured points and account for the spatial configuration of the sample points around the prediction location.

Fig. 2. Zoom on the urban area in Al Kharj city.

(LandSat7 Image from RSI-KACST*, 2014).

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Deterministic interpolation techniques can be divided into two groups, global and local. The geo-statistical analyst provides the Global Polynomial as a global interpolator and the IDW, Local Polynomial, and RBF as local interpolators, (ESRI, 2010). Mathematically, the formula used in the IDW method to calculate Z variable for a kernel (the point whose third dimension is to be interpolated) is :

$$Z(x,y)=[\sum_{i=1}^{n}(Z_i/r_i^{p})/\sum_{i=1}^{n}r_i^{p}] \qquad (1)$$

Where : Z_i is variable at point i, n is the number of points in the neighborhood, r_i is the distance from the kernel to point i, p is the weight exponent that allow very distant points to be penalized with respect to closer ones. The effect of the exponent upon interpolation accuracy has already been investigated (Declercq, 1996). An exponent p of value 1 or 2 is usually preferable (Yang and Hodler, 2000).

Kriging is similar to IDW in that it weights the surrounding measured values to derive a prediction for an unmeasured location. The general Kriging formula for interpolation is formed as a weighted sum of the data :

$$Z(x,y)=\sum_{i=1}^{n}\lambda_i Z_i \qquad (2)$$

Where : Z_i is the measured value at the ith location; λ_i is an unknown weight for the measured value at the ith location;

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n is the number of measured values.

In IDW, the weight, λ_i, depends solely on the distance to the prediction location. However, in Kriging, the weights are based not only on the distance between the measured points and the prediction location but also on the overall spatial arrangement among the measured points. To use the spatial arrangement in the weights, the spatial autocorrelation must be quantified. Thus, in Ordinary Kriging, the weight, λ_i, depends on a fitted model to the measured points, the distance to the prediction location, and the spatial relationships among the measured values around the prediction location.

In Geo-statistical Analyst, RBFs are formed over each data location. An RBF is a function that changes with distance from a location. RBF methods are a series of exact interpolation techniques; that is, the surface must go through each measured sample value. There are five different basis functions : thin-plate spline, spline with tension, completely regularized spline, multi-quadric function, and inverse multi-quadric function. Each basis function has a different shape and results in a slightly different interpolation surface. RBF methods are a form of artificial neural networks. An example of RBF function is the Thin Plate Spline method which has well been described by Wahba (1990). It is based on modeling the measurements $Z(S_i)$ where $S_i = (x_i, y_i)$ is a point of coordinates x_i, y_i in a domain D as follows :

$$Z(S_i) = f(S_i) + \varepsilon(S_i), \quad i = 1, \ldots, n \qquad (3)$$

Where : n is the number of measurement points (control points) ; f is an unknown deterministic smooth function, and ε_i are random errors. The function can be estimated by minimizing :

$$\Sigma [Z(S_i) - f(S_i)]^2 + \lambda J_2 (f) \qquad (4)$$

Where : $J_2(f)$ is a measure of smoothness of f calculated by means of the following double integral :

$$J_2(f) = \iint_R^2 \{(\delta^2 f / \delta x^2)^2 + 2(\delta^2 f / \delta x \delta y) + (\delta^2 f / \delta y^2)\} dxdy \qquad (5)$$

Where : λ is the smoothing parameter which regulates the trade off between the closeness of the function to the data and the smoothness of the function.

The first step in this approach was to identify the main soil and rock types that are exit in the area by studying the boreholes logs in the area. The second step was to generalize the vertical distribution of the soil and rock stratum layers in each log to the main identified soil and rock types. The number of soil and rock stratum layers to be presented was taken same as the main soil and rock types identified; 5 layers to be represented in the system. This number may be changed from an area to another. Any layer type does not exist at a borehole log was given a zero depth value in the attribute table. Following to that is the application of the interpolation technique to the depths of each layer using the known depths at boreholes location, by means of using Spatial and Geo-statistical Analyst extensions. The interpolation was applied also to the elevation values of the bottom of the lower layer. Then it was applied to the depth of each of the 5 layers. Following to that was to find the elevation of each layer by means of adding the derived depths from the interpolation to the top elevations of the lower layer. Using the Arcscene10 extension a superimposing display of the 5 layer on top of each other could represent the spatially continuous distribution of the layers for the whole area as seen in Fig. 7. At the same time the vertical log at any point in the area could be displayed using the Identification Icon of the ArcGIS10, Fig. 5. shows an example of soil and rock type spatial distribution using Kriging interpolation for layer 2. Fig. 6 illustrates an example of layer depth spatial distribution using IDW method for Layer 1. Also longitudinal cross section in any direction that show elevation, depth, and soil and rock type could be displayed by the Spatial Analyst extension; for example cross section AA (along boreholes at the middle of Fig. 3) in Fig. 4. All the aforementioned information could be drawn for all layers. Three methods of interpolation were applied to predict depths in testing points. The depths are measured in the field and predicted from interpolations and are different than the points used for interpolations. Two deterministic and one geo-statistical methods were used : they are IDW, RBF, and Kriging respectively for depths interpolation, while Kriging only was used for soil and rock types prediction for each layer. The ArcGIS10 default parameters for these methods were used for the sake of comparison. In order to determine the effect number of known log points on the predicted values of other log points for the area, three sets were used as training points 40%, 50%, and 60% of the total known points. Accordingly 60%, 50%, and 40% were used as testing points for each of the three interpolation methods. The choosing of the locations of the training data was random according to the default of the software. Fig. 8 presents the results of the average error resulted from the three methods of interpolation for the three sets of training boreholes points. Chi 2 test for independent frequencies showed that there are no significant differences between the measured and predicted depths at the level of 1% for all methods. The maximum value for the average error in depth based on individual layer reached 1.8 m at layer 2 with 40% modeling points using the RBF method. The behavior of the average errors from the three methods is almost the same in

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all cases except for the average error of layers 2 and 3 resulted from the RBF method at the case of using 50% of points. The average error for the five layers is minimal when using 50% of the points for modeling the area for the three methods. Using 60% as training ratio resulted higher and positive average error, which means that predicted depths are smaller than measured. In the contrary when using 40% of points as training, it gave negative average error; which means that the predicted depths are bigger than the measured. Therefore 50% of the executed boreholes were adequate to construct strata depths model for this area with average error ranges between 0.13 and 0.5 m.

Fig. 3. Displaying the boreholes distribution for geotechnical investigation.

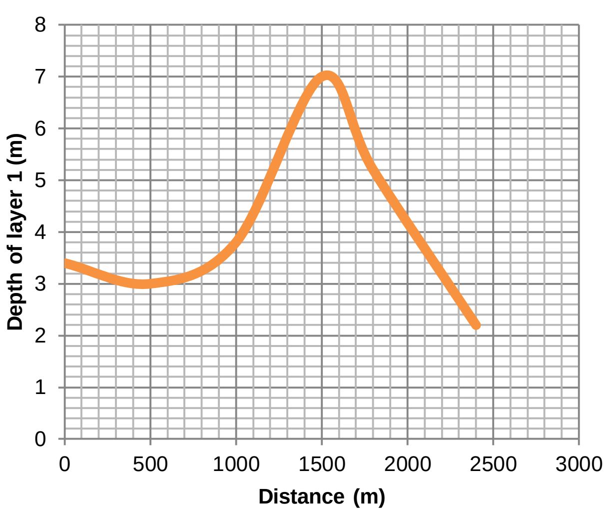

Fig. 4. Depth of layer 1 along cross-section A-A.

3 Results and Discussions

GIS approach proved to be a useful technique that could be used in mapping and enhancing the soil and rock information. By means of interpolating from points data spatial 3D information could be developed using the ArcGIS10 software and its extensions (Spatial, 3D, Geo-statistical analyst and ArcScene10). Information at any location in the site could then be identified. It was found that; using interpolation methods for soil and rock type could not be applied using such simple coding system. That was due to the fact that the interpolation gives value for any new point lies in between its neighbor codes. Behavior of natural soil and rock type distribution allows for any soil and rock type to be neighbors and is not limited to the one with next higher or lower code. Therefore, additional studies concerning reasonable coding for soil and rock types that suit the interpolation approach, are suggested for better predicting soil and rock types through the use of GIS tool. The three methods of interpolation; IDW, RBF, and Kriging promise to give good results when applied to predicting depths of soil and rock layers. For the site used for this study (about 30 boreholes) three sets of training points (12, 15 and 18 boreholes) were used in predicting the rest (18, 15 and 12 respectively). The maximum average error in layer depths reached 1.88 m as absolute figure when using RBF method for modeling the area using 40% of the data. The best interpolation method was the IDW, where the average error in layer depths ranged from 0.13 to 0.16 m. However, one can expect better results if a study made concerning the distribution of the chosen training points in the site. Also there are several parameters in the interpolating methods which need additional investigation to be determined precisely, for better results. For example, the distance power, radius of searching data and number of used surrounding points used in the IDW. Also determining the barrier limits to be respected when searching for data. For this site, in general when using 50% of the points to predict the other points the results showed the minimum average error in the depths for the three methods of interpolation; 0.13, 0.26 and 0.16 m for IDW, RBF and Kriging respectively. On the other hand for all the methods used, when using 40% of the points to predict the rest, the average error had negative values : -0.49, -0.50 and -0.54 m. This result means that the predicted depths are larger than the measured ones. When using 60% of the points to predict the rest, the average errors were, 0.58, 0.62 and 0.56 m, which mean that the predicted depths were smaller than the measured. It can be said that the IDW method of interpolation is the best for constructing the spatial strata depths model for this site using 50% of the

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measured data. For all layer depths determined by different methods the Chi 2 test showed no significant differences between measured and predicted values at the level of 1%. One would say that average errors when using 60% of the data were bigger due to random choice of the location of the controlling data points that might not be well distributed all over the site. Generally one must recall that all interpolation techniques are some type of estimation that should not be taken as exact values, but as a rough guide specially when needed for foundation or structure design.

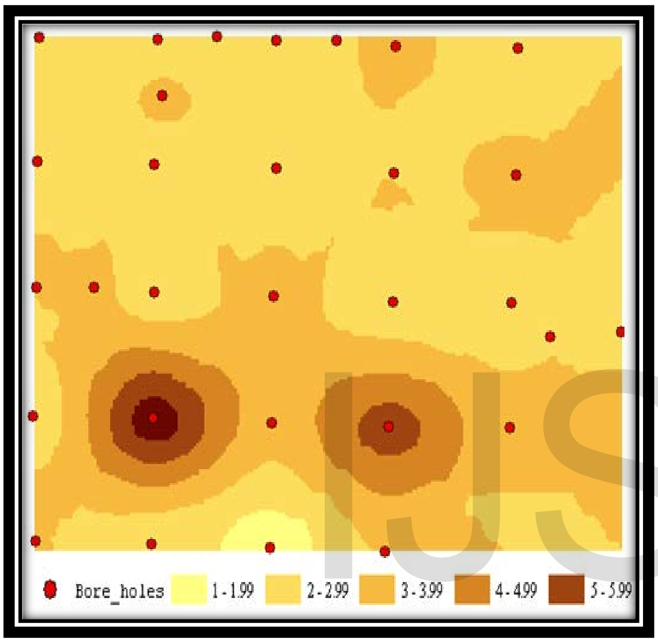


Fig. 5. Mapping distribution of soil type for layer 2 according to Kriging method.

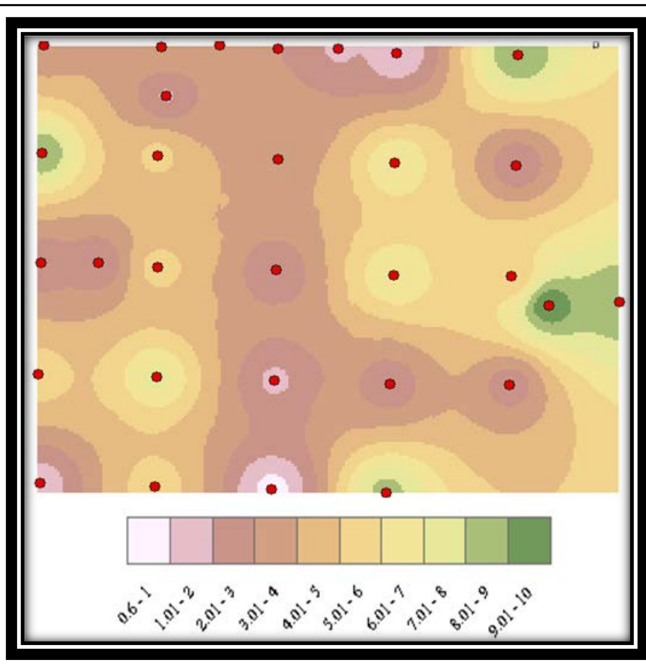


Fig. 6. Mapping distribution of soil type for layer 1 according to IDW method.

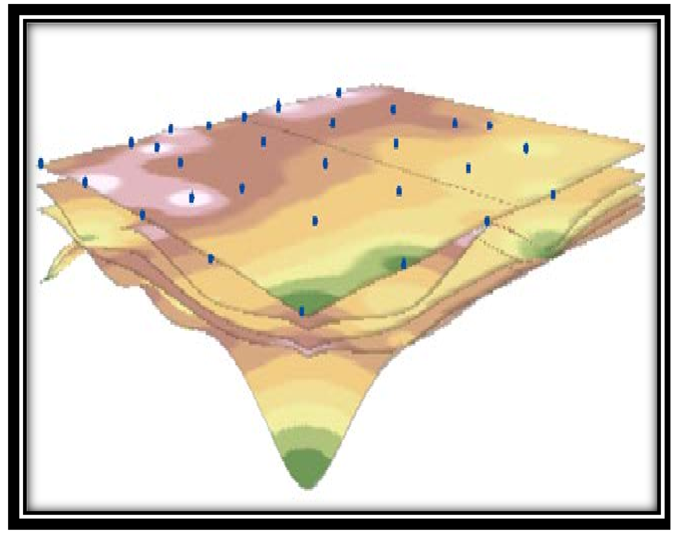
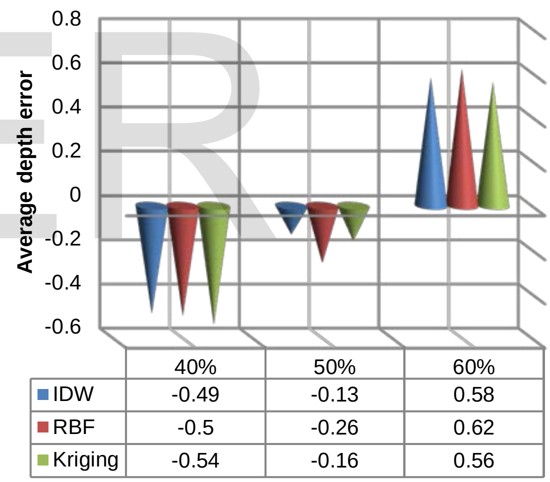


Fig. 7. 3D presentation of the layers depths, colors indicate soil types in each layer..



	40%	50%	60%
IDW	-0.49	-0.13	0.58
RBF	-0.5	-0.26	0.62
Kriging	-0.54	-0.16	0.56

Fig. 8. Average depth error for all layers by different methods of interpolation.

4 Conclusions

The Municipality of Al Kharj gives a great importance for the geotechnical investigation in order to predict a 3D representation of the soil and rock stratum layers quality for design foundations. In the sense, many failure and damage under the foundations have long been a challenge for management building construction in Al Kharj region. Improperly designed shallow foundations might result in increased cost of construction, insufficient support loading from structure, inconvenience, not satisfied customers and more. Such problems might not only be caused by operating a poorly maintained infrastructure. The 3D

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distribution of geotechnical data can be done by three geo-statistics methods implemented within ArcGIS10 software. These three geo-statistics methods give a comparable results and can be optimized. The geo-statistics simulations using ArcGIS10 software predict 3D distribution of different shallow layers and estimate the quality of these layers. This paper has been focused on geo-statistics modeling techniques applied to predict 3D representation of the quality of shallow soil and rock stratum layers referring to GIS Geo-database. The results have been undertaken to help to take decision for designing foundations under heavy buildings in Al Kharj city. We recommend continuing this work by introducing geophysics aspect to investigate the deep layers. In order to design the optimal foundations taking into account the underground voids called "karsts" within this area (Al Kharj) a Civil Engineering study will be required in order to choose the optimum depth and materials used for good stability of new heavy building in this area.

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Tab. 1 : Reduced layers description for boreholes.

Borehole No	Elevation (m)	Total Depth (m)	Layer Description	Code	Layer Depth (m)
BH1	585	10	Sand, Gravel	1,2	9,1
BH2	585.05	10	Sand	1	10
BH3	584.42	20	Sand, Clay, Sand, Gravel, Limestone	1,3,1,2,4	2.4,4.6,2.8,5.2,5
BH4	585.51	10.7	Sand, Gravel, Sand, Gravel	1,2,1,2	5,2,2.6,1.1
BH5	585.33	11	Sand, Clay, Gravel, Material of Lim, clay	1,3,2,5	2.2,1.5,6.1,1.2
BH6	585.84	20	Sand, Gravel, Limestone	1,2,4	9,3,8
BH7	585.92	10.5	Sand, Clay, Sand, Gravel, Limestone	1,3,1,2,4	1,6,1,1,1.5
BH8	585.48	10.5	Sand, Gravel, Limestone	1,2,4	7,0.5,3
BH9	585	11	Sand, Gravel, Sand, Limestone	1,2,1,4	7,1.4,1.6,1
BH10	584.48	10.5	Sand, Material of Lime Clay, Sand, Gravel	1,5,1,2	2.3,3.4,2.9,2.9
BH11	584.48	10	Sand, Gravel	1,2	8.4,1.6
BH12	584.9	10	Gravel, Sand, Gravel	2,1,2	0.6,6.9,2.5
BH13	584.9	10	Sand, Clay, Sand, Material of Lime, Clay, Limestone	1,3,1,5,4	1.8,1.8,4.4,1.5,.5
BH14	585.2	20	Sand, Clay, Sand, Gravel, Limestone	1,3,1,2,4	2.2,3.2,1.6,1.5,11.5
BH15	585.4	10	Sand, Gravel, Sand, Gravel, Limestone	1,2,1,2,4	3.7,1.8,1.5,1.5,1.5
BH16	585.09	10	Sand, Gravel, Limestone	1,2,3	3,4.5,2.5
BH17	585.09	10.5	Sand, Gravel, Limestone	1,2,4	3.8,3.7,3
BH18	585.3	10	Sand, Gravel	1,2	5.3,4.7
BH19	585.3	10	Sand, Gravel, Limestone	1,2,4	5.4,1.6,3
BH20	584.91	10	Sand, Material of Lime Clay	1,6	7.3,2.7
BH21	584.08	10	Sand, Gravel, Limestone	1,2,4	5.5,1.5,3
BH22	583.94	20	Gravel, Sand, Gravel, Limestone	2,1,2,4	1.5,2.2,0.8,15.5
BH23	584.89	10	Sand, Gravel, Material of Lime Clay, Limestone	1,2,5,4	5.5,1.5,1.5,1.5
BH24	585.46	10	Sand, Clay, Gravel, Limestone	1,3,2,4	2.3,3.2,3,1.5
BH25	585.97	10	Sand, Gravel	1,2	9,1
BH26	585.043	20	Sand, Gravel, Limestone	1,2,4	3.4,4.1,12.5
BH27	585.32	11	Sand, Clay, Sand, Gravel, Limestone	1,3,1,2,4	1.8,1,0.9,2.3,5
BH28	585.92	20	Sand, Clay, Gravel, Limestone	1,3,2,4	1.9,1.2,2,14.9
BH29	585.94	20	Sand, Clay, Sand, Limestone	1,3,1,4	2,4.4,1.1,12.5
BH30	585.97	11	Sand, Gravel, Limestone	1,2,4	3.6,2.4,5

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Tab. 2 : Attribute data for the boreholes using in ArcGIS10 software.

ID	LA 1	LA 2	LA 3	LA 4	LA 5	Description	TY1	TY2	TY3	TY4	TY5
BH1	9.0	1.0	0.0	0.0	0.0	Sand, Gravel	1	2	0	0	0
BH2	10.0	0.0	0.0	0.0	0.0	Sand	1	0	0	0	0
BH3	2.4	4.6	2.8	5.2	5.0	Sand, Clay, Sand, Gravel, Limestone	1	3	1	2	4
BH4	5.0	2.0	2.6	1.1	0.0	Sand, Gravel, Sand, Gravel	1	2	1	2	0
BH5	2.2	1.5	6.1	1.2	0.0	Sand, Clay, Gravel, limestone Clay	1	3	2	5	0
BH6	9.0	3.0	8.0	0.0	0.0	Sand, Gravel, Limestone	1	2	4	0	0
BH7	1.0	6.0	1.0	1.0	0.0	Sand, Clay, Sand, Gravel	1	3	1	2	0
BH8	7.0	0.5	3.0	0.0	0.0	Sand, Gravel, Limestone	1	2	4	0	0
BH9	7.0	1.4	1.6	1.0	0.0	Sand, Gravel, Sand, Limestone	1	2	1	4	0
BH10	2.3	3.4	2.9	1.9	0.0	Sand, Limestone, Clay, Sand, Gravel	1	5	1	2	0
BH11	8.4	1.6	0.0	0.0	0.0	Sand, Gravel	1	2	0	0	0
BH12	0.6	6.9	2.5	0.0	0.0	Gravel, Sand, Gravel	2	1	2	0	0
BH13	1.8	1.8	4.4	1.5	0.5	Sand, Clay, Sand, Limestone Clay, Li	1	3	1	6	4
BH14	2.2	3.2	1.6	1.5	11.5	Sand, Clay, Sand, Gravel, Limestone	1	3	1	2	4
BH15	3.7	1.8	1.5	1.5	1.5	Sand, Gravel, Sand, Gravel, Limestone	1	2	1	2	4
BH16	3.0	4.5	2.5	0.0	0.0	Sand, Gravel, Limestone	1	2	4	0	0
BH17	3.8	3.7	3.0	0.0	0.0	Sand, Gravel, Limestone	1	2	4	0	0
BH18	5.3	4.7	0.0	0.0	0.0	Sand, Gravel	1	2	0	0	0
BH19	5.4	1.6	3.0	0.0	0.0	Sand, Gravel, Limestone	1	2	4	0	0
BH20	7.3	2.7	0.0	0.0	0.0	Sand, Limestone Clay	1	5	0	0	0
BH21	5.5	1.5	3.0	0.0	0.0	Sand, Gravel, Limestone	1	2	4	0	0
BH22	1.5	2.2	0.8	15.5	0.0	Gravel, Sand, Gravel, Limestone	2	1	2	4	0
BH23	5.5	1.5	1.5	1.5	0.0	Sand, Gravel, Limestone Clay, Limestone	1	2	5	4	0
BH24	2.3	3.2	3.0	1.5	0.0	Sand, Clay, Gravel, Limestone	1	3	2	4	0
BH25	9.0	1.0	0.0	0.0	0.0	Sand, Gravel	1	2	0	0	0
BH26	3.4	4.1	12.5	0.0	0.0	Sand, Gravel, Limestone	1	2	4	0	0
BH27	1.8	1.0	0.9	2.3	5.0	Sand, Clay, Sand, Gravel, Limestone	1	3	1	2	4
BH28	1.9	1.2	2.0	14.9	0.0	Sand, Clay, Gravel, Limestone	1	3	2	4	0
BH29	2.0	4.4	1.1	12.5	0.0	sand, Clay, sand, Limestone	1	3	1	4	0
BH30	3.6	2.4	5.0	0.0	0.0	Sand, Gravel, Limestone	1	2	4	0	0

ID : Borehole number; **LA**. : thickness of layer (m); **1**, **2**, **3**, **4** and **5** : layer number; **TY** : Type of layer.

Tab. 3 : Attribute data for the boreholes using in ArcGIS10 software.

ID	EL. G	Description	EL. B	EL. 5	EL. 4	EL. 3	EL. 2	EL. 1
BH1	585.00	Sand, Gravel	575.00	575.00	575.00	575.00	576.00	585.00
BH2	585.05	Sand	575.05	575.05	575.05	575.05	575.05	585.05
BH3	584.42	Sand, Clay, Sand, Gravel, Limestone	564.42	569.42	574.62	577.42	582.02	584.42
BH4	585.51	Sand, Gravel, Sand, Gravel	574.81	574.81	575.91	578.51	580.51	585.51
BH5	585.33	Sand, Clay, Gravel, limestone Clay	574.33	574.33	575.53	581.63	583.13	585.33
BH6	585.84	Sand, Gravel, Limestone	565.84	565.84	565.84	573.84	576.84	585.84
BH7	585.92	Sand, Clay, Sand, Gravel	576.92	576.92	577.92	578.92	584.92	585.92
BH8	585.48	Sand, Gravel, Limestone	574.98	574.98	574.98	577.98	578.48	585.48
BH9	585.00	Sand, Gravel, Sand, Limestone	574.00	574.00	575.00	576.60	578.00	585.00
BH10	584.73	Sand, Limestone, Clay, Sand, Gravel	574.23	574.23	576.13	579.03	582.43	584.73
BH11	584.48	Sand, Gravel	574.48	574.48	574.48	574.48	576.08	584.48
BH12	584.90	Gravel, Sand, Gravel	574.90	574.90	574.90	577.40	584.30	584.90
BH13	584.90	Sand, Clay, Sand, Limestone Clay, Li	574.90	575.40	576.90	581.30	583.10	584.90
BH14	585.20	Sand, Clay, Sand, Gravel, Limestone	565.20	576.70	578.20	579.80	583.00	585.20
BH15	585.40	Sand, Gravel, Sand, Gravel, Limestone	575.40	576.90	578.40	579.90	581.70	585.40
BH16	585.09	Sand, Gravel, Limestone	575.09	575.09	575.09	577.59	582.09	585.09
BH17	585.09	Sand, Gravel, Limestone	574.59	574.59	574.59	577.59	581.29	585.09
BH18	585.30	Sand, Gravel	575.30	575.30	575.30	575.30	580.00	585.30
BH19	585.30	Sand, Gravel, Limestone	575.30	575.30	575.30	578.30	579.90	585.30
BH20	584.91	Sand, Limestone Clay	574.91	574.91	574.91	574.91	577.61	584.91
BH21	584.08	Sand, Gravel, Limestone	574.08	574.08	574.08	577.08	578.58	584.08
BH22	583.94	Gravel, Sand, Gravel, Limestone	563.94	563.94	579.44	580.24	582.44	583.94
BH23	584.89	Sand, Gravel, Limestone, Clay, Limestone	574.89	574.89	576.39	577.89	579.39	584.89
BH24	585.46	Sand, Clay, Gravel, Limestone	575.46	575.46	576.96	579.96	583.16	585.46
BH25	585.97	Sand, Gravel	575.97	575.97	575.97	575.97	576.97	585.97
BH26	585.04	Sand, Gravel, Limestone	565.04	565.04	565.04	577.54	581.64	585.04
BH27	585.32	Sand, Clay, Sand, Gravel, Limestone	574.32	579.32	581.62	582.52	583.52	585.32
BH28	585.92	Sand, Clay, Gravel, Limestone	565.92	565.92	580.82	582.82	584.02	585.92
BH29	585.94	sand, Clay, sand, Limestone	565.94	565.94	578.44	579.54	583.94	585.94
BH30	585.97	Sand, Gravel, Limestone	574.97	574.97	574.97	579.97	582.37	585.97

ID : Borehole number; **EL.** : Elevation (m); **G** : Ground; **B** : Borehole; **1**, **2**, **3**, **4** and **5** : layer number.