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Evaluating the Spatial Distribution of some Soil Geotechnical Properties Using Various Interpolation Methods (Case Study: Sulaimani Province, Iraq)

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ABSTRACT

Soil geotechnical parameters are important inputs for the prediction of ground suitability for construction projects. The aim of the study is the evaluation of spatial distribution of some soil geotechnical characteristics for Sulaimani governorate, northern Iraq which has a semi-arid climate. Sixty different soil specimens were taken from a distance of 2.0 meters from natural ground surface, around the Sulaimani city which are suitable for resettlement purposes. Several required laboratory experiments were performed to obtain some engineering properties of the collected soils according to ASTM standards, namely field water content, field wet density, initial void ratio (IVR), and degree of saturation (DS). Three different interpolation methods namely Inverse Distance Weighted (IDW), and Thin Plate Spline (TPS), which are deterministic interpolation methods in addition to and one geostatistical method, Ordinary Kriging (OK), were applied. Cross validation and accuracy assessment of model performance are also applied and analyzed. In general, the geostatistical method performance was compared with the deterministic methods. Ok method found to be more accurate and less biased method than the other two methods, which has lower RMSE (1.38%, 11.33%, 0.07 and 0.82 gm cm^{-3}) and ME (-0.63%, 0.94%, -0.16 and 0.3 gm cm^{-}3) for water content, DS, IVR and wet density respectively. According to the interpolation maps 65 to 70 % of study area is likely suitable for construction purposes compare to the other 30 to 35 %, which need some precautions for the suitability issue for construction projects. The results yielded in the reliability of the obtained soil geotechnical properties from geospatial maps, which may importantly engage to suitable engineering management application and modeling of land use.

Keywords: Soil Geotechnical properties; Interpolation; IDW; TPS; Ordinary Kriging

INTRODUCTION

Soil is one of the most important materials on earth surface that most structures foundations are placed on it. Spatial variability of geotechnical properties of soils is a significant index of quality of soils, in addition to suitability for construction projects (Metwally *et al*., 2019). Hence, civil engineers have to study its geotechnical properties which helps to discover an understanding about their suitability for foundation laying material (Khatri, 2018). Accurate prediction of these properties is very important because these properties have a great influence on superstructures stability (Taleb Bahmed *et al*., 2019). Kalantary et.al; 2012 Kalantary and Kordnaeij (2012) asserted that subsurface investigation must be undertaken to obtain a sufficient number of undisturbed soil samples and then tested in the laboratory to obtain the necessary soil's geotechnical properties such as consistency, compressibility, and shear parameters (Kalantary and Kordnaeij, 2012; Laskar and Pal, 2012; Nesamatha and Arumairaj, 2015). In addition to the other soil's geotechnical properties, the amount of water in the fine-grained soils is a great factor for identifying the physical state of a soil (Kollaros, 2016). So, water content is one of the factors that the behavior of cohesive soil depends on, in different consistency stages such as solid, plastic, and liquid (Hrubesova *et al*., 2016).

Traditionally engineers have been trying hard to predict the variation of soil and its properties by sketch maps and manual diagrams. Soil mapping has been done since decades using paper maps by cartographers (using symbols and lines). Most of these old methods are cumbersome and uneconomical (Khatri, 2018). The knowledge of expert are considered more for other models, where current information is determined based on a clear guideline choice to understand soil kinds and their geotechnical characteristics distribution spatially (Zhu *et al*., 2001; Wielemaker *et al*., 2001; Egli *et al*., 2005; Egli *et al*., 2006).

According to the cost effective and time consuming of soil sampling and testing for a huge number of samples, it is necessary to find robust alternative methods for soil's geotechnical properties prediction. Hence, now the use of digital maps using Geographical Information system (GIS) has provided the way out to store and manipulate the soil variation in a most optimum way possible and enhances our capability to map the exact variation of the landscape around the globe (Khatri, 2018; Abulude *et al*., 2015). Therefore, accurate interpolations of soil's geotechnical properties at un-sampled places are necessary in order to be within preferable planning and management (Rahman *et al*., 1997; Tognina, 2004; Behrens *et al*., 2005).

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Globally, the most effective and accurate interpolation methods have been significantly considered and used (Kravchenko and Bullock, 1999; Robinson and Metternicht, 2006; Zhu *et al*., 2001). These studies evaluated the effectiveness of different interpolation techniques in measuring soil properties, however, few of the techniques were actually related to soil geotechnical properties (Meul and Van Meirvenne, 2003; Karydas *et al*., 2009; Ließ *et al*., 2012). For instance, geostatistical methods found to be one of the most accurate ways to study soil characteristics spatial distribution (Saito *et al*., 2005; Kumar *et al*., 2012; Kumar *et al*., 2013; Liu *et al*., 2014; Behera and Shukla, 2015). Previous studies have used the geospatial techniques to assess the soils spatial association and the soil characteristics changeability geographically (Wei *et al*., 2008; Egli *et al*., 2006; Egli *et al*., 2005), and the relations between soil types and environmental variables (Lagacherie and Holmes, 1997; Behrens *et al*., 2005; Carré *et al*., 2007), different soil types for some points in Sulaimani Governorate (Salih, 2020). Moreover, spatial variability is omitted as some studies were conducted at a regional scale. So there is a gap and there is not much information existing on the accurate various soil types' distribution and their geotechnical properties, usually, detailed spatial distribution maps for soils are not available in developing countries such as Iraq. Hence, this study aim is to evaluate some soil geotechnical properties spatial distribution in a semi-arid region in addition to assess the precision of predicted map based on different interpolation methods and finally evaluate geotechnical properties effect on stability of construction project.

Methodology

1. The study area and soil samples locations

This study was conducted and carried out in Sulaimani Governorate, Iraq (Figure 1). The study region altitude ranges between 633 m to 1706 meters above sea level. The study area climate is hot and dry over summer and cold over winter (Najmaddin *et al*., 2017b). The mean annual precipitation is between 450-700 mm (Najmaddin *et al*., 2017a). Site investigations were performed to obtain the required field information and obtain soil natural samples. From various 60 locations, the required soil specimens were collected in March-May 2019. All the collected soil specimens were taken from 2.0 meters depths from natural ground surface. Moreover, in order to discover the soils physical characteristics of around selected sites, collection of undisturbed and disturbed soil samples was carried out. The collected soil samples for all locations were kept undisturbed by extracting them via thin wall tubes to find the real field density of the soil samples. This scenario is carried out to obtain representative samples of the selected sites in order to understand in-situ field properties of the soils of the selected locations. In addition, the collected specimens were directly put in plastic bags in order to save their natural geotechnical properties, especially field moisture content and field density.

2. Laboratory Work

Soils geotechnical characteristics were obtained via both field and laboratory test methods. Several required laboratory experiments were performed so to obtain the collected soils physical properties according to ASTM standards as follow.

Water Content Determination (ASTM D 2216 – 10)

This test was performed according to ASTM standards in order to find the collected soil samples natural moisture content. Soils moisture content is the ratio of water mass in a given soil sample mass to the dry soil solids mass of the same sample. Water content is denoted as percentage.

Density (Unit Weight) Determination (ASTM D 2937-10)

This test is a laboratory experiment, which was implemented to find in-place density of natural soil gotten by a thin-walled cylinder according to ASTM standards. The in-place density is the mass ratio of wet soil sample to the volume of same sample. So, the dry density is the mass ratio of the dry soil sample to total volume of same sample. This test method overall principles have been effectively utilized to gain specimens of some fine-grained soils fields have 4.75 mm as a maximum particle-size for other purposes than determination of density, such as conduction of other laboratory tests for soil's engineering properties determination.

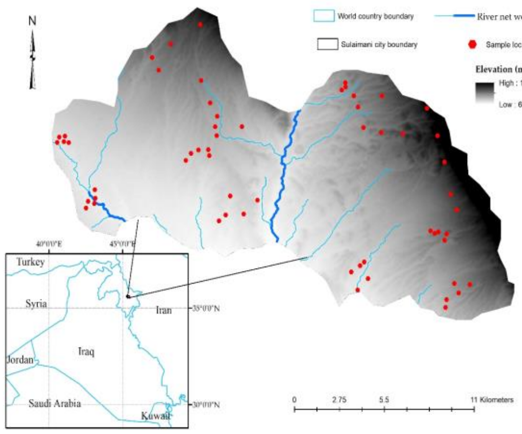

Figure 1. The study area geographical location.

Actual values of degree of saturation for all the tested soil samples were calculated from the in-situ density and initial water content values. Also, to measure the soils void ratio, volume of solids should be known first. After that, the volume of voids can be found by deducting the volume of solids from the total soil sample volume

3. Interpolation Methods

In the current research, different interpolation methods were used containing deterministic interpolation (inverse distance weighted (IDW)), degree of smoothing which well known as radial basis function namely Thin Plate Spline (TPS) an geostatistical interpolation, namely Ordinary Kriging (OK).

Inverse Distance Weighting (IDW)

It is one of the practical and deterministic interpolation methods in the field of soil science. Based on adjacent known places, IDW estimation was made. The weights assigned for the interpolation points are the opposite of their distance from the point of interpolation. The close points are therefore prepared to have additional weights (so, additional impact) compared to remote points and vice versa. The established sample points are implicit in being self-governing (Robinson and Metternicht, 2006).

$$Z(X_o) = \frac{\sum_{i=1}^{n} \frac{x_i}{h_{ij}^{\beta}}}{\sum_{i=1}^{n} \frac{1}{h_{ij}^{\beta}}} \quad (1)$$

Where $Z(X_o)$ **is the interpolated value, the total number of sample data values** $is\ represented\ by\ n,\ i$**th data value is** x_i, h_{ij} **is the separation distance between the sample data value and the interpolated value, and** β **represents weighting power.**

Ordinary Kriging (OK):

It includes measured data statistical characteristics (spatial autocorrelation). The kriging technique takes advantage of the semi-variogram to demonstrate spatial continuity (autocorrelation). As a function of distance the semi-variogram tests the frequency of the statistical association. The range is the distance the spatial correlation, and the sill corresponds to the maximum variability in the absence of spatial dependence. OK estimates $Z(X_o)$ and the minimum error or variance of σ^2 were calculated as follow respectively.

$$Z(X_o) = \sum_{i=1}^{n} \lambda_i Z\ (X_i) \quad (2)$$

$$\sigma^2 = \mu + \sum_{i=1}^{n} \lambda_i \gamma\ (X_o - X_i) \quad (3)$$

The weights are λ_i; the lagrange constant is μ; and γ $(X_o - X_i)$ is the semi-variogram value corresponding to the distance between X_o and X_i (Vauclin *et al.*, 1983; Agrawal *et al.*, 1995).

The semi-variogram expressed as follow, which were used to inspect the soil characteristics spatial distribution. Based on intrinsic hypotheses and the regionalized variable theory (Nielsen and Wendroth, 2003).

$$\gamma_{(h)} = \frac{1}{ZN(h)} \sum_{i=1}^{n} [Z(X_i) - Z(X_i + h)]^2 \quad (4)$$

The semi-variance is $\gamma_{(h)}$, the lag distance is h, the parameter of the soil characteristic Z, the number of pairs of locations is $N, which$ separated by a lag distance h, $Z(X_i)$ and $Z(X_i + h)$ are values of Z at X_i and $X_i + h$ positions (Wang and Shao, 2013).

In current research, the spherical model $\gamma_\theta(h)$ was considered for the sample variogram fitting changes in the variogram function. Spherical model is defined by:

$$\gamma_\theta(h) = \begin{cases} 0 & h = 0 \\ C_0 + C_1\left(\frac{3}{2}\left(\frac{|h|}{C_2}\right) - \frac{1}{2}\left(\frac{|h|}{C_2}\right)^3\right), & 0 > h \geq C_0 \\ C_0 + C_1 & h > C_0 \end{cases} \quad (5)$$

The vector of free parameters that fully determines the variogram shape where characterized by θ. For the considered variogram models, it will often be the case that θ = $(C_0, C_1,\ C_2)$; where C_0 is the *nugget* parameter, i.e. the nonzero limit *lim h* →0 $\gamma_{(h)} = C_0$ in case the variogram model is assumed to be discontinuous in the origin, C_1 is called *sill* parameter, that is the limit value *lim h* →1 $\gamma_{(h)} = +1$; and C_2 is the *range*, which is the typical spatial scale associated to significant.

2.3.3. Thin plate splines (TPS)

The TPS interpolation can be used to represent any location in space to a new location given a set of control points in terms of radial basis functions (Duchon, 1977; Wahba and Wendelberger, 1980). The TPS corresponds to the radial basis as

$$Z_{(r)} = r^2 \log r \quad (6)$$

r is the distance between un-sampled places and sample points. More details about the TPS estimation can be found in (Duchon, 1977; Wahba and Wendelberger, 1980; Ikechukwu *et al.*, 2017).

2.4. Cross validation

The performance of spatial interpolation methods were assessed by the Split-data-sets-cross-validation method. It is to divide the points into two collections: the used points in the interpolation operation and the used points to validate the obtained results. In this study we randomly hold 20 points for validation and 40 points for interpolation operation.

To assess the accuracy of the interpolation methods, the Mean Error (*ME*), Mean Absolute Error (*MAE*), Root Mean Squared Error (*RMSE* and determination coefficient (R^2 value) were calculated.

$$ME = \frac{1}{n} \sum_{i=1}^{n} (X_i^{\cdot\cdot} - X_i) \quad (7)$$

$$ME = \frac{1}{n} \sum_{i=1}^{n} |X_i^{\cdot\cdot} - X_i| \quad (8)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} (X_i^{\cdot\cdot} - X_i)^2}{n}} \quad (9)$$

The interpolated value at the un-sampled place i is $X_i^{\cdot\cdot}$ (i.e. place where the sample point was removed or did not use in interpolation operation), X_i is the right value at place i and n is the number of points in the dataset.

RESULTS AND DISCUSSION

Results

1. Moisture content spatial distribution (%)

Figure 2 displays spatial distribution of the water content %, applied three methods IDW, OK and TPS characterizing the bulk of the data have critical water content (12%–18%). Predicted water content is plotted against observed water content (Figure 3), with the linear regression best fit and 1:1 line. RMSE value were 1.38% For OK and TPS methods and slightly higher for IDW which were 1.5%. A statistical summary between predicted and observed water content is shown in Table 2. The R^2 value between predicted and observed water comet were low but significant for all methods at p> 0.05.

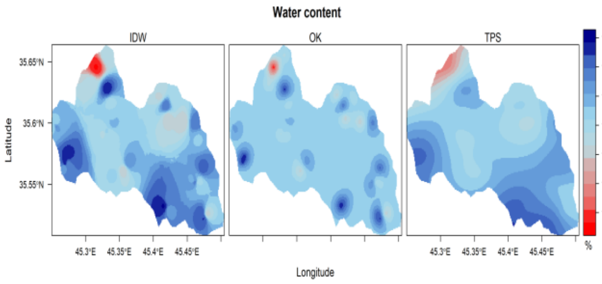

Figure 2. Spatial distribution of predicted water content using inverse distance weighting (IDW), Ordinary kriging (OK) and Thin Pate Spline model (TPS) methods.

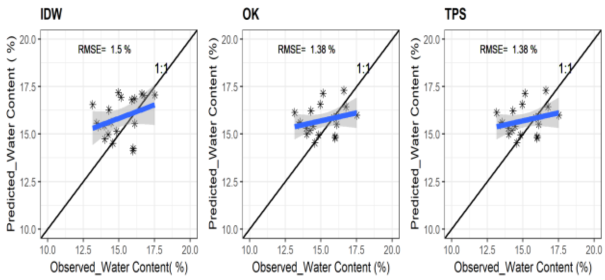

Figure 3. Scatter plot between observed and predicted water content using (IDW), (OK) and (TPS) methods. The blue line shows the best-fit regression with 95% confidence interval.

2. Spatial distribution of Degree of Saturation (DS %)

Figure 4 represents the spatial variation of the degree of saturation %, which illustrates that the predicted_DS % range of 50–85. The relationship of the predicted_DS % versus the observed_DS is shown in Figure 5, in addition to the linear regression best fit and 1:1 line. RMSE value was increased gradually form 11.23% For IDW, 11.3% for OK and 12.12 % for TPS. The R^2 value between predicted_DS % and observed_DS % is shown in in Table 2, which were 0.31, 0.27 and 0.12 for IDW, Ok and TPS respectively.

Table 1. Statistical summer of cross validation for different soil geotechnical properties using different interpolation methods.

Soil Geotechnical Properties	Interpolation methods	ME	MAE	R^2
Water Content (%)	IDW	-0.77	1.24	0.34
	OK	-0.63	1.13	0.28
	TPS	-0.68	1.22	0.32
Degree of Saturation (%)	IDW	1.75	9.8	0.31
	OK	0.94	9.8	0.27
	TPS	0.43	10.7	0.12
Initial Void Ratio	IDW	-0.15	0.068	0.37
	OK	-0.16	0.066	0.42
	TPS	-0.17	0.07	0.28
Wet Density (gm cm^{-3})	IDW	0.42	0.71	0.18
	OK	0.36	0.66	0.12
	TPS	0.33	0.81	0.1

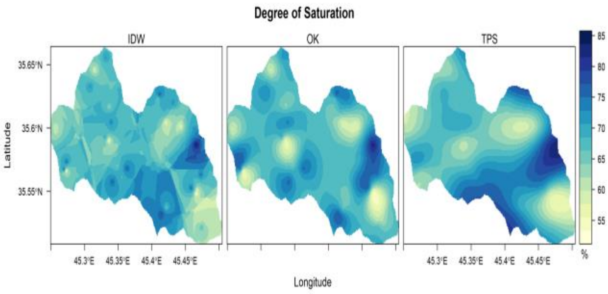

Figure 4. Spatial distribution of predicted degree of saturation using (IDW), (OK) and (TPS) methods.

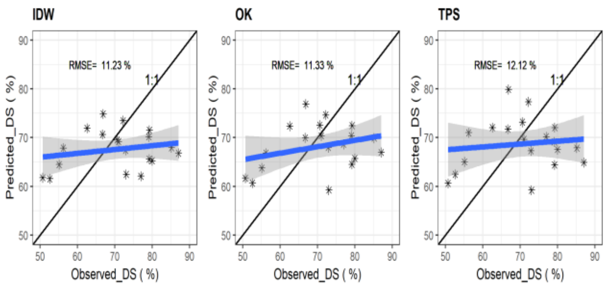

Figure 5. Scatter plot between observed and predicted degree of saturation using (IDW), (OK) and (TPS) methods. The best-fit regression with 95% confidence interval is the thick blue line.

3. Spatial distribution of Initial Void Ratio (IVR)

The spatial distribution of the IVR is shown in Figure 6, which demonstrates the predicted_IVR values ranged between 0.4–0.67. In Figure 7, the predicted_IVR % relation with the observed_IVR is drawn, along with the linear regression best fit and 1:1 line. RMSE value were ranged between 0.07 -0.08 for all methods. The R^2 of predicted_IVR % and observed_IVR % is shown in in Table 2, which were 0.37, 0.42 and 0.28 for IDW, Ok and TPS respectively.

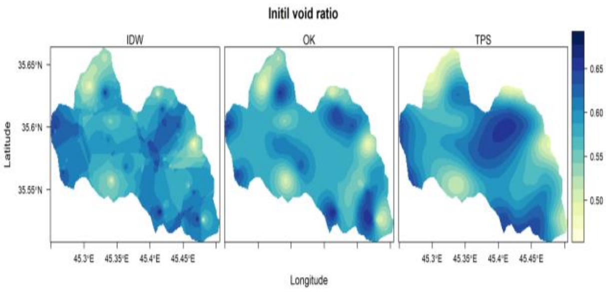

Figure 6. Spatial distribution of predicted initial void ratio using (IDW), (OK) and (TPS) methods.

4. Spatial distribution of Wet density (gm cm $^{-3}$)

Figure 8 represents the spatial variation of the wet density, which illustrates that the predicted_ wet density ranged from 16.5–195. Predicted wet density is plotted against observed wet density (Figure 9), with the linear regression best fit and 1:1 line. RMSE value was ranged between 0.88 gm cm $^{-3}$ For IDW, 0.86 gm cm $^{-3}$ for OK and 0.95 gm cm $^{-3}$ for TPS. The R^2 value between predicted wet density and observed Wet density is shown in in Table 2, which were 0.18, 0.12 and 0.1 for IDW, Ok and TPS respectively.

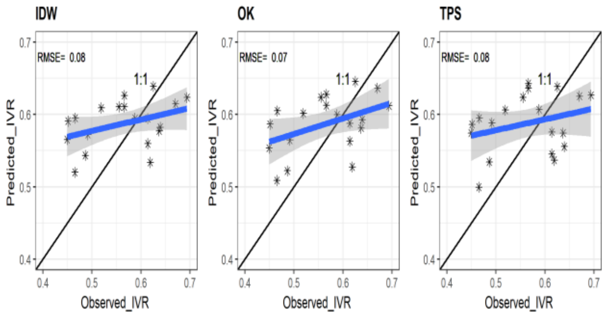

Figure 7. Scatter plot between observed and predicted initial void ratio using (IDW), (OK) and (TPS) methods. The best-fit regression with 95% confidence interval is represented by the blue line.

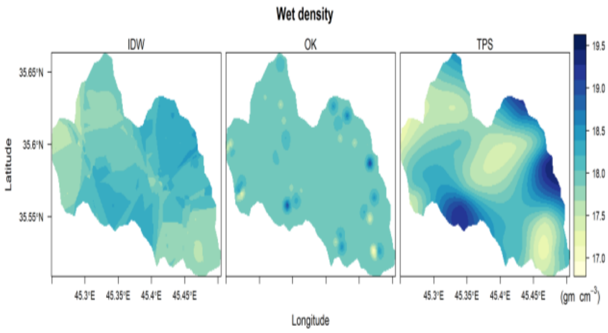

Figure 8. Spatial distribution of predicted wet density using (IDW), (OK) and (TPS) methods.

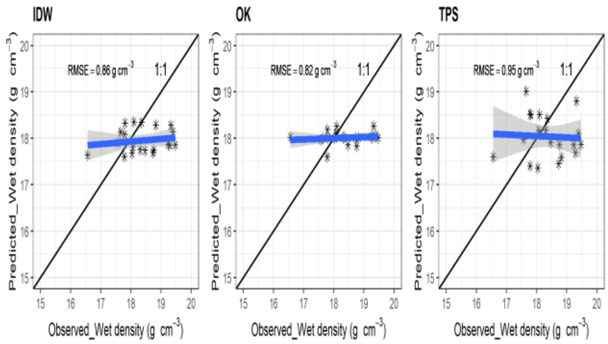

Figure 9. Scatter plot between observed and predicted wet density using (IDW), (OK) and (TPS) methods. The best-fit regression with 95% confidence interval is represented by the blue line.

5. Interpolation methods Comparison

Spatial distributions for moisture content, degree of saturation, initial void ratio and wet density were analysed in the study region gained via three approaches (IDW, Ok &

TPS). ME, MAE and R^2 value are presented in Table 2. Ok method from the comparative results, found to be more precise compare with the other approaches, which has lower MAE (1.3%, 10.34%, 0.06 and 0.6 gm cm^{-3}) for water content %, DS %, IVR and wet density respectively. While the TPS has the higher value of MAE, which were (9.8%, 0.07 and 0.81 gm cm^{-3}) for Ds, IVR and wet density respectively except for water content (Table 2). The bias level (ME values) for estimation is the lowest for Ok and the highest for IDW (Table 2).

Discussion

In this study, three separate methods of geostatistical and deterministic interpolation were chosen to determine the spatial distribution of geostatistical characteristics of the soils. Cross validation was applied in order to discover the most appropriate spatial interpolation technique. Assessment measures of model performance are analyzed. Coefficients of determination high value, and ME, MAE and RMSE low values showed an acceptable match between experimental and predicted different soils geotechnical properties. In general, the geostatistical method performance was significantly better compared with the deterministic methods. Superiority of Ok method over IDW and TPS to predict water content, degree of saturation, initial void ration and wet density. The lowest error was provided by OK method (ME, MAE and RMSE values) and the highest R^2 value in the spatial interpolation compared to deterministic methods. This might be because of OK as a geostatistical method include spatial autocorrelation and optimize the masses statistically (Ford and Quiring, 2014). This results is in agreement with previous researches which stated that OK method frequently provide superior interpolation for values estimation at the unmeasured places (Bhunia *et al*., 2018; Nayanaka *et al*., 2010; Tripathi *et al*., 2015) and disagree with (Ikechukwu *et al*., 2017; Yao *et al*., 2013) who stated that the deterministic models give better interpolation than OK for land study.

The ME, which provided relative error or sometimes refer to as a bias of the predicted data in comparison with the observed data, was lowest for OK method and highest for IDW.. This possibly due to IDW utilizes a linear set of values at captured sample locations, by an inverse function assigns weights of the separation among the sample places to be estimated and points captured to estimate values of the unknown place (Robinson and Metternicht, 2006). However masses are identified randomly, we use an ideal mass management function that allocates a mass that is most appropriate for points within the data set that captured. Robinson and Metternicht (2006) Asserted that IDW's expectations are affected by this mass obligation. This does not imply IDW method is not suitable for soil geotechnical properties mapping. TPS method on the other hand performs better than IDW.

The importance of the carried out soil tests is in the right decision for a proper soil foundation for construction projects. Specifically, the natural soil geotechnical properties. In Figures 2 and Figure 4, which are representing the spatial distribution of the prediction of natural moisture content and the degree of saturation, the places in the study area which have a lower level of degree of saturation and moisture content are more suitable for construction projects compare with the other locations. This is might be because; increasing degree of saturation and moisture content can lead to more lubrication around soil particles resulting in a damp/wet soil state. This soil state is not preferable for construction foundations, due to its weak capability to resist superstructures loads. For example, grade color bar in these two figures showed that the darkness grade increases the effects on the suitability of the place for construction projects foundations. The majority of the mid-area is light blue, which means that is better according to lower water content compare to the dark blue places. However, the very dark blue places are quite small percent and distributed randomly in the region. The region potentially might be divided to three places according to the predicted maps, red (5 %), light blue (70 %), and dark blue (25 %), which means that likely the most suitable places yielded in large percent compare with the remain probably unsuitable and hence requires some precautions for the foundation areas of construction projects.

In the same way, soil's initial void ratio is significant for sustainability of construction project.

In Figure 6, which is representing the distribution of the prediction of the initial void ratio, hence the places with high void ratio are weak and not suitable for construction project. Because, higher initial void ratio can cause more openings to be available in the soil structure, which can be filled either by air and/or water. This lead to less solid proportions to resist the superstructures loads. According to the spatial; distribution of IVR. The region potentially might be divided to three places according to the available predicted map, yellow color area (15 %), light green (50 %), and dark green (35 %). The IVR distribution yielded in almost 65 % of likely suitable for construction purposes compare to the other 35 %, which unlikely requires some precautions for the suitability issue for construction projects.

Similarly, soil wet density do the same behavior as the mentioned properties. In Figure 8, which is representing the spatial distribution of the prediction of the wet density. Hence, the places with high wet density are weak and not suitable for construction projects foundations. Because, more wet state can be weak for foundation soil state and might lead to sever structure collapse problems. So, the places with very light yellow color are the most suitable compare with the other places, however they cover a very small part of the region and distributed randomly. On the other hand, the very dark green places representing the worse places compare with the other places, which are lightly concentrated and randomly distributed in the region, and more likely found in the methods of OK and TPS. The wet density distribution yielded in almost 75-95 % of probably suitable for construction purposes compare to the other 5-25 %, which unlikely requires some precautions in order to be suitable for construction projects.

It is important to be mention here, the majority of natural soil samples were collected in spring time and a very small number of samples were collected at the end on winter seasons. This is means that almost the samples were collected in the wet seasons, which might possibly cause increase in the magnitudes of some geotechnical properties such as water content, degree of saturation and wet density. Unfortunately, the magnitudes of these properties might decrease if the sampling taking place in summer season. However, the effects may be small, as the specimens were extracted from 2.0 meters deepness below natural ground level. In addition, the initial void ratio is related to the type of soil and the season's wetness is not influence in its magnitude.

CONCLUSION

Understanding the spatial distribution of the geotechnical characteristics of the soils is crucial for sustainable land management. Coefficient of determination (R^2 value) was used to assess the efficiency, and the root mean square error (RMSE), mean error (ME) and mean absolute error (MAE) were used to represent the errors. The results show that the OK interpolation method gave better results. Compare to TPS and IDW methods. IDW skill is driving higher RMSE and ME compare to the other deterministic and geostatistical methods, it has the worst presentations. Based on predicted maps for these properties more than 65% of the study area is likely suitable for construction project. Finally, the outcomes guide to the amplification of reliable soil geotechnical properties maps, which can notably participate in the appropriate application of agricultural and engineering managements and land modeling.

Author Contributions: Study design: P.M.N. and N.B.S.; Data curation: T.A.A.; Investigation: N.B.S.; Methodology: P.M.N.; Resources, T.A.A.; Software, P.M.N.; Supervision and Writing: the first draft, P.M.N; Writing: review & editing: P.M.N. and N.B.S. P.M.N. is co- author of this article. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare that no conflict of interest.

REFERENCES

Abulude FO, Akinnusotu A and Adeyemi A. (2015) Global positioning system and its wide applications. Continental J. Information Technology 9: 22-32.

Agrawal O, Rao K, Chauhan H, *et al.* (1995) Geostatistical analysis of soil salinity improvement with subsurface drainage system. Transactions of the ASAE 38: 1427-1433.

Behera SK and Shukla AK. (2015) Spatial distribution of surface soil acidity, electrical conductivity, soil organic carbon content and exchangeable potassium, calcium and magnesium in some cropped acid soils of India. Land Degradation & Development 26: 71-79.

Behrens T, Förster H, Scholten T, *et al.* (2005) Digital soil mapping using artificial neural networks. Journal of plant nutrition and soil science 168: 21-33.

Bhunia GS, Shit PK and Maiti R. (2018) Comparison of GIS-based interpolation methods for spatial distribution of soil organic carbon (SOC). Journal of the Saudi Society of Agricultural Sciences 17: 114-126.

Carré F, McBratney AB, Mayr T, *et al.* (2007) Digital soil assessments: Beyond DSM. Geoderma 142: 69-79.

Duchon J. (1977) Splines minimizing rotation-invariant semi-norms in Sobolev spaces. Constructive theory of functions of several variables. Springer, 85-100.

Egli M, Margreth M, Vökt U, *et al.* (2005) Modellierung von Bodentypen und Bodeneigenschaften im Oberengadin (Schweiz) mit Hilfe eines Geographischen Informationssystems (GIS). Geographica Helvetica 60: 87-96.

Egli M, Wernli M, Kneisel C, *et al.* (2006) Melting glaciers and soil development in the proglacial area Morteratsch (Swiss Alps): I. Soil type chronosequence. Arctic, Antarctic, and Alpine Research 38: 499-509.

Ford TW and Quiring SM. (2014) Comparison and application of multiple methods for temporal interpolation of daily soil moisture. International Journal of Climatology 34: 2604-2621.

Hrubesova E, Lunackova B and Brodzki O. (2016) Comparison of Liquid Limit of Soils Resulted from Casagrande Test and Modificated Cone Penetrometer Methodology. Procedia Engineering 142: 364-370.

Ikechukwu MN, Ebinne E, Idorenyin U, *et al.* (2017)Accuracy Assessment and Comparative Analysis of IDW, Spline and Kriging in Spatial Interpolation of Landform (Topography): An Experimental Study. Journal of Geographic Information System 09: 354-371.

Kalantary F and Kordnaeij A. (2012) Prediction of compression index using artificial neural network. Scientific Research and Essays 7: 2835-2848.

Karydas CG, Gitas IZ, Koutsogiannaki E, *et al.* (2009) Evaluation of spatial interpolation techniques for mapping agricultural topsoil properties in Crete. EARSeL eProceedings 8: 26-39.

Khatri S. (2018) Spatial analysis and thematic mapping of geotechnical properties of Udham Singh Nagar district soil using Geographical Information System (GIS). GB Pant University of Agriculture and Technology, Pantnagar-263145 (Uttarakhand).

Kollaros G. (2016) Liquid limit values obtained by different testing methods. Bulletin of the Geological Society of Greece 50: 778-787.

Kravchenko A and Bullock DG. (1999) A comparative study of interpolation methods for mapping soil properties. Agronomy Journal 91: 393-400.

Kumar S, Lal R, Liu D, *et al.* (2013) Estimating the spatial distribution of organic carbon density for the soils of Ohio, USA. Journal of Geographical Sciences 23: 280-296.

Kumar S, Lal R and Lloyd CD. (2012) Assessing spatial variability in soil characteristics with geographically weighted principal components analysis. Computational Geosciences 16: 827-835.

Lagacherie P and Holmes S. (1997) Addressing geographical data errors in a classification tree for soil unit prediction. International Journal of Geographical Information Science 11: 183-198.

Laskar A and Pal SK. (2012) Geotechnical characteristics of two different soils and their mixture and relationships between parameters. EJGE 17: 2821-2832.

Ließ M, Glaser B and Huwe B. (2012) Uncertainty in the spatial prediction of soil texture: comparison of regression tree and Random Forest models. Geoderma 170: 70-79.

Liu L, Wang H, Dai W, *et al.* (2014) Spatial variability of soil organic carbon in the forestlands of northeast China. Journal of forestry research 25: 867-876.

Metwally MS, Shaddad SM, Liu M, *et al.* (2019) Soil Properties Spatial Variability and Delineation of Site-Specific Management Zones Based on Soil Fertility Using Fuzzy Clustering in a Hilly Field in Jianyang, Sichuan, China. Sustainability 11: 7084.

Meul M and Van Meirvenne M. (2003) Kriging soil texture under different types of nonstationarity. Geoderma 112: 217-233.

Najmaddin PM, Whelan MJ and Balzter H. (2017a) Application of Satellite-Based Precipitation Estimates to Rainfall-Runoff Modelling in a Data-Scarce Semi-Arid Catchment. Climate 5: 32.

Najmaddin PM, Whelan MJ and Balzter H. (2017b) Estimating Daily Reference Evapotranspiration in a Semi-Arid Region Using Remote Sensing Data. Remote Sensing 9: 779.

Nayanaka V, Vitharana W and Mapa R. (2010) Geostatistical analysis of soil properties to support spatial sampling in a paddy growing alfisol.

Nesamatha R and Arumairaj P. (2015) Numerical modeling for prediction of compression index from soil index properties. Electron. J. Geotech. Eng 20: 4369-4378.

Nielsen DR and Wendroth O. (2003) Spatial and temporal statistics: sampling field soils and their vegetation: Catena Verlag.

Rahman S, Munn L, Vance G, *et al.* (1997) Wyoming Rocky Mountain forest soils: mapping using an ARC/INFO geographic information system. Soil science society of America journal 61: 1730-1737.

Robinson T and Metternicht G. (2006) Testing the performance of spatial interpolation techniques for mapping soil properties. Computers and electronics in agriculture 50: 97-108.

Saito H, McKenna SA, Zimmerman D, *et al.* (2005) Geostatistical interpolation of object counts collected from multiple strip transects: ordinary kriging versus finite domain kriging. Stochastic Environmental Research and Risk Assessment 19: 71-85.

Salih NB. (2020) Geotechnical characteristics correlations for fine-grained soils. IOP Conference Series: Materials Science and Engineering 737: 012099.

Taleb Bahmed I, Harichane K, Ghrici M, *et al.* (2019) Prediction of geotechnical properties of clayey soils stabilised with lime using artificial neural networks (ANNs). International Journal of Geotechnical Engineering 13: 191-203.

Tognina G. (2004) Hilfsmittel Bodenkarte: Methodik, Realisierbarkeit, Anwendungspotential am Beispiel eines Gebirgskantons. Bulletin BGS 27: 49-52.

Tripathi R, Nayak A, Shahid M, *et al.* (2015) Characterizing spatial variability of soil properties in salt affected coastal India using geostatistics and kriging. Arabian Journal of Geosciences 8: 10693-10703.

Vauclin M, Vieira S, Vachaud G, *et al.* (1983) The use of cokriging with limited field soil observations. Soil science society of America journal 47: 175-184.

Wahba G and Wendelberger J. (1980) Some new mathematical methods for variational objective analysis using splines and cross validation. Monthly weather review 108: 1122-1143.

Wei J-B, Xiao D-N, Zeng H, *et al.* (2008) Spatial variability of soil properties in relation to land use and topography in a typical small watershed of the black soil region, northeastern China. Environmental geology 53: 1663-1672.

Wielemaker W, De Bruin S, Epema G, *et al.* (2001) Significance and application of the multi-hierarchical landsystem in soil mapping. Catena 43: 15-34.

Yao X, Fu B, Lu Y, *et al.* (2013) Comparison of four spatial interpolation methods for estimating soil moisture in a complex terrain catchment. PLoS One 8: e54660.

Zhu A-X, Hudson B, Burt J, *et al.* (2001) Soil mapping using GIS, expert knowledge, and fuzzy logic. Soil science society of America journal 65: 1463-1472.

تقييم التوزيع المكاني لبعض الخواص الجيوتقنية للتربة باستخدام طرق الاستيفاء المختلفة (دراسة حالة: محافظة السليمانية، العراق

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تعتبر المعلومات الجيوتقنية للتربة مدخلات مهمة للتنبؤ بملاءمة الأرض لمشاريع البناء. تهدف هذه الدراسة إلى تقييم التوزيع المكاني لبعض الخواص الجيوتقنية للتربة في محافظة السليمانية شمالي العراق ذات المناخ شبه الجاف. حيث تم أخذ ستين عينة مختلفة من التربة بعمق 2.0 متر من سطح الأرض الطبيعية حول مدينة السليمانية والتي تناسب أغراض الاستيطان. وقد تم إجراء العديد من الفحوص المختبرية المطلوبة لتحديد الخواص الفيزيائية للتربة التي تم جمعها وفقًا لمعايير ASTM، وهي عبارة عن محتوى المياه الحقلي، والكثافة الرطبة الحقلية، ونسبة الفراغ الأولي (IVR) ، ودرجة التشبع (DS). وتم تطبيق طريقتين لاستكمال الداخلي القطعي العكسي للمسافة العكسية (IDW)، وشريحة الألواح الرقيقة (TPS) و تم تطبيق الطريقة الجغرافية الإحصائية الواحدة Kriging الاعتيادي (OK). كما تم تطبيق وتحليل التحقق المتبادل وتقييم دقة أداء النموذج. بشكل عام، وتم مقارنة أداء الطريقة الجيوستاتيكية بدقة مع أداء الاساليب القطعية. وتم التوصل الى ان طريقة Ok أكثر دقة وأقل انحيازًا من الطرق الاخرى، والتي لديها RMSE أقل (1.38٪ و 11.33٪ و 0.07 و 0.82 غم/سم3) و ME ‎-0.63٪ ، 0.94٪، -0.16 و 0.3 جم سم3) لمحتوى الماء، DS، IVR، والكثافة الرطبة على التوالي. وفقًا لخرائط الاستيفاء، ومن المرجح أن 65 إلى 70 ٪ من منطقة الدراسة مناسبة لأغراض البناء مقارنةً بنسبة 30 إلى 35 ٪ الأخرى، والتي تحتاج إلى بعض الاحتياطات لقضية الملاءمة لمشاريع البناء. وتدل النتائج على ابراز الخصائص الجيوتقنية الموثوق بها للتربة بحسب الخرائط الجغرافية المكانية، كما تساهم بشكل كبير في التطبيق السليم للإدارة الهندسية ونمذجة استخدام الأراضي.