Iraqi Journal of Agricultural Sciences –2022:53(1):164-172 Masood & Salim

SPATIAL VARIABILITY OF HYDRO-RELATED PHYSICAL PROPERTIES OF AL-RASHEED LOAM

Tareq K. Masood Salloom B. Salim
Lecturer Prof.
Dep. Soil and Water Resources -Coll. Agric. Engine. Sci. University of Baghdad
E-mail: tareqmasood@coagri.uobaghdad.edu.iq

ABSTRACT

A field study was conducted on 2 hectare area at Al- Rashid district, south of Baghdad to analyze the spatial variability of saturated hydraulic conductivity (Ks), initial infiltration rate (IR), Porosity (F) and bulk density (BD). Based on measured BD values Rosetta software was used in this study to estimate water retention parameters, water content at θ_{33} and θ_{1500} kPa and unsaturated hydraulic conductivity at 33 kPa(k_{33}), 100 kPa(k_{100}) and 1500 kPa(k_{1500}) according to Van Genuchten-Mualem model. Measured and predicted data were analyzed both statistically and geostatistically and, the results showed a strong to moderate spatial dependence for the studied characteristics. The spatial correlation values (r^2) were obtained with a spherical model for Ks, θ_{33}, θ_{1500}, k_{33}, k_{100} and k_{1500}, an exponential model for IR, and a Gaussian model for F and BD. Ks increased significantly with increasing of IR ($r^2 = 0.49^{**}$) and decreased with increasing of F and BD, IR increased with decreasing of BD ($r^2 = -0.326^{*}$) and BD increased with increasing of F ($r^2 = 0.989^{**}$). In general the spatial distribution was moderately skewed (-0.5 to 0.5) for the studied characteristics with pronounced kurtosis (>2.5). The limit distance for the search radius to estimating spatial dependency varied from 29.9 m for BD to 105 m for IR.

Key words: geostatistic, semivariogram, hydraulic conductivity, infiltration, pedotransfer functions.

مجلة العلوم الزراعية العراقية- 2022: 53:(1):164-172 مسعود و سالم

التغاير المكاني للخصائص الفيزيائية والمائية لتربة ناحية الرشيد المزيجة

طارق كمال مسعود سلوم برغوث سالم
مدرس استاذ
قسم علوم التربة والموارد المائية/كلية علوم الهندسة الزراعية/جامعة بغداد

المستخلص

اجريت تجربة حقلية على مساحة 2 هكتار في ناحية الرشيد جنوب بغداد لتحليل التغاير المكاني للايصالية المائية المشبعة (Ks) ومعدل الغيض الابتدائي (IR) والمسامية (F) والكثافة الظاهرية (BD). استخدام برنامج Rosetta في هذه الدراسة بناءاً على قيم BD المقاسة لتقدير عوامل منحنى المواصفات الرطوبية ومن ثم الحصول على محتوى الماء عند 33 (θ_{33}) و1500 (θ_{1500}) كيلو باسكال، والايصالية المائية غير المشبعة عند 33 (k_{33}) و 100 (k_{100}) و 1500 (k_{1500}) كيلو باسكال وفقًا لانموذج van Genuchten−Mualem. تم تحليل البيانات المقاسة والمقدرة إحصائياً وجيواحصائياً، وأظهرت النتائج اعتمادًا مكانيًا قويًا إلى متوسط للخصائص المدروسة. تم الحصول على قيم الارتباط المكاني (r^2) باستخدام نموذج الكروي لـ Ks و θ_{33} و θ_{1500} و k_{33} و k_{100} و k_{1500} ، و النموذج الأسي لـ IR والانموذج Gaussian لـ F و BD. زادت قيم Ks بشكل معنوي مع زيادة IR ($r^2=0.49^{**}$)، وانخفضت مع زيادة F و BD ، وازدادت قيم IR مع انخفاض BD ($r^2=-0.362^{*}$)، وازادت قيم BD بزيادة F ($r^2=0.989^{**}$). كان التوزيع المكاني منحرفًا بشكل معتدل (−0.5 إلى 0.5) للخصائص المدروسة مع تفلطح واضح (< 2.5). وتفاوت الارتباط المكاني من 29.9 مترًا لـ BD إلى 105 متر بالنسبة IR.

الكلمات المفتاحية: الاحصاء الجيولوجي، دالة التباين النصفي، الايصالية المائية، الغيض، دوال نقل الخصائص.

Received:22/12/2020, Accepted:1/3/2021

INTRODUCTION

There is a lack of information and knowledge about soil variability, which necessitates more research because variations in soil properties must be controlled to allow for better soil and crop management (16, 3). There are many spatially variable factors that affect yield of agricultural crops. These factors are related to soil, topographic and biological properties (7).This covariance is determined in soils using the classical statistical method which assumes that soil properties have random variables; hence, it is insufficient to analyze spatially dependent variables (3). Understanding the spatial variation of soil properties is critical for crop production in agricultural management systems and is regarded as a cornerstone of site-specific agriculture especially most soil properties are spatially variable, and that this variance is normal and attributable to geological and biological soil formation factors (14).Some physical properties of various soils, such as saturated and unsaturated hydraulic conductivities, have been discovered to have a lot of statistical variance (5,29).The occurrence of changes in soil structure, bulk density, soil porosity and water characteristics (infiltration rate and saturated hydraulic conduction) in space and time is mostly due to spatial variability in some practices in the field (23,30). As a result, an evaluation of the variability in these soil properties is needed to improve our understanding of water transport in soils, which may vary significantly due to heterogeneity (2,8). Furthermore, soil compaction, which is primarily caused by wheel movement, decreases large pores, increases bulk density, lowers semi-saturated hydraulic conductivity, and can result in spatial variations in soil physical properties (13,21). Soil water content and unsaturated hydraulic conductivity measurements are both costly and time-consuming. To estimate those in terms of readily available soil properties, pedotransfer functions (PTFs) have been developed (1). Many Earth science applications depend on saturated hydraulic conductivity (Ks). The use of easily measurable simple soil properties to obtain this soil property is heavily reliant on soil pedotransfer functions (35). It uses geological statistics to investigate soil properties, which is a useful tool for determining soil changes based on a collection of spatial and temporal data (26). Using Kriging, variation is used to predict values of soil properties at other unestimated sites between sampling sites. The aim of this study is to determine the spatial variability of Ks, IR, F, BD, θ_{33}, θ_{1500}, k_{33}, k_{100} and k_{1500} along 100 m × 200 m coordinates at Al-Rasheed district, south of Baghdad.

MATERIALS AND METHODS

The study area was chosen in Al-Rasheed district, south of Baghdad (Latitude 33º 04' 28″ North and Longitude 44º 29' 41″ East), the field soil was classified as a sedimentary Typic Torrifluevents; Entisols (24), it's mainly cultivated for wheat crops. This experiment was conducted on 2 hectare field during the agricultural season of 2019-2020. The climate is characterized by hot and dry summers and short and cold winter. The field was divided into squared grids with dimensions of 25 m x 25 m. Measurements were performed on 40 sites. Double rings infiltrometer (20) were used to estimate the initial infiltration rate (initial time step corresponding to IR= 2 minutes). Values of saturated hydraulic conductivity were assumed to be equal to constant IR values obtained the end of the infiltration process. Samples from the surface layer 0-5 cm were taken from the measurement sites to estimate BD and F. Hhydrus-1D program was used to estimate the parameters of van Genuchten model (32) based on implemented pedotransfer functions of Rosetta hyperlink (28):

$$\theta(h) = \theta_r + \frac{\theta_s - \theta_r}{\left[1 + (\alpha h)^n\right]^{1-1/n}} \qquad (1)$$

For each measured point in the field, the water retention curve functions were obtained. The moisture content was calculated using equation (1) at suction 33 and 1500 kPa, which represent the field capacity and permanent wilting point, respectively. Unsaturated hydraulic conductivity as a function of water contents at 33, 100, and 1500 kPa were calculated using Mualem model (22) as follows:

$$K(\theta) = KsS_e^l \left\{1 - \left[1 - S_e^{n/(n-1)}\right]^{1-1/n}\right\}^2 \qquad (2)$$

$$S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r}$$

Using the Kriging technique, geostatistics was used to track the spatial variation of the intended soil physical properties. The GS+9 software (10) were used to measure the variogram and semivariogram functions (11) according to the following relationship:

$$p(h) = \left[\frac{1}{2n(h)}\right]\sum_{n=1}^{n(h)}(z(x_i + h) - z(x_i))^2 \qquad (3)$$

As:

(h) : semivariance for interval class h

$N(h)$: the number of pairs separated by lag distance (separation distance between sample positions),

$Z(xi)$: measured variable at spatial location i,

$Z(xi+h)$: measured variable at spatial location $i+h$.

Three semivariogram models were used in describing the studied characteristics as follows:

Spherical model;

$$\gamma(h) = C + C_0\left[1.5\frac{h}{a} - 0.5(\frac{h}{a})^3\right] \qquad (4)$$

$$for \quad 0 \le h \le a \quad otherwisC + C_0$$

Exponential model;

$$\gamma(h) = C_0 + C\left[1 - \exp(-\frac{h}{A})\right] \qquad (5)$$

$$for \quad h \ge 0$$

Gaussian model;

$$\gamma(h) = C_0 + C\left[1 - \exp(\frac{-h^2}{A^2})\right] \qquad (6)$$

$$for \quad h \ge 0$$

As:

h: lag interval

C_o: nugget variance≥0

C :structurevariance≥C_o

A :range parameter

The best model was chosen based on highest R^2 value and the lowest Root Mean Square Errors (RMSE) for each of the studied soil characteristics according to the following criteria:

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left[z(x_i) - z(x_i)\right]}^{2} \qquad (7)$$

At the same time, Spatiality Dependent (Variogram Model Error) was calculated according to the following relationship (14):

$$\text{Spatiality Dependent} = \text{Nugget}/\ \text{Nugget} + \text{sill} \quad (8)$$

Spatiality Dependent is described as Strong when it's less than 0.25, Moderate when it's between 0.25-0.75, and Weak when it's more than 0.75. The number of samples to be taken from field was calculated by the geostatistics method (Spatiality Dependent) by dividing longest axis of the study area by effective distance (range).

RESULTS AND DISCUSSION

Soil texture as measured by the hydrometer method (9) indicated that the sand, silt, and clay contents were 32.3%, 48.6% and 19.1%, respectively and classified as loam by the USDA's texture triangle. The bulk density was estimated by the core method (6), Ks values were assumed to be equal to final (basic) IR, IR was measured with double ring infiltrometer. θ_{33}, θ_{1500}, k_{33}, $k_{100}$and k_{1500} were estimated with Rosetta software**.** The results of chemical analysis showed that electrical conductivity ($EC_{1:1}$) was 1.7 dSm $^{-1}$, pH was 7.2, the exchange capacity of the positive ions (CEC) was 22.9 C mol. Kg^{-1} and the sodium adsorption ratio (SAR) was 2.7 (mmol. Liter^{-1})^{½}. Table 1 shows some descriptive characteristics such as minimum, maximum, average, standard deviation, coefficient of variation (CV), skewness and kurtosis of soil characteristics. Values of initial infiltration measured after 2 minutes ranged between 2.46 and 15.52 cm h^{-1}, Ks between 0.40 and 2.40 cm h^{-1}, bulk density between 1.23 and 1.48 g cm^{-3}, porosity between 0.46 and 0.56, θ_{33} between 0.237and 0.283 cm^3 cm^{-3}, θ_{1500} between (0.082 and 0.088 cm^3 cm^{-3}) and k between 7.16E-03 and 3.47E-08 cm hr^{-1}. The coefficient of variation for Ks was 34.3 % and for k_{33}ranged between 45.2 and 49.6 % (Table 1), which is high on Wilding et al. (34) scale, or exhibited moderate (CV 25-75 %). These findings are similar with those of Benson (4).While the coefficients of variance (CV %) for BD, F, θ_{33} and θ_{1500} were 3.3, 3.2, 3.5 and 1.4 %, respectively, this indicates the presence of low variability (CV <25%), which is what was discovered by (34).

Table 1.Valuesof statistical analysis of measured soil properties

	Min.	Max.	Mean	Std. Dev.	CV,%	Sekwness	Kurtosis
Ks	**0.40**	**2.40**	**1.084**	**0.481**	**34.3**	**0.57**	**-0.26**
IR	**2.46**	**15.52**	**7.493**	**2.804**	**24.8**	**0.37**	**-0.03**
F	**0.46**	**0.56**	**0.501**	**0.019**	**3.2**	**0.69**	**0.79**
BD	**1.23**	**1.48**	**1.328**	**0.050**	**3.3**	**0.66**	**0.62**
θ_{33}	**0.237**	**0.283**	**0.263**	**0.009**	**3.5**	**-0.45**	**3.30**
θ_{1500}	**0.082**	**0.088**	**0.085**	**0.001**	**1.4**	**-0.07**	**2.77**
k_{33}	**7.16E-03**	**4.50E-02**	**1.94E-02**	**1.00E-02**	**49.6**	**0.79**	**2.64**
k_{100}	**1.67E-04**	**1.05E-03**	**4.55E-04**	**2.00E-04**	**49.1**	**0.78**	**2.66**
k_{1500}	**5.56E-09**	**3.47E-08**	**1.55E-08**	**1.11E-09**	**45.2**	**0.58**	**2.65**

This may be attributed to the homogeneity of the field in texture and the agricultural operations and practices that take place in field. Frequent tillage and use of land for cultivation may evenly incorporate soil constituents and reduce variability of measured soil contributes (25). Furthermore, the presence of organic matter and plant residues on soil may have contributed to decrease in bulk density (15). At the same time, the coefficient of variation was 24.8% for initial infiltration, which is less than 25%, indicating that the coefficient of variation is also low. Pronounced increase in CV was accompanied with Ks, k_{33}, k_{100} and k_{1500}due to nonlinearity characteristic of the hydraulic conductivity as it’s a function of water content and water potential which exhibit higher variability (18). The results showed that the highest values of dispersion were at IR through the high values of standard deviation, which reached (2.804).This is because IR depends on initial soil moisture content. As there is a variation in soil moisture as a result of rainfall and irrigation and evaporation processes (17,19). Except θ_{33}, positive skewness values (Table 1) were obtained for measured soil contributes and ranged between 0.37 and 0.69, meaning that the distribution is skewed to the right. When both skewness and kurtosis are zero (a situation that researchers are very unlikely to ever encounter, the pattern of responses is considered a normal distribution (12). This indicates a lack of symmetry in the frequency distribution, or so-called symmetrical distribution. The results of kurtosis indicate the values of the studied soil properties with a platykurtic distribution (meaning values less than +3) and not leptokurtic, and this means that its peak is more straight and less than normal distribution. Except for θ_{33} had a leptokurtic distribution, this conformed to Std. Deviation. The results of Pearson's linear correlation analysis (Table 2) showed a significant negative correlation between BD and IR (-0.326*). This may be due to agricultural practices or low surface layer bulk density due to the presence of root canals (14). At the same time, a positively significant correlation was found between IR and Ks (0.490 **), BD and F (0.989**), $k_{(33,100 \text{ and } 1500)}$ and Ks (0.970**, 0.975** and 0.999**) respectively. And significant negative correlation between BD and k_{33} and k_{100} (-0.374* and -0.354*) respectively.

Table 2. Pearson's correlation of some soil properties

	Ks	IR	BD	F	θ_{33}	θ_{1500}	k_{33}	k_{100}
IR	**0.49****							
BD	**-0.146**	**-0.326***						
F	**-0.142**	**-0.282**	**0.988****					
θ_{33}	**0.160**	**0.328***	**-0.998****	**-0.989****				
θ_{1500}	**0.133**	**0.359***	**-0.963****	**-0.938****	**0.968****			
k_{33}	**0.970****	**0.543****	**-0.374***	**-0.367***	**0.386***	**0.352***		
k_{100}	**0.975****	**0.539****	**-0.354***	**-0.347***	**0.367***	**0.334***	**1.00****	
k_{1500}	**0.999****	**0.495****	**-0.164**	**-0.161**	**0.181**	**0.157**	**0.973****	**0.979****

***Significant at 5% probability levels. **Significant at 1% probability levels**.

After computing semivariance function with (GS+9) program, the relationship between variogram and the lag distance was drawn.To evaluate the spatial variability of the physical properties of the soil .Figure 1 and Table 3 and 4 show the calculated geostatistical factors for soil. It seems that the spherical model was the best in evaluating of Ks, θ_{33}, θ_{1500}, k_{33}, k_{100} and k_{1500}. The exponential and Gaussian models were used to evaluate the spatial variability the

IR and F and BD respectively. The criteria of fitted models are based on largest R^2 and lowest RMSE values (Table 4). The type of the model matching the data distribution suggests the spatial continuity of the phenomenon investigated. The Gaussian model describes a more continuous random function, and the spherical model is a relatively more erratic random function. Gaussian model, showed a relative of the nugget effect and a decrease in the range values.

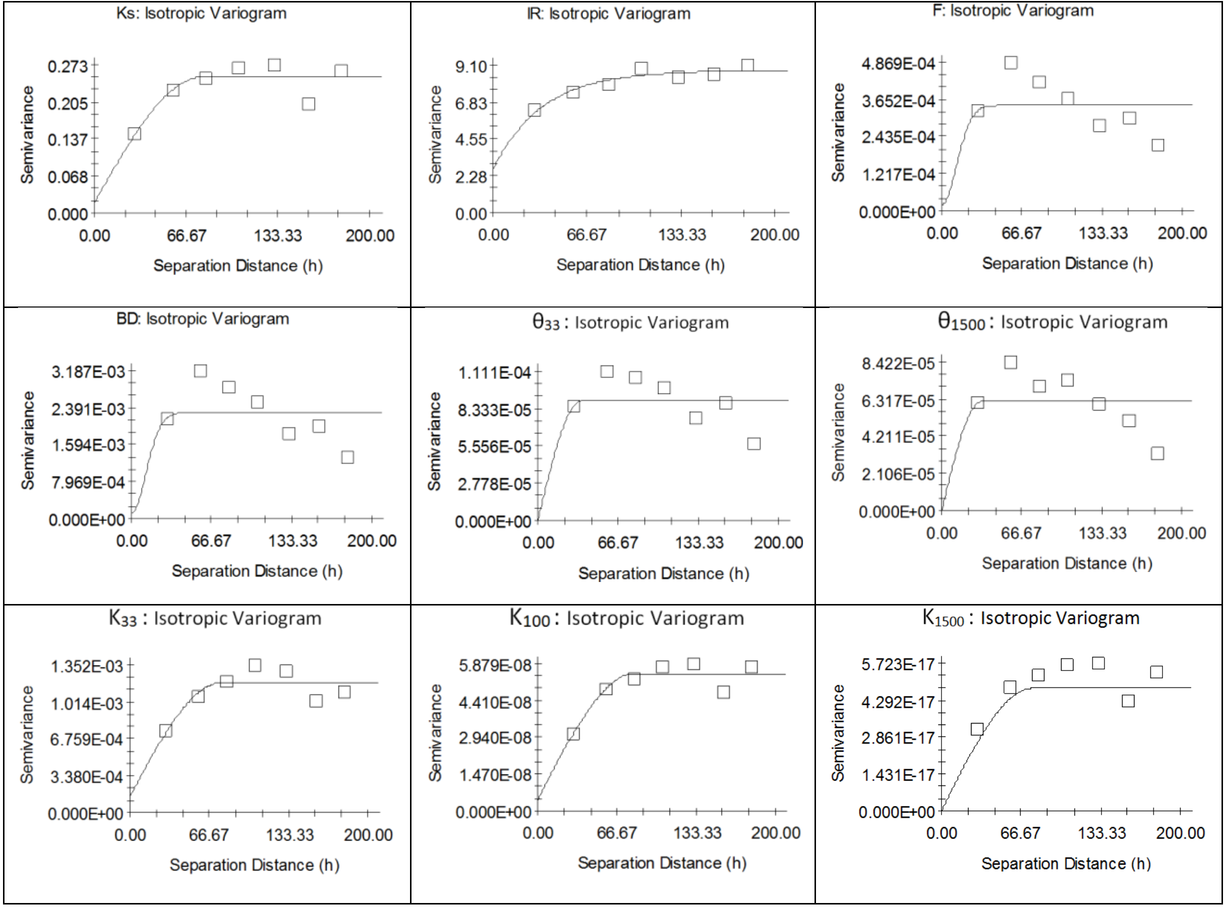


Figure 1.Experimental and fitted theoretical semivariograms for the soil attributes

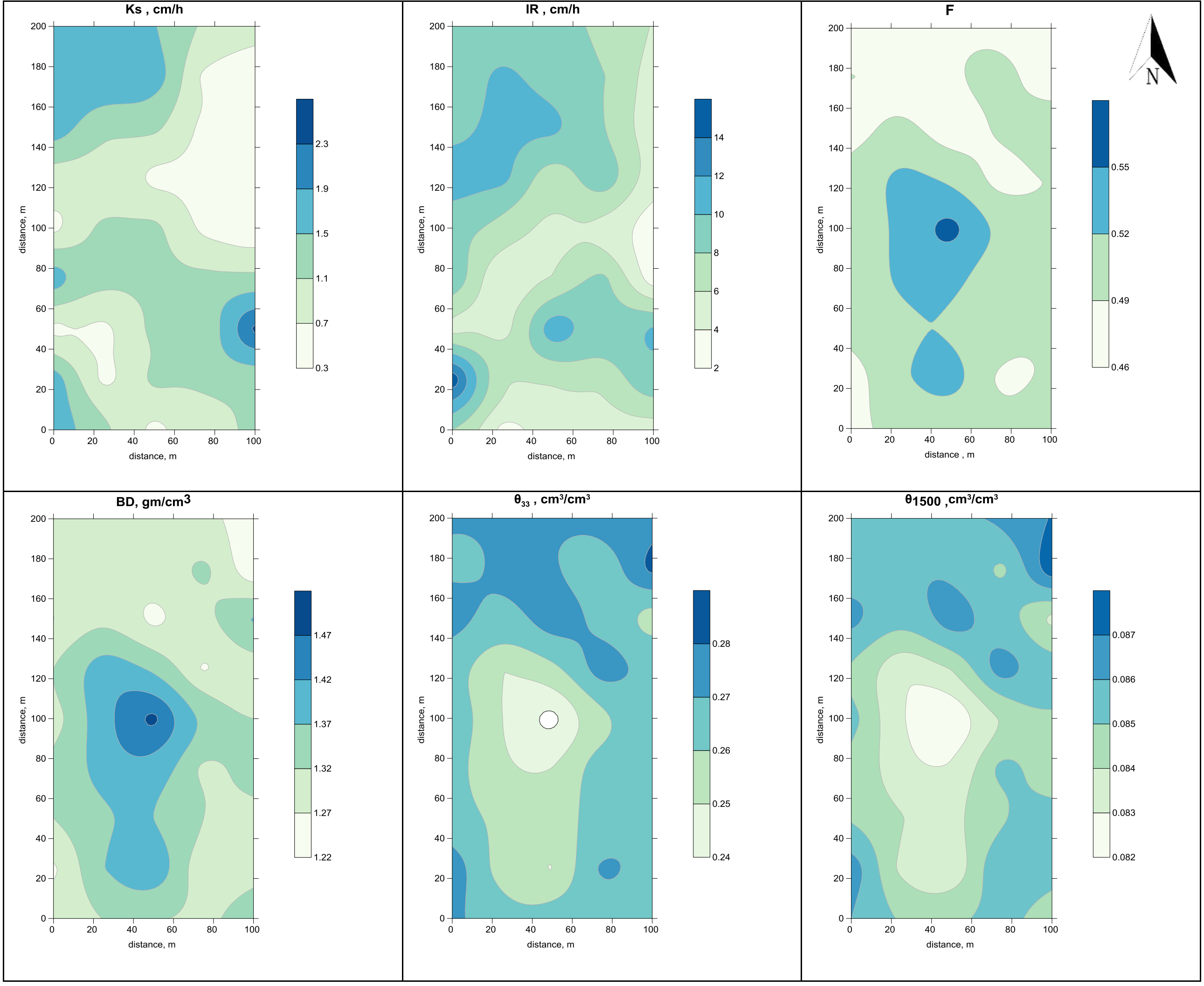
Table 3. Statistical analysis of some soil properties using geological statistics

	Model	**Variogram Model Error**
Ks	**Spherical**	**Strong**
IR	**Exponential**	**Moderate**
F	**Gaussian**	**Strong**
BD	**Gaussian**	**Strong**
θ_{33}	**Spherical**	**Strong**
θ_{1500}	**Spherical**	**Strong**
k_{33}	**Spherical**	**Strong**
k_{100}	**Spherical**	**Moderate**
k_{1500}	**Spherical**	**Strong**

Table 4. Parameter values for the estimated theoretical semivariogram

	Nugget (C_0)	**Sill (C_0+C)**	**C0/(C_0+C)**	**Range A**	**R^2**	**RMSE**	**N**
Ks	**1.89E-02**	**2.51E-01**	**7.53E-02**	**78.4**	**0.735**	**3.31E-03**	**3**
IR	**2.69E+00**	**8.79E+00**	**3.06E-01**	**105.3**	**0.904**	**5.24E-01**	**2**
F	**2.00E-05**	**3.47E-04**	**5.76E-02**	**30.5**	**0.006**	**4.86E-08**	**7**
BD	**1.17E-04**	**2.28E-03**	**5.13E-02**	**29.9**	**0.005**	**2.39E-06**	**7**
θ_{33}	**1.00E-007**	**8.52E-005**	**1.17E-03**	**36.3**	**0.006**	**1.976E-09**	**6**
θ_{1500}	**1.00E-007**	**6.200E-005**	**1.61E-03**	**33.2**	**0.002**	**1.683E-09**	**6**
k_{33}	**1.44E-004**	**1.188E-003**	**1.21E-01**	**76.5**	**0.696**	**7.311E-08**	**3**
k_{100}	**4.0.E-08**	**5.4E-08**	**7.41E-01**	**81.6**	**0.849**	**8.769E-17**	**3**
k_{1500}	**0.000**	**5.26E-17**	**1.90E+00**	**76.7**	**0.736**	**3.0E-34**	**3**

The spatial correlation of semivariograms varies with soil characteristics are shown in figure1.It can be observed that the largest spatial dependency (range), 105.3 m, occurred with IR and smallest range (29.96 m) occurred with BD and F. It's worth noting that effective distance of BD and F is within sampling limits. That is, with high variability and a short effective distance (30 m), where range refers to the distance beyond which measured properties in a field are no longer spatially associated (31). The spatial decadency of BD and F increased with increasing distance to about 50 m with a positive semivariogram values. At 100 m range there was no spatial dependency (semivariogarm=0) after which the value of semivariogram became negative. This suggests that more spatial variability exists in these three soil attributes (IR, BD and θ_{1500}) so that measurements should be made at smaller lags. There was a strong spatial correlation between soil characteristics except for IR and k_{100} where spatial correlation was moderate. This is due to the strong spatial dependency of soil properties that are related to basic soil factors including soil texture and parent matter. Other variables also have an effect on these properties (36). It is evident from the results that low value of C_0 / (C_0 + C) is associated with an increase in range value to high resolution of studied characteristic (27).Table 4 shows the number of samples calculated by spatiality dependent method, as they amounted to 3 samples for Ks, k_{33}, k_{100} and k_{1500} , and 2 samples for IR. This indicates that variance is low for these characteristics in comparison to BD and F. The Surfer 13 software was used to create the kriging maps of soil characteristics, which were based on a 25 x 25 m^2 grid structure (Fig.2).



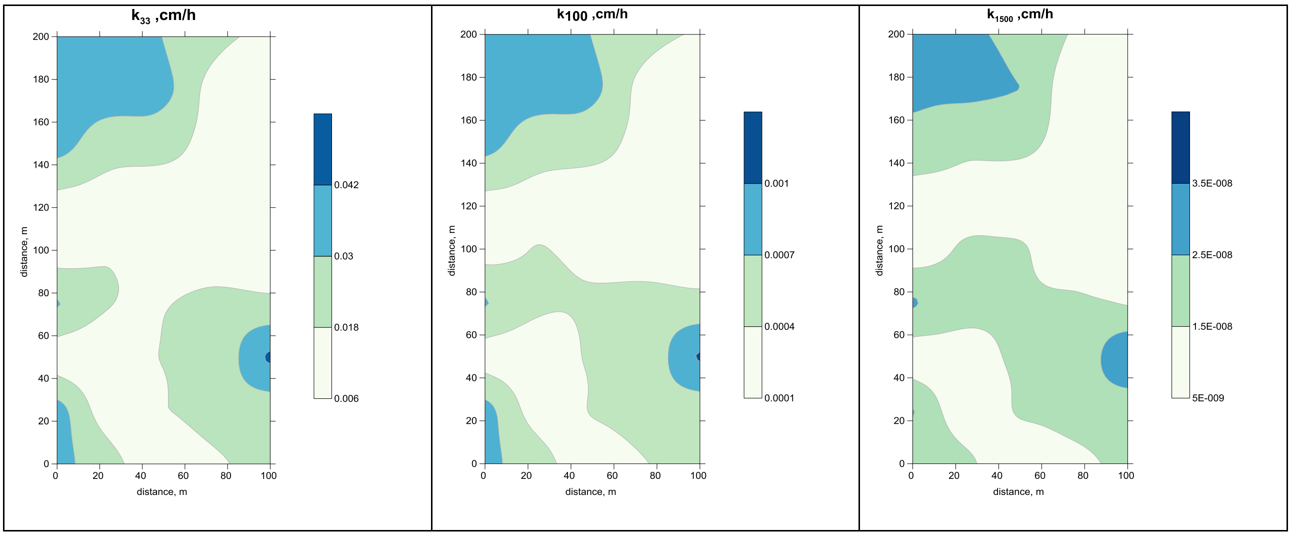


Figure 2.Field map for some soil properties (scale 1:3300 for all images).

In general, Ks, k $_{(33,\ 100\ \text{and}\ 1500)}$ values increased from the northeast towards the northwest, and at the same time they increased at the southeast of the field. Whereas, the highest IR values were at the northwest and decreased towards the southeast of the field. The highest values of BD and F were concentrated in center of the field and decreased towards the northwest and east direction. Figure 2 clearly shows that the generated 2-D surfer distribution raster map is in agreement with the experimental semivariogram in figure 1.

CONCLUSION

It can be concluded from this study that all measured soil contributes don’t exhibit normal distribution which necessitate using geostatistical analysis to assess spatial variability and dependency. The range of soil physical parameters of BD and F is within the limits of sampling distance of approximately 29.9 m in field. It has a strong spatial dependence. Semivariance demonstrated the importance of reducing the number of samples required in estimating characteristics. Spatial distribution maps allow comparison of soil properties, and were able to explain variation within the study area. At the same time, the maps are important in guiding farmers to follow agricultural and irrigation methods. Irrigation, especially drip and sprinkler systems, depends on IR and the saturated hydraulic conductivity.

REFERENCES

1. Abdelbaki, A. 2021.Selecting the most suitable pedotransfer functions for estimating saturated hydraulic conductivity according to the available soil inputs.Ain Shams Engineering Journal. https://doi.org/10.1016/j.asej.2021.01.030

2. Alletto, L., Y. Coquet, and J. Roger-Estrade. 2010. Two-dimensional spatial variation of soil physical properties in two tillage systems.Soil Use and Management. 26(4), 432–444. https://doi.org/10.1111/j.1475-2743.2010.00295.x

3. Al-Omran, A. M., M. I. Al-Wabel, S. E. El-Maghraby, M. E. Nadeem, and S. Al-Sharani. 2013. Spatial variability for some properties of the wastewater irrigated soils. Journal of the Saudi Society of Agricultural Sciences. 12(2), 167-175.https://doi.org/10.1016/j.jssas.2012.12.001

4. Benson, C. H. 1993. Probability distributions for hydraulic conductivity of compacted soil liners. Journal of Geotechnical Engineering. 119(3), 471–486.

5. Biggar, J. W., and D. R. Nielsen. 1976. Spatial variability of the leaching characteristics of a field soil. Water Resources Research. 12(1), 78-84.https://doi.org/10.1029/WR012i001p00078

6. Blake, G. R., and K. H. Hartge, 1986. Particle density. Methods of soil analysis: Part 1 physical and mineralogical methods. 5, 377-382

7. Corwin, D. L. 2005. Delineating Site-Specific Crop Management Units: Precision Agriculture Application in GIS. In Proceedings of the 2005 ESRI International Users Conference, San Diego, CA, USA (pp. 25-29).

8 Coutadeur, C., Y. Coquet, and J. Roger-Estrade. 2002. Variation of hydraulic conductivity in a tilled soil. European Journal

of Soil Science. 53(4), 619–628. https:// doi. org/ 10.1046/j.1365-2389.2002.00473.x

9. Day, P.R. 1965. Particle Fractionation and Particle Size Analysis. In: Black et al. (eds.) Methods of Soil Analysis, Part 1, pp.545-567. Agron., No.9 , ASA : Madison. WI

10. Gamma Design Software.2010. GS+ Version 9 GeoStatistical Software for the Environmental Science.Gamma Design Software, LLC Plainwell, Michigan 49080, USA

11. Goovaerts, P. 1997. Geostatistics for Natural Resources Evaluation. Oxford Univ. Press, New York

12. Hair Jr, J. F., G. T. M. Hult, C. Ringle, and M. Sarstedt. 2017. A Primer On Partial Least Squares Structural Equation Modeling (PLS-SEM). 2nd ed. Thousand Oaks,CA:Sage, pp:61

13. Heddadj, D., and C. Gascuel-Odoux. 1999. Topographic and seasonal variations of unsaturated hydraulic conductivity as measured by tension disc infiltrometers at the field scale. European Journal of Soil Science. 50, 275–283.https://doi.org/10.1046/j.1365-2389.1999.00232.x

14. Iqbal, J., J. A. Thomasson, N. Johien, R.O. Jenkins, D.W. Phillip, and D. Frank . 2005. Spatial variability analysis of soil physical properties of alluvial soils .Soil Sci. Soc. Am. J. 69 (4):1338 -1350. https://doi.org/10.2136/sssaj2004.0154

15. Lal R, and J.M. Kimble. 2001. Importance of soil bulk density and methods of its importance. In Advances in Soil Science: Assessment Methods for Soil Carbon, Lal R, Kimble JM, Stewart BA (eds). CRC Publishers: Boca Raton, FL; 31–44

16. Lin, H.S., D. Wheeler, J. Bell, and L. Wilding. 2005. Assessment of soilspatial variability at multiple scales. Ecol. Modell. 182, 271–290.http://dx.doi.org/10.1016/j.ecolmodel.2004.04.006

17. Masood, T. K. 2017. Effect of irrigation methods on water content distribution, water - and corn productivity. Iraqi Journal of Agricultural Sciences, 48(1),178-184.https://doi.org/10.36103/ijas.v48i1.433

18. Masood, T. K., and S. B. Salim. 2019. In situ determination of zero flux plane and evaporative flux under alternate use of fresh and ground irrigation water. Iraqi Journal of Soil Science. 19(1):1-11

19. Masood, T. K., and S. S. S. Shahadha. 2021. Simulating the effect of climate change on winter wheat production and water / nitrogen use efficiency in Iraq: case study. . Iraqi Journal of Soil Science. 52(4):999-1007

20. Michael, A.M. 1978. Irrigation Theory and Practice.Vikas Publishing House.Pvt. ,lst ed., new delhi . India

21. Mooney, S.J.,and W. Nipattasuk. 2003. Quantification of the effects of soil compaction on water flow using dye tracers and image analysis. Soil Use & Management, 19, 356–363.https://doi.org/10.1111/j.1475-2743.2003.tb00326.x

22. Mualem, Y. 1976. A new model predicting the hydraulic conductivity of unsaturated porous media. Water Resour. Res. 12:513–522

23. Mueller, L, U. Schindler, N. Fausey, and L. Rattan. 2003. Comparison of methods for estimating maximum soil water content for optimum workability.Soil and Tillage Research. 72(1): 9-20.https://doi.org/10.1016/S0167-1987(03)00046-1

24. Muhaimeed, A.S., A. J. Saloom, K. A. Saliem, K. A. Alani, and W. M. Muklef. 2014. Classification and distribution of Iraqi soils. Int J AgricInnov Res. 2(6), 997-1002

25. Osunbitan, J.A., D. J. Oyedele, and K. O. Adekalu. 2005. Tillage effects on bulk density, hydraulic conductivity and strength of a loamy sand soil in southwestern Nigeria. Soil and Tillage Research.82: 57–64.https://doi.org/10.1016/j.still.2004.05.007

26. Özgöz, E., F. Akbş, M. ÇEtİn, S. ErŞAhİn, and H. Günal. 2007.Spatial variability of soil physical properties as affected by different tillage systems. New Zealand journal of crop and horticultural science. 35(1), 1-13.https://doi.org/10.1080/01140670709510162

27. Reza, S. K., D. C. Nayak, D. C. S. Mukhopadhyay, T. Chattopadhyay, and S. K. Singh. 2017. Characterizing spatial variability of soil properties in alluvial soils of India using geostatistics and geographical information system.Archives of Agronomy and Soil Science. 63(11), 1489–1498. https://doi.org/10.1080/03650340.2017.1296134

28. Schaap, M. G., F. J. Leij, and M. T. Van Genuchten. 2001. Rosetta: A computer program for estimating soil hydraulic parameters with hierarchical pedotransfer functions. Journal of hydrology. 251(3-4), 163-176.https://doi.org/10.1016/S0022-1694(01)00466-8

29. Sisson, J. B., W. M. Klittich, and S. B. Salem. 1988. Comparison of two methods for summarizing hydraulic conductivities of a layered soil. Water Resources Research, 24(8), 1271-1276.https://doi.org/10.1029/WR024i008p01271

30. Strudley, M.W., T. R. Gren, C. James, and J.C. Ascough II. 2008. Tillage effects on soil hydraulic properties in space and time: State of the science. Soil and Tillage Research. 99: 4–48.https://doi.org/10.1016/j.still.2008.01.007

31. Tabi, F. O., and A. O. Ogunkunle. 2007.Spatial variation of some soil physico-chemical properties of an Alfisol in Southwestern Nigeria. Nigerian Journal of Soil and Environmental Research. 7, 82-91. DOI: 10.4314/njser.v7i1.28421

32. Van Genuchten M. Th. 1980. A closed form equation for predicting the hydraulic conductivity of unsaturated Soil Science Society of America Journal. 44:892-898 . https://doi.org/10.2136/sssaj1980.03615995004400050002x

33. Vieira, S. R. J. L., J. Hatfield, D. Nielsen, and J. Biggar. 1983. Geostatistical theory and application to variability of some agronomical properties. Hilgardia, 51(3), 1-75

34. Wilding, L. P., J. Bouma, and D. W. Goss. 1994.Impact of spatial variability on interpretive modeling. Quantitative Modeling of Soil Forming Processes. 39,61-75. https://doi.org/10.2136/sssaspecpub39.c4

35. Zhang, Y., and M.G. Schaap. 2019. of saturated hydraulic conductivity with pedotransfer functions: A review. Journal of Hydrology. 575, 1011-1030.https://doi.org/10.1016/j.jhydrol.2019.05.058

36. Zheng, H., J. Wu and S. Zhang. 2009. Study on the spatial variability of farmland soil nutrient based on the kriging interpolation. In 2009 International Conference on Artificial Intelligence and Computational Intelligence (Vol. 4, pp. 550-555). IEEE.