A Comparative Study of Interpolation for Mapping Soil Physical Properties

دراسة مقارنه تقنيات التقدير لرسم خرائط بعض الصفات الفيزياويه للتربة

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Summary

The choice of an optimal interpolation technique for estimating soil properties at unsampled location is an important issue in site-specific management. The first objective of this study was to evaluate Inverse Distance Weighting (IDW) method, Ordinary Kriging(OK) method to determine the optimal interpolation method for mapping some soil physical properties. The second objective was to analyze the relationships between statistical properties of the data and performance of the interpolation techniques .The relationships between statistical properties of the data and performance of the methods were analyzed using soil test saturated hydraulic conductivity, bulk density and volumetric water content data from a fallow field in Hillia city/Iraq. The results suggest that (OK) method has a preference on (IDW) method in estimating and mapping the soil bulk density. On other hand, the (IDW) method has the preference on the ordinary kriging method in estimating and mapping of saturated hydraulic conductivity and volumetric water content. The accuracy of the method in estimating and mapping the soil physical properties using the goodness of prediction(G) and mean square error(MSE) as criteria, related very well to the regression coefficient (R^2) for the fitted line of measured and estimated values of soil physical properties. Regression coefficient(R^2) of fitted line for the measured and estimated were higher for (IDW) than that of (OK) for hydraulic conductivity and water content, whereas the (R^2) was higher for (OK) then that of (IDW) for bulk density.

All studied soil physical parameters were strongly spatially dependent, but the range of spatial dependence varies within the soil physical properties. Bulk density had the shortest range of spatial dependence (6.3 m) and the saturated hydraulic conductivity had the longest range (15.4m).

الخلاصة

إن اختيار تقنية التقدير المثالية للتنبؤ بقيم صفات التربة المختلفة عند المواقع التي لم يؤخذ لها نماذج تربه تعتبر من الأمور المهمة في إدارة التربة عند بعض مواقع الحقول. الهدف الأول لهذه الدراسة هو لتقيم طريقة وزن المسافة المعكوس(**WDI**) ،و طريقة الكريجنك الاعتيادي (**KO**) من اجل تحديد طريقة التقدير المثالية لرسم خرائط بعض صفات التربة الفيزياويه. الهدف الثاني هو لتحليل العلاقة بين الصفات الإحصائية للمعطيات وأداء تقنيات تقدير ومن ثم رسم الخرائط لصفات التربة المختلفة.

العلاقات بين الصفات الإحصائية للمعطيات وأداء هذه التقنيات درست وحللت باستخدام معطيات بعض صفات التربة مثل الإيصالية المائية المشبعة،الكثافة الظاهرية،المحتوى الرطوبي الحجمي والتي أخذت نماذج التربة لها من حقل بورفي مدينة الحلة/ العراق.

النتائج أظهرت إن طريقة الكرييجنك الاعتيادي لها أفضليه على طريقة وزن المسافة المعكوس في تقدير ورسم خريطة الكثافة الظاهرية للتربة. من جهة أخرى وجد إن طريقة وزن المسافة المعكوس لها الأفضلية على طريقة الكريجنك الاعتيادية في تقدير ومن ثم رسم خرائط كل من الإيصالية المائية المشبعة للتربة والمحتوى الرطوبي ألحجمي للتربة. كما وجد إن قياس دقة طريقة تقدير ورسم الخرائط لصفات التربة والتي تمت باستعمال قيم جودة التنبؤ (**G**) وقيم معدل مربع الخطأ (**ESM**)

قد تطابقت بشكل جيد مع قيمة معامل الانحدار(R^2)لخط التطابق للعلاقة بين القيم ألمقاسه والقيم المقدرة لمختلف صفات التربة المدروسة. لقد كانت قيم (R^2) لخط التطابق بين القيم المقاسة والقيم المقدرة بواسطة طريقة وزن المسافة المعكوس أعلى من قيم (R^2) بطريقة الكريجنك الاعتيادية لكل من الايصالية المائية المشبعة والمحتوى الرطوبي الحجمي للتربة، بينما كانت قيمة(R^2)أعلى بطريقة الكريجنك الاعتيادية من طريقة وزن المسافة المعكوس لصفة الكثافة الظاهرية.

إن جميع الصفات الفيزياويه المدروسة كانت لها اعتمادية مسافة قويه ولكن قيمة المدى لهذه الاعتمادية تختلف تبعا إلى الصفة المدروسة. الكثافة الظاهرية كانت لها اقصر مدى اعتمادية وهو(6.3 متر) بينما الايصالية المائية المشبعة كان لها أطول مدى اعتمادية وهو (15.4 متر).

Introduction

Precision agriculture applies principles of farming according to the field variability, which creates new requirements for estimating and mapping spatial variability of soil properties. Improvement in estimation quality depends, first, on reliable interpolation methods for obtaining soil property values at unsampled locations and, second, on appropriate application of the methods with respect to data characteristics.

The interpolation technique commonly used in agriculture include inverse distance weighting and kriging (6,29, 21, 16).Both methods estimate values at unsampled location based on the measurements from the surrounding location with certain weights assigned to each of the measurements. Inverse distance weighting is easier to implement, while kriging is more time consuming and cumbersome ; however, kriging provides a more accurate description of the data spatial structure, and produces valuable information about estimation error distribution.

The accuracy of these two procedures has been compared in a number of studies. (26) reported kriging to be better than inverse distance weighting for mapping potato yield and soil properties, such as percent of sand Ca content, and infiltration rate. (16) found kriging to be more accurate than inverse distance weighting for predication of saturated hydraulic conductivity in south west of Iran, also (18) showed the performance of kriging method relative to inverse distance weighting method improved with increasing sampling intensity.(21) reported kriging to be better than inverse distance weighting for prediction of pH, EC, organic matter content of the soil.

Several other studies, however; found inverse distance weighting to be more accurate than (27) found that squared inverse distance weighting produced better interpolation results than any other method, including kriging. (28) compared inverse distance weighting and kriging for mapping soil (P) and (K) levels and found inverse distance weighting method to be relatively more accurate. (7) observed the best results in mapping soil organic matter contents and soil NO_3 levels for several fields when inverse distance weighting was used as an interpolation technique.

Most of the studies used mean squared error as a main criterion for comparison (27; 7). Kriging performance can be significantly affected by variability and spatial structure of the data (15) and by the choice of variogram

model, search radius, and the number of the closest neighboring points used for estimation (22).

The saturated hydraulic conductivity is of utmost importance to drainage design and affects the economic and technical feasibility of large-scale subsurface drainage projects. However; it is one of the most difficult factors to evaluate any drain spacing equation (17) Spatial distribution of the properties of natural aquifers, such as hydraulic conductivity often exhibit high heterogeneity. However; in a field investigation, only a small fraction of in situ data can be analyzed owing to time and cost constrains (11). Mapping of soil attributes in unsampled areas is the main contribution of geostatistics to soil science (4).

Spatially and temporally varying soil moisture is being increasingly used as input to hydrological and meteorological models. Knowing of spatial and temporal variability of field soil helps in characterization of the soil. The use of mathematical model to estimate the water and solute movement into the field soil has accelerated the need to understand the variability of soil properties like soil moisture, hydraulic conductivity and bulk density that affect the interpretation of model output variability. The soil hydraulic properties spatially vary both vertically and laterally due to the evaprotranpiration and precipitation influenced by topography, soil texture, and vegetation, therefore; finding a good method to predicate and map these properties in unsampled location and mapping these properties will help establishing a successful irrigation and drainage system.

The first objective of this study is to compare the performance of inverse distance weighting and ordinary kriging methods for interpolation and mapping of some soil physical properties (saturated hydraulic conductivity, bulk density and volumetric water content).The second objective was to analyze relationships between statistical properties of the data and performance of the interpolation technique.

Material and methods

The study was conducted on 10 hectare fallow field on October, 2010 in Hilla city (N 32° 46′, E 44° 41′) about 102 km south of Baghdad, IRAQ. The field was cultivated with barely crop in previous year. Undisturbed core samples have been taken with radius of 10X10 cm for saturated hydraulic conductivity measurements and another set of 5X5 cm core samples was taken for bulk density and volumetric water content measurements. Sixty-four core samples of each type were taken on two orthogonal axes, 32 samples in east-west direction and 32 samples in north-south direction. The distances between samples in both directions were 5 meter. The soil samples were taken to the laboratory to conduct the necessary measurements.

The saturated hydraulic conductivity for each soil sample has been measured by using falling head method(12), and bulk density of each sample was measured by the core method (3).The gravimetric method was used to measure soil water content for all samples (2).

Random samples have been taken from the study field to measure the soil texture and some chemical properties of the soil. The particle size distribution of the soil sample was measured using the hydrometer method (5), and all chemical analysis were carried out according to Black, et al (1965). Table 1 shows the chemical analysis and particle size distribution of soil samples.

Table 1: Chemical analysis and Texture of the field soil.

$SO4^{--}$ Meq/L	CL^{-} Meq/L	$HCO3^{-}$ Meq/L	Mg^{++} Meq/L	Ca^{++} Meq/L	K Meq/L	Na Meq/L	Ec ds/m	PH	Texture
172	123	9.10	65	14.50	1.90	95	30.1	7.45	Sandy clay loam

Interpolation Techniques:

Since detailed information about interpolation procedures can be found elsewhere in the literature (10, 9, 22); we only briefly describe the methods used in the study.

For both Inverse Distance Weighting(IDW) and Ordinary Kriging(OK) interpolation methods, the value of variable Z at unsampled location x_o, $Z^*(x_o)$ is estimated based on the data from the surrounding locations $Z(x_o)$ as:

$$Z^*(x_o) = \sum_{i=1}^{n} w_i \, Z(x_i) \qquad (1)$$

Where w_i are the weights assigned to each $Z(x_i)$ value and n is the number of the closest neighboring sampled data points used for estimation. The weights for the inverse distance weighting method (IDW) are:

$$w_i = (1/(d_i)^P) / \left(\sum_{i=1}^{n} (1/(d_i)^P \right) \qquad (2)$$

Where d_i is the distance between the estimated point and the sample ,and(p) is an exponent parameter. Most of the commercial software that is available currently for production of soil maps uses default exponent value of (2 or 4)according to (1).The other factor affecting the precision of (IDW) method is the number of the closest samples used for estimation. The exponent value and the number of the closest neighboring points producing the best agreement between the measured data and the estimates were chosen as the optimal (IDW) parameters.

Kriging calculates the values for w_i by estimating spatial structure of the variable's distribution represented by a sample variogram as:

$$\gamma(h) = ½ \sum_{i=1}^{n} [Z(x_i + h) - Z(x_i)]^2 \qquad (3)$$

Where (x_i) and (x_i+h) are sampling locations separated by a distance h

$Z(x_i)$ and $Z(x_i + h)$ are measured values of the variable Z at the corresponding locations.

The sample variogram is fitted with a variogram model and adequacy of the chosen model is tested using cross-validation. In this study, Spherical, Gaussian and Exponential models were considered for the sample variogram fitting. The cross-validation was conducted with varying model parameter values and with numbers of the closest neighboring samples ranging from 5 to 30 until the highest estimation accuracy was reached. Accuracy of the selected variogram model was measured through the error between the measured data and the estimated values (30) Cross-validation criteria used for sample variogram selection were the correlation coefficient between measured and estimated values (19) The two criteria used to check and compare interpolation methods accuracy were the mean square error (MSE) and a goodness of prediction (G), (14).

$$MSE = 1/n \sum_{i=1}^{n}[\ Z^*(x_i) - Z(x_i)\ ]^2 \qquad (4)$$

$$G = 〔1- MSE/MSE\ average\ 100 \qquad (5)$$

$$MSE\ average = 1/n \sum_{i=1}^{n}[\ Zm - Z(x_i)\ ]^2 \qquad (6)$$

Zm =Sample mean
$Z^*(x_i)$ = Estimated value
$Z(x_i)$ = measured value
n = Number of the measured values

Geostatistical analysis consisting of variogram calculation, cross validation, ordinary kriging (OK),inverse distance weighting (IDW) and mapping of all predicted data were performed by using geostatistical software package GS+ (Gamma Design software, 1994).
Regression coefficients of the fitted models were used to select the best fitting variogram model.

Results and Discussion

Statistical analysis:

The summary statistics of soil parameter is shown in Table 2. The descriptive statistics of soil data suggested that they were all normally distributed.

Table 2. The summary statistics of the soil properties.

Properties	Mean	S.D	Min	Max	Skewness	Kurtosis	C.V (%)
Hydraulic conductivity (cm/min)	0.148	0.166	0.01	0.98	4.15	16.86	112.1622
Bulk density (gm/cm^3)	1.287	1.56	0.95	1.96	0.79	2.88	121.2121
Volumetric water content (%)	26.95	7.752	9.33	50.06	0.37	-0.12	28.76438

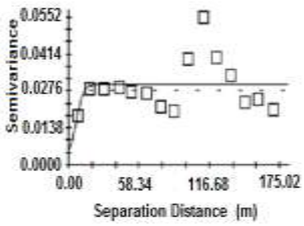
Coefficient of variation (C.V) for all variables was very different. Saturated hydraulic conductivity and the bulk density had high variation (C.V> 100%) whereas the soil water content exhibited a medium variation (C.V = 15%-50%) according to the guidelines provided by Warrick (1998) for variability of soil properties. Moreover; saturated hydraulic conductivity has high positive skew value (4.15) and high kurtosis value (16.86), and the water content has low skew value(0.37) and negative kurtosis value(- 0.12). The bulk density has a low positive skew value (0.79) and low kurtosis value (2.88).

In order to identify the possible spatial structure of different soil properties, semivariogram were calculated according to equation (3), and the best model that describe these spatial structure were identified. The spatial variation depicted by the semivariogram models are shown on Table 3.

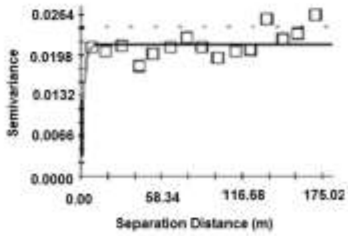
Table 3. Different parameters of the fitted model of semivariogram for soil properties

Properties	Type of model	Nugget (C_o)	Sill (C_o+C)	Range (A)	(C_o/C_o+C)	Spatial dependence
Hydraulic conductivity	Gaussian	0.00602	0.02994	15.4	0.201068804	Strongly dependent
Bulk density	Exponential	0.00002	0.02164	6.3	0.000924214	Strongly dependent
Volumetric water content	Spherical	0.1	49.94	13.1	0.002002403	Strongly dependent

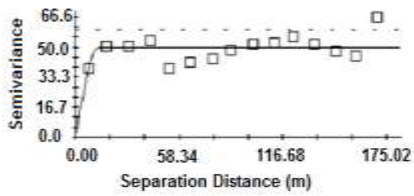
Spherical, Gaussian and Exponential models were found to fit well the experimental semivariograms (figure 1)



Saturated hydraulic conductivity



Bulk density



Volumetric water content

Figure 1: semivariogram for soil parameters

The geostatistical analysis presented different spatial distribution models and spatial dependent level for the soil properties. As seen in Table 3, the ranges of spatial dependences vary from (6.3 m) for bulk density, (13.1 m) for volumetric water content and (15.4 m) for saturated hydraulic conductivity. Knowledge of the range of influence for various soil properties allows one to construct independent data sets to perform classical statistical analysis. Furthermore, it aids in determining where to resample if necessary and in the design of future field experiments to avoid spatial dependency.

The level of spatial dependency can be determined by the ratio of nugget effect (Co) to the sill (Co + C). Table 3 shows a strong spatial dependency for all soil parameters. All values of the semivariogram model error (Co/Co+C) were less than 0.25 (0.20 for saturated hydraulic conductivity, 0.0009 for bulk density and 0.002 for volumetric water content). These values indicated a low random variability (Co) and high spatial variability (C), which the sum of them and equal to the total variability of the parameter data.

Similar results for volumetric water content were found by(16).

They found a strong spatial dependency of soil water content at different depth after and before irrigating the field. However; Moradi, et al., 2012, show a weak spatial dependency for soil hydraulic conductivity in west of Iran. They found, the semivariogram model error of the hydraulic conductivity (Co/Co+C) to be 0.81. Their different results from this study may be due to differences in region conditions like climate, hydrology, hydrogeology, and topography and soil type, in addition to the differences in soil management practices (16). According to (20),if the semivariogram error less than 0.25, a desired variable will shows strong spatial correlation; if it is between 025-0,75, variable will shows a medium a spatial correlation, and if it is more than 0.75, variable will shows weak spatial correlation (29) suggest that the spatial structure of the measured properties should be related to topography and soil types rather than to soil use, irrigation management or tillage.

Comparison between Ordinary Kriging and Inverse Distance Weighing prediction procedure:

Table 3 shows mean square error (MSE) and goodness of prediction (G) obtained for each properties by estimating and mapping them using ordinary kriging(OK) and inverse distance weighing(IDW) methods. for the saturated hydraulic conductivity and volumetric water content data, the accuracy of (OK) method in predicting the estimated data seems to be less than the (IDW) method (G% is smaller and MSE is larger), but, for the bulk density, precision of (OK) method is larger than the (IDW) method(G is larger and MSE is smaller).

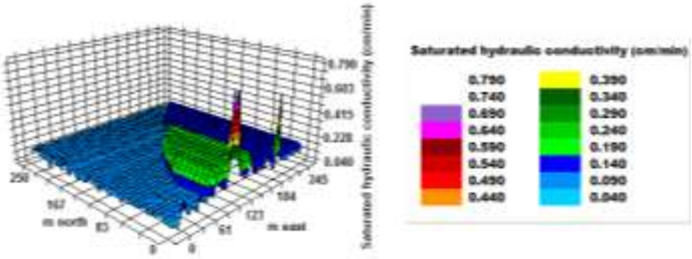
A result also showed that Ordainary Kriging with high relative value of (Co/Co+C) was much less accurate than Inverse Distance Weighting. Accuracy that can be achieved in mapping soil properties strongly depends on spatial structure. The stronger spatial correlation (low Co/Co+C), the more accurate the soil properties map. (14 ,17, 13) also made the same observations.

Table 3. Result of mean square error and goodness of prediction for soil properties

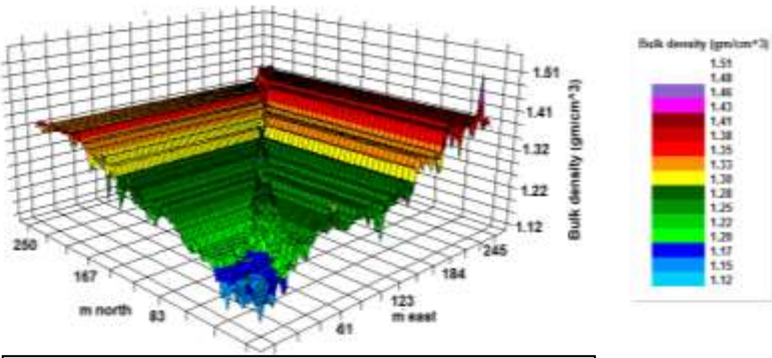
Properties	MSE		G (%)	
	Kriging	IDW	Kriging	IDW
Hydraulic conductivity	0.0247	0.0214	9.63	21.500
Bulk density	0.0222	0.0227	8.17	6.24
Volumetric water content	78.08	46.53	-31.23	21.778

The interpolation maps of estimated soil parameters by Ordinary Kriging and Inverse Distance Weighing methods showed in Figure 2 and Figure 3 respectively.

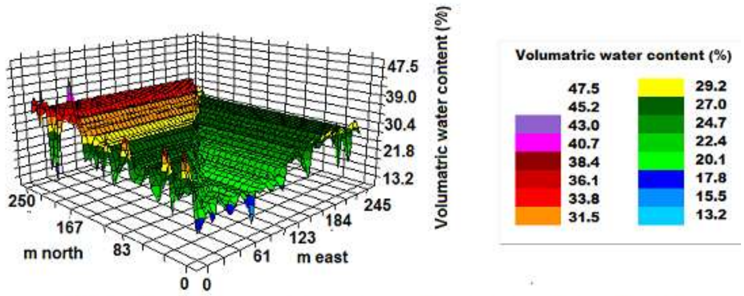
The fitted curves for measured and estimated values by Ordinary Kriging and Inverse Distance Weighing showed in Figure 4 and Figure 5 respectively.



Saturated hydraulic conductivity

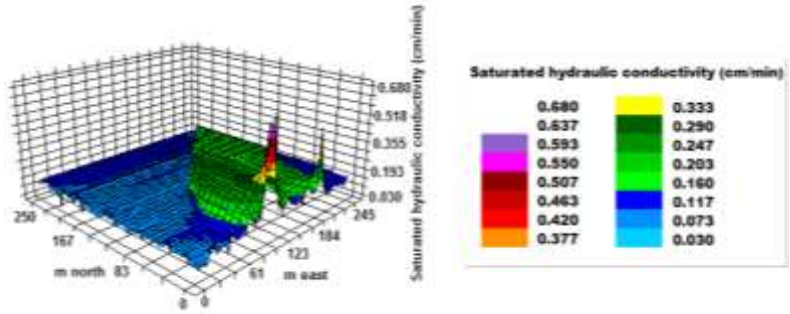


Bulk Density

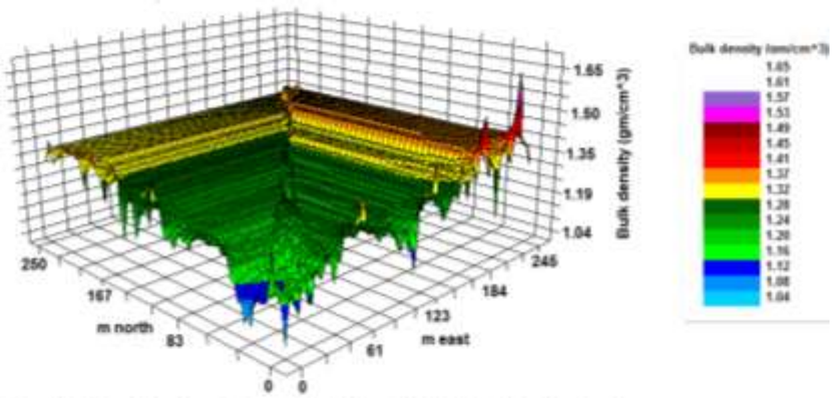


Volumetric water content

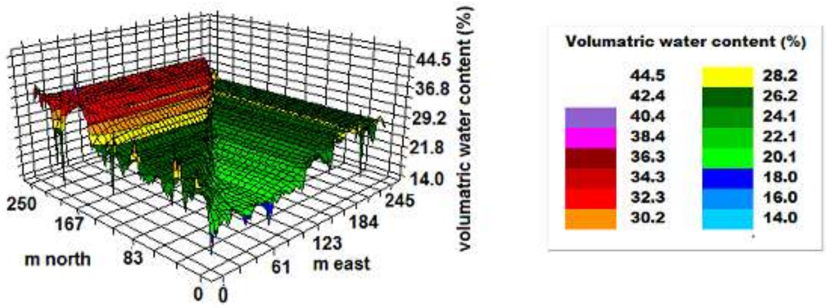
Figure 2: Three dimension maps estimated by Ordinary Kriging method for different soil properties.



Saturated hydraulic conductivity



Bulk Density



Volumetric water content

Figure 3: Three dimension maps estimated by Inverse Distance Weighing method for different soil properties.

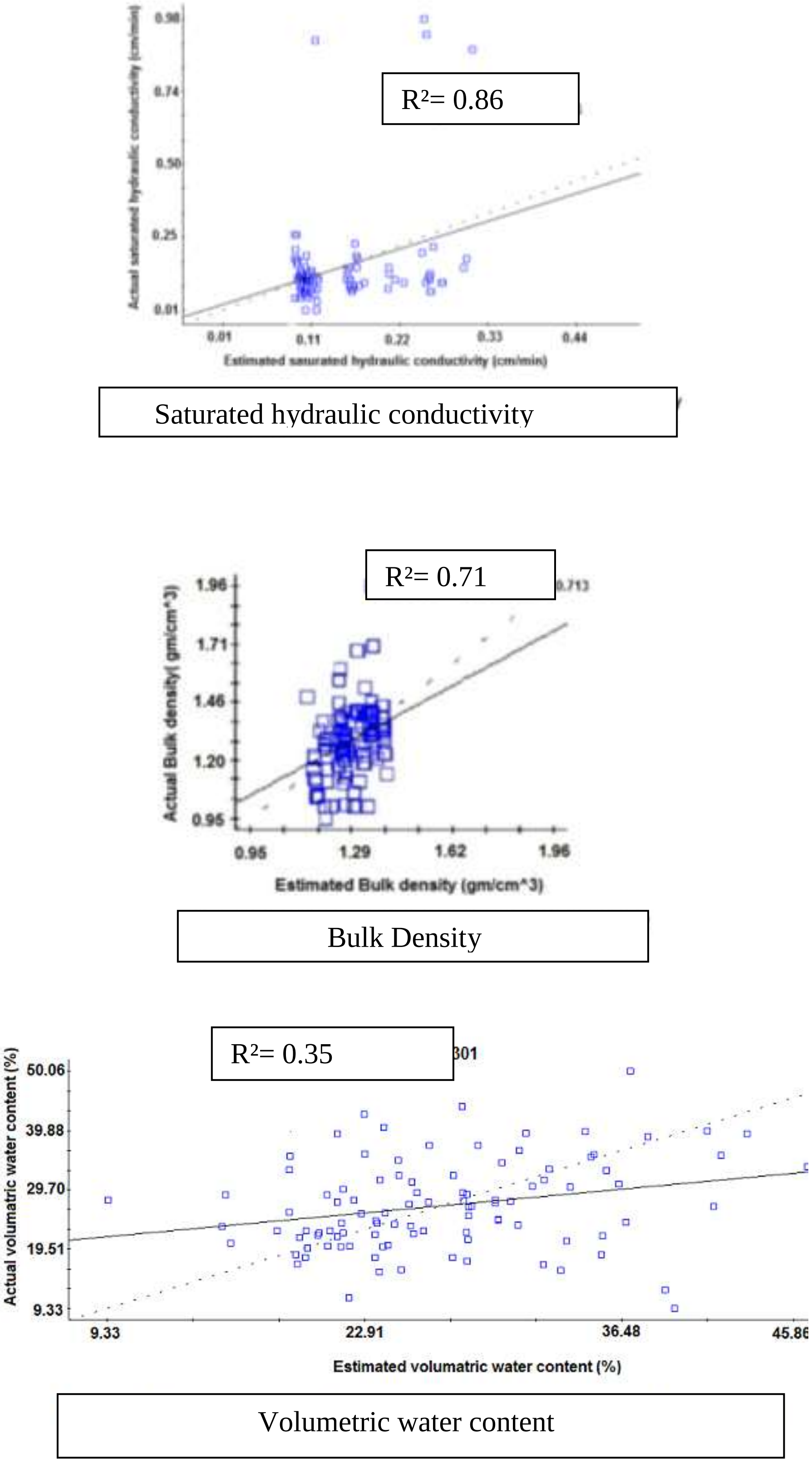


Figure 4: The fitted line for the actual and estimated values of different soil properties by Ordinary Kriging method.

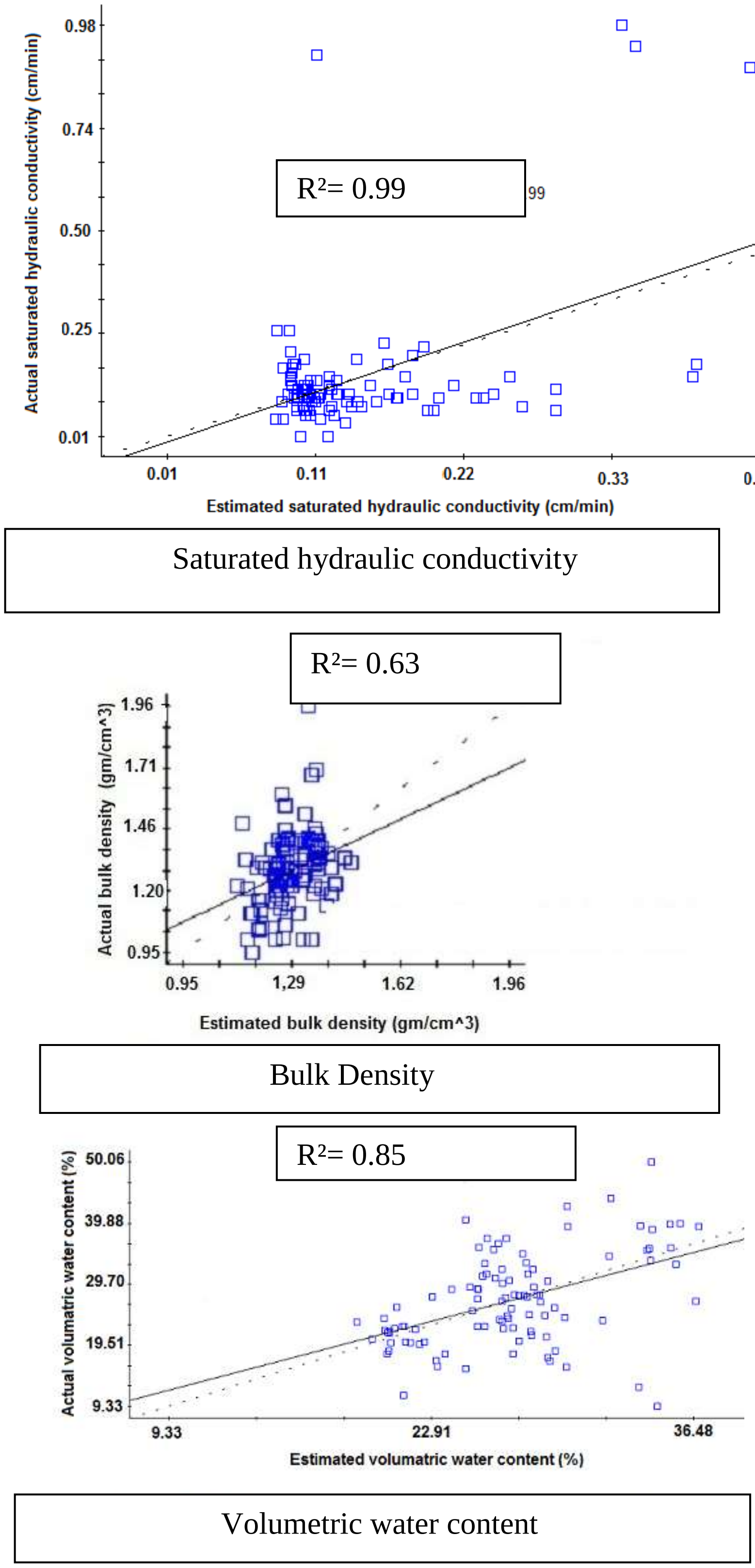


Figure 5: The fitted lines for the actual and estimated values of different soil properties by Inverse Distance Weighing method.

The regression coefficient (R^2) for the fitted line of measured and estimated saturated hydraulic conductivity by ordinary kriging method (OK) was 0.86, and by inverse distance weighing method (IDW) was 0.99. This results agree very well with the conclusion has been made from G% and MSE values which indicate the preference of IDW on OK method in estimating and mapping the saturated hydraulic conductivity. Similar results was found for the fitted line of measured and estimated volumetric water content which indicate the preference of (IDW) on(OK) method in estimating and mapping this variable(R^2= 0.35 for OK method and R^2= 0.85 for IDW method). On the other hand; the regression coefficients of the fitted line for measured and estimating bulk density show a preference of (OK) on (IDW) in estimating the bulk density (R^2= 0.71 for OK method and R^2= 0.63 for IDW method). This result, also agree very well with conclusion which has been made previously from G% and MSE values(Table 3), which indicated the preference of OK on IDW method for estimating and mapping the bulk density.

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