Maping and Estimation of Soil Moisture Constants and Hydraulic Conductivity Using Geostatistical Analysis in Banger EL-Sokker Region, Egypt

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ABSTRACT

Geostatistical analysis provides descriptive tools to characterize the spatial distribution of soil attributes. Kriging techniques rely on the spatial dependence between observations to predict attribute values at un-sampled locations. A survey of the soils of Bangar El-Sokker area (Elzuhur village) was carried out in 2009 and measurmenets of surface properties were made at 90 random sites. The soil attributes have been statistically and geostatistically analyzed to assess the degree and nature of spatial variability and spatial dependence of soil moisture constants and hydraulic conductivity. Classical analysis showed that the C.V. values were 0.68, 0.28, 0.22, 0.17 and mean values were 3.97 $cm.h^{-1}$, 5.56 $cm.m^{-1}$, 10.37 $cm.m^{-1}$ and 48 $cm.m^{-1}$ for hydraulic contactivity (Kh), wilting point (WP), field capacity (FC), and available water (AW) respectively. Variance appeared to be isotropic. The semi-variogram was spherical for (Kh, FC, WP) and Gaussian (AW).the area of each calss of the (AW) were (489.5,855.11,156.49,19.4) hectare for the the classes (36-45,45-55,55-64,64-73) respctivliy,and for the (FC) were (350.22,906.9,237.59,25.71) hectare for the classes (6-9,9-12,12-15,15-18) respectively, and for the (WP) were (285.89,850.09,355.66,288.7) hectare for the classes (3-4,4-6,6-8,8-10) respectively, and for (Kh) were (67.42,756.04,666.84,30.21) hectare for the classes (0.53-1.7,1.7-3.9,3.9-7.4,7.4-13) respectivily.

Key Words: Geostatistics, isotropic semi-variogram, Kriging, estimation variance, soil properties, Bangar El-Sokker.

INTRODUCTION

Spatial variability using geostatistics has been applied by many researchers to predict the values of soil attributes at un-sampled locations by different kriging techniques, and quantify the spatial distribution of these attributes using the semivariogram (Trangmar *et al.*, 1985; Warrick *et al.*, 1986; Webster and Oliver, 1989; Burrough, 1989; Webster, 1991; Bahnassy *et al.* 1995; Bahnassy and Morsy, 1996 and El-Zahaby *et al.* 1999; Goovaerts, 1998 and 1999). Geostatistics is basically a technique to estimate the variation of properties in space whether in one, two or three dimensions (Oliver & Webster, 1991). The semi-variogram is the central tool of geostatistics. It can quantify the scale and intensity of spatial variation and it provides the essential spatial information for local estimation by kriging and for optimization sample intensity (Oliver 1987). Xu and Webster (1984) applied geostatistics to study the topsoil properties in Zhangwu county, China, over 100 sites with a total area of 3635 Km^2 and found the variation to be isotropic in soil pH, sand, organic matter, nitrogen, phosphorus, and potassium. Ramadan (1992), El-Menshawy (1994), and Morsy (1994) applied the geostatistical technique to find out the optimum sampling distnace of different soil properties, both at different scale and spatial extent.

Hydraulic conductivity is one of the most important soil physical properties for determining infiltration rate, irrigation and drainage practices, and other hydrological processes. Hydraulic conductivity is not an exclusive property of the soil alone, since it depends on the properties of the soil and of the fluid together. Hydraulic conductivity may change as water permeates and flows in a soil due to various chemical, physical and biological processes. Some soil physical characteristics which affect hydraulic conductivity are the total porosity, the distribution of pore sizes, and the pore geometry of the soil (Hillel, 1982). Water holding abilities of the soils are related to removing water from soil by surface flow, drainage or evapotransporation and storing water in the soil by rainfall or irrigation. Soil water retention, which is the points at a series of matric potentials or parameters of analytical water retention equations, is needed for the study of plant available water, infiltration, drainage, hydraulic conductivity, irrigation, water stress on plants and solute movement (Brady, 1974).

Moisture percentages in field capacity and permanent wilting point are the most common soil moisture constants used in soil-plant-water relationships and influenced by soil structural properties, clay type and content. Field capacity represents the upper limit of water available to plants and equilibration presaturated soil samples with a matric suction value of 33 kPa tension. Permanent wilting point represents to lower limit of plant available water which is retained by soil particles with 1500 kPa tension (Slatyer, 1967). The amount of water retained at relatively low values of matric suction (between 0 and 100 kPa) depends primarily upon the capillary effect and pore size distribution, and hence is strongly affected by the soil structure. To explain this phenomenon, Vanapalli *et al.* (1999) suggested that when investigating the structure of partially saturated soils, there are two levels to be considered: macrostructure and microstructure. Macrostructure governs the soil water characteristic behavior for the soil particularly at low suction values, while microstructure governs the behavior of soil water characteristic at relatively high suction values. The spatial dependence of the saturated hydraulic conductivity has been often investigated (Cressie, 1993; Bosch and West, 1998; Moustafa, 2000).

Soil texture is one of the important soil properties governing most of the physical, chemical and hydrological properties of soils. Variation in soil texture in the field directly contributes to the variation in nutrient storage and availability, water retention, availability and transport hence may influence the yield potential of any site. Warrick and Gardner (1983) found a significant impact of this variability on soil performances and therefore the crop yield. Crave and Gascuel-Odoux (1997) found that variations in soil moisture content were directly related to the soil texture.

Precision farming or site-specific management is aimed at managing soil spatial variability by applying inputs in accordance with the site-specific requirements of a specific soil and crop (Fraisse *et al.*, 1999). Such management practices require quantification of soil spatial variability across the field. One of the recent approaches to quantify soil spatial variability for site-specific management is to divide fields into productivity level management zones (Fleming *et al.*, 2000 ; Khosla *et al.*, 2002). A management zone is a subregion of a field with homogeneous yield-limiting factors, for which a single rate of a specific crop input is appropriate (Doerge, 1999). Inman *et al.* (2005) reported that fields that have a high degree of spatial variability in soil properties could be better managed using site-specific management zones. Geostatistical technique is recommended as a powerful and convenient simulation-based algorithm for not only spatial prediction but also for evaluating both local and spatial uncertainty, which should be incorporated in many decision-making processes (Delbari *et al.*, 2009).

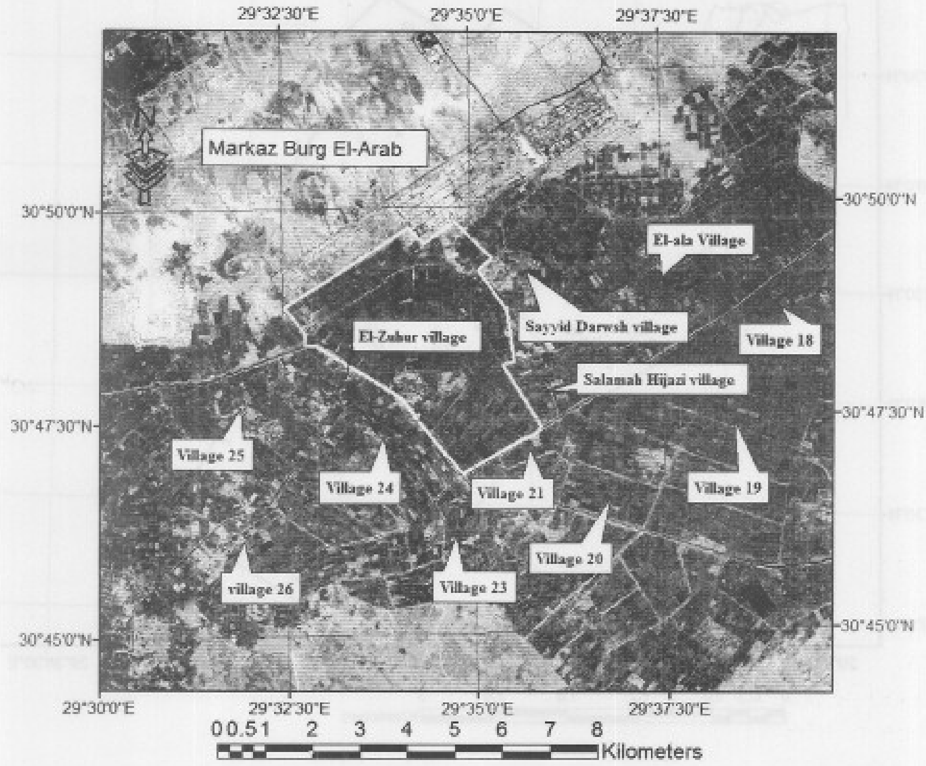
Spatial variability in measured AW and Kh has significant spatial correlation to study predictions of AW and Kh from clay using kriging and cokriging procedures. (Agaga, 2006).

The objectives of this study were to investigate and quantify the spatial distribution and spatial dependence of soil moisture constants and hydraulic conductivity, estimation of available water using soil texture and create soil mapping of the selected phoilysical properties.

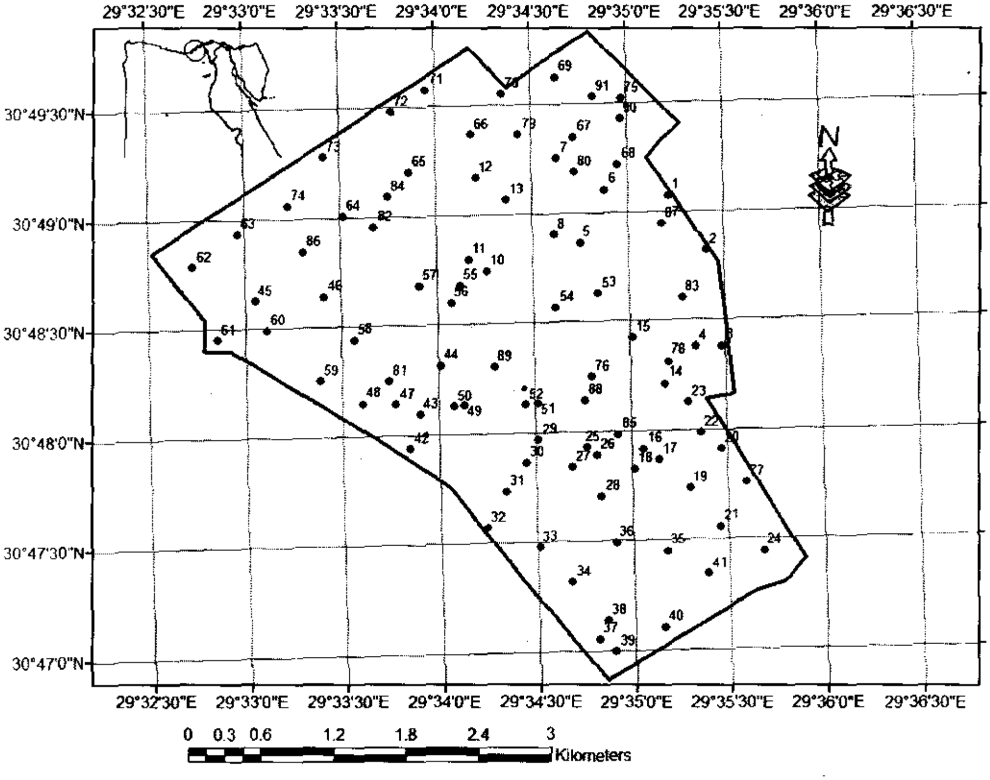
MATERIALS AND METHODS

Spatial Extent and soil Sampling and analysis

The area under study comprise part of Bangar El-Sokkar which include Elzuhur village and covers an area of 1520.534 Hectares (Map 1). Ninety soil augers were dug, and Magellantm NAV 5000 DTM Global position System Instrument (GPS) was used to record the samples locations in Universal Transverse Mercator projection System (UTM). The locations of these augers are shown on (Map 2) and the samples represent the surface horizon (0-30 cm), The soil samples were air dried and greatly crushed with a wooden pestle, sieved through < 2 mm sieves and then subjected to laboratory analysis. The soil chemical and physical analyses were carried out according to the methods described by page *et al.* (1982). Some soil properties were presented in Table (1). Also field capacity (FC), wilting point (WP), available water (AW) and hydraulic conductivity (Kh) are given in Table 2.



Map (1): Location of the study area.



Map(2): Observation sites in the study area.

Classical Statistical analysis

Mean, median, minimum, maximum, variance, standard deviation, coefficient of variance, were obtained using the SYSTAT 12 © Copyright 2007, SYSTAT Software, Inc.

Geostatistical Methodology

The Semi-Variogram:

The semi-variogram is the most important tool in geostatistical applications to soil. It represents the average rate of change of property with distance. It is the basis for modeling the data set and for drawing a contour maps or isarithms, (Burgess & Webster, 1980 a) The semi-variogram γ (h) is defined as :

$$\gamma(h) = \frac{1}{2}\operatorname{var}[Z(X) - Z(X+h)] \qquad (1)$$

Where z(x) and (x+h) are the values of a random function representing the soil property of interest z, at places x and x+h separated by the vector (h) known as the lag or interval. Under the zero drift assumption E[z(x)-z(x+h)] = 0, then equation 4 becomes:

$$\gamma(h) = \frac{1}{2}E[|Z(X) - Z(X+h)^2|] \qquad (2)$$

An estimate semi-variance function is given by:

$$\gamma^*(h) = \frac{1}{2n(h)}\sum_{i=1}^{n(h)}[z(X_i + h) - Z(X_i)]^2 \qquad (3)$$

with n(h) the number of pairs spirited by a distance h.

The obtained semi-varigram values for each lag were fitted to one of the semi-variogram function using the GSplus Geostatistical analysis software, Gamma Design (2008).

A spherical semi Variogram model given by:

$$\gamma(h) = C_0 + C_1\left\{1.5\left(\frac{h}{A_0}\right) - 0.5\left(\frac{h}{A_0}\right)^3\right\} \qquad for \quad h < A_0 \quad (4)$$

The Gaussian model:

$$\gamma(h) = C_0 + C_1\left(1 - \exp\left(\frac{3h^2}{A_0^2}\right)\right) \qquad (5)$$

The exponential model:

$$\gamma(h) = C_0 + C_1\left(1 - \exp\left(\frac{-h}{A_0}\right)\right) \qquad (6)$$

Where γ is the semi-variogram, C_O is the nugget variance, C_O+C is the sill variance, A_O is the range distance, and h is the lag distance.

The nugget (C_O) is the semi-varogram values due to short scale or inherited variability, the range (A_O) is the distance at each the semi-varigram reaches its maximum, after which there is no spatial dependence among the samples occur, and within it interpolation is worth while; and the sill (C_O+C) is the plateau (constant value) the semi-variogram reaches, Warrick *et al.* (1986), Issaks & Srivastava (1989).

Punctual Kriging:

Kriging is a method of interpolation using the weighted local averaging. It is optimal in a sense that the weights are chosen to give unbiased estimates while keeping the estimation variance at minimum (Webster, 1985). If a property is measured at a number of places, x_i, to given $z(x_i)$, i=1,2,....,n; then the estimate at point x_i will be the linear sum, so that,

$$Z^{-}(\beta) = \lambda_1 Z(X_1) + \lambda_2 Z(X_2) + \ldots\ldots\ldots\ldots + \lambda_n X_n \quad (7)$$

where the γ_i are the weights associated with the sampling points. The estimate is unbiased since.

$$E[Z(\beta) - Z^{-}(\beta)] = 0 \quad (8)$$

and this is guaranteed if the weights sum to 1, i.e.

$$\sum_{i=1}^{n} = 1 \quad (9)$$

The estimation variance (kriging variance) at x_i is the expected square difference between the estimate and the true value, which is

$$\sigma_2^E(\beta) = E[|Z(\beta - Z^{-}(\beta)|^2] \quad (10)$$

$$= 2\sum_{i=1}^{n} \lambda_i \gamma^{-}(X_i, \beta) - \sum_{i=1}^{n} \sum_{j=1}^{n} \lambda_i \lambda_j \gamma^{-}(\beta, \beta) \quad (11)$$

Where γ^{-} (x_i, xj) is the average semi-variance of the property between x_i and x_j taking into account the distance h separating them.

γ^{-} (x_i, xj) is the average semi-variance between x_i and the point to be estimated B, and γ^{-} (x_i, xj) is the average semi-variance within the block.In punctual kriging, the last term=0.

RESULTS AND DISCUSSION

According to the data in Table (1), the texture of soil samples are sandy clay loam and classified as calciorthiods. The calcium carbonate equivalent ranged from 19 to 33%. Organic matter content ranged from 0.21 to 0.64%. The pH of the soils ranged from 7.88 to 8.24 which indicated that all the soil are alkaline. According to EC values (soil survey staff., 1993), the soil samples are saline and non saline soils. Also, Table (2) summarized descriptive statstics of the mosiutre constansts and the KH of the soil samples. The FC, WP, Kh and AW have mean values of 10.37, 5.56, 3.97 and 48.59 with C.V values of 0.23, 0.28, 0.68 and 0.17, respectively. The Kh has the highest C.V value (0.68).

Table (1): Statistical parameters of some properties of the soil samples

Soil Property	Mean	Min.	Max.	S.D.	Var.	C.V	Median
pH	8.24	7.88	8.59	0.15	0.02	0.02	8.25
EC, dSm^{-1}	3.54	1.00	15.00	2.80	7.84	0.79	2.60
$CaCO_3$, %	33.44	19.05	51.82	7.19	51.69	0.21	33.33
OM, %	0.64	0.21	1.32	0.32	0.10	0.49	0.61
Mechanical analysis							
Sand, %	81.20	61.20	94.80	9.16	83.93	0.11	83.10
Silt, %	6.22	1.30	18.30	4.31	18.58	0.69	5.05
Clay, %	12.58	3.00	26.65	6.31	39.80	0.50	11.70
Soluble ions, meq l^{-1}							
Ca	22.28	16.00	40.20	5.61	31.52	0.25	20.40
Mg	5.90	2.00	18.00	4.94	24.44	0.84	4.00
Na	9.38	3.70	49.58	8.49	72.16	0.91	6.63
K	1.47	0.13	8.18	1.91	3.66	1.30	0.97
HCO_3	3.51	2.10	12.40	1.74	3.03	0.50	3.10
Cl	15.27	8.75	47.50	7.35	53.95	0.48	12.50
SO_4	20.25	8.82	53.97	11.81	139.38	0.58	17.34
SAR,%	2.36	1.11	9.36	1.60	2.56	0.68	1.87
ESP, %	2.13	0.38	11.15	2.14	4.57	1.01	1.47
Bulk density (gcm^{-3})	1.31	1.08	1.68	0.10	0.01	0.08	1.31

Table (2): Statistical parameters of the moisture constants and the hydraulic conductivity.

Statistical parameters	FC (cm m^{-1})	WP (cm m^{-1})	Kh (cm h^{-1})	AW (mm m^{-1})
Min	6.15	2.56	0.33	35.80
Max	17.60	10.25	13.17	73.49
Median	9.94	5.12	3.59	46.59
Mean	10.37	5.56	3.97	48.10
S.D	2.33	1.58	2.70	8.34
Variance	5.45	2.49	7.30	69.67
C.V	0.22	0.28	0.68	0.17

Semi-Variogram of the variables

Two semi-variograms were mainly fitted to the individual soil properties Figure (1). Hydrualic contactivity, wilting point and field capacity were fitted to the Spherical model. Available water was fitted to the Gaussian model. The parameters of these models for different soil properties are shown in Table (3).

Table (3): Best-fitted semivariogram models parameters for the moisture constants and the hydraulic conductivity.

Variable	Model	C_0	C_0+C	A	R^2
AW	Gaussian	33.90	81.90	2059	*0.83*
FC	Spherical	1.76	6.23	2025	*0.80*
WP	Spherical	0.62	2.74	1570	*0.70*
KH	*Spherical*	*3.33*	*7.42*	*1046*	*0.72*

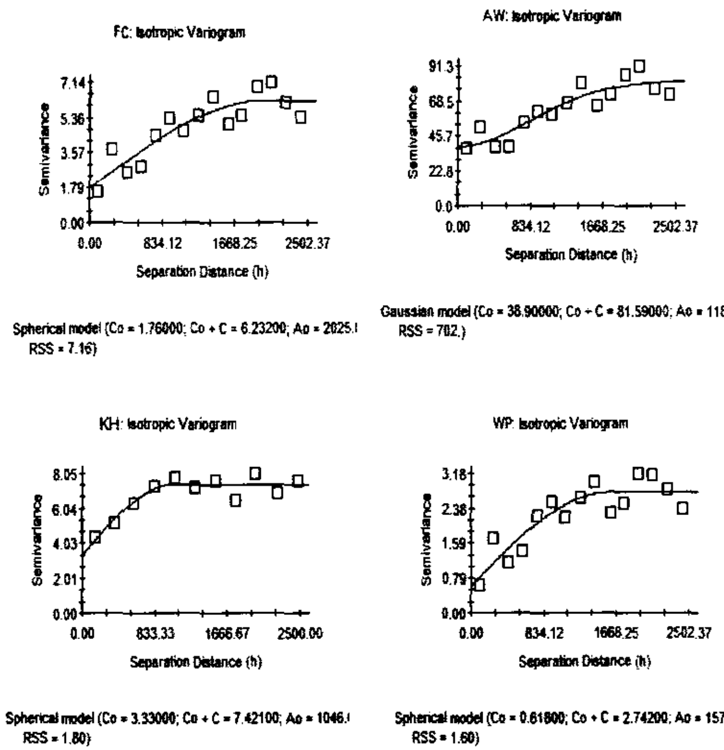
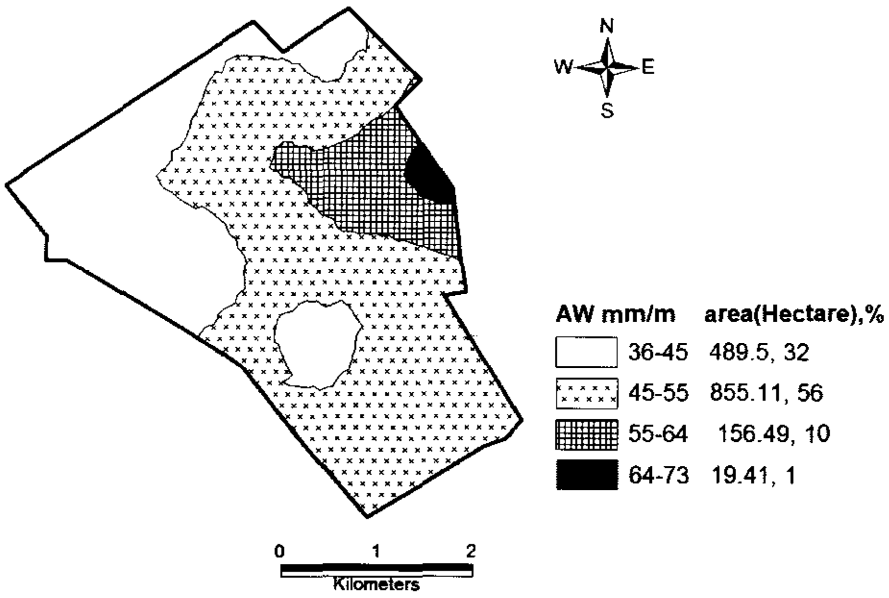


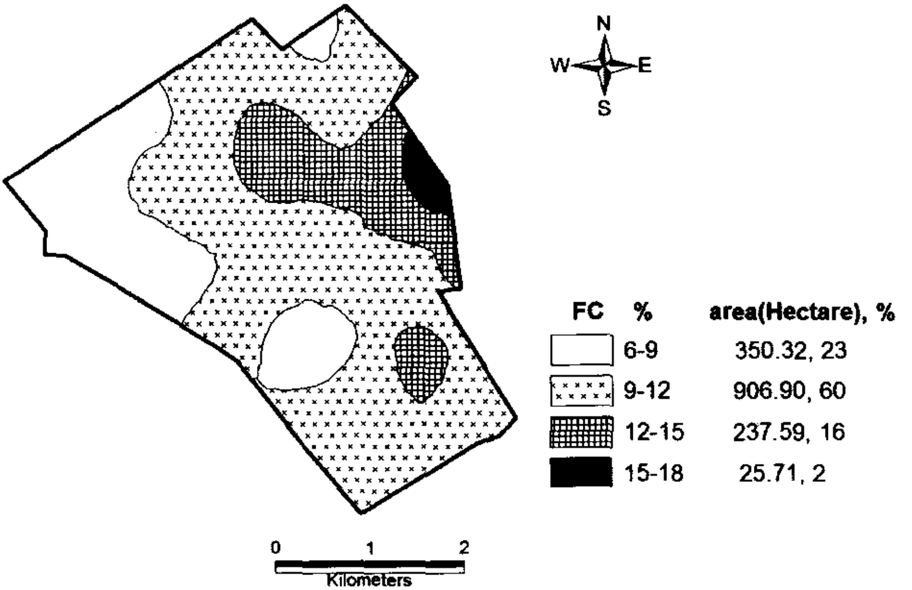
Figure (1): The modeled semi-virogram for moisture constants and the hydraulic conductivity.

Kriging Map

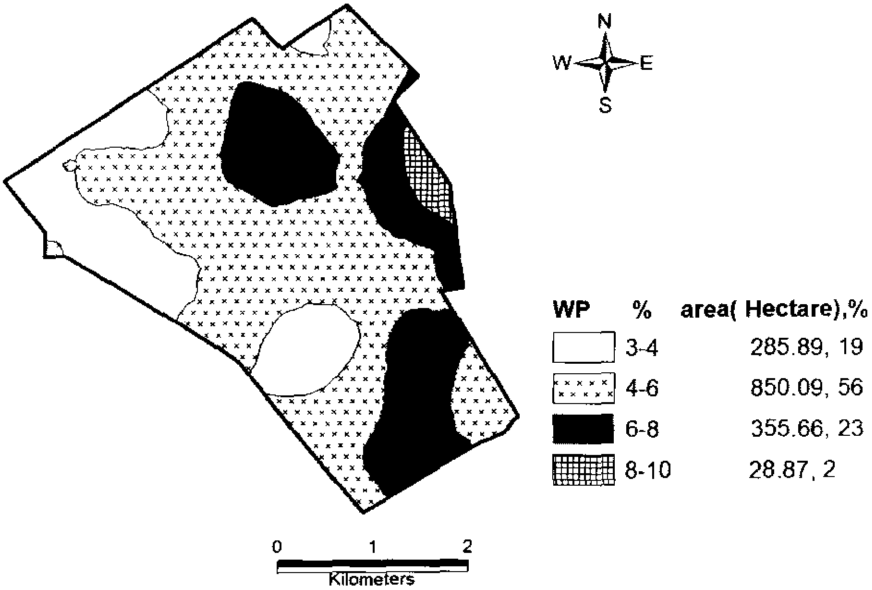
The Studied soil variables were used to produce kriging maps.Punctual kriging method was used in this analysis. Map (3) and Map (4)and map (5) and map(6) shows the kriged spatial distribution of studied moisture constants and the KH and the area of each calss using the result of the semi-variogram analysis. The reason of using punctual kriging is that we want to produce estimates using individual point's rathar than a block average, since there was no compositing of the original samples to use block kriging. The main advantage of kriging over other interpolation methods is that it provides estimates of the interpolation errors, which could be contoured, and so provide a reliability maps, Xu and Webster (1984).



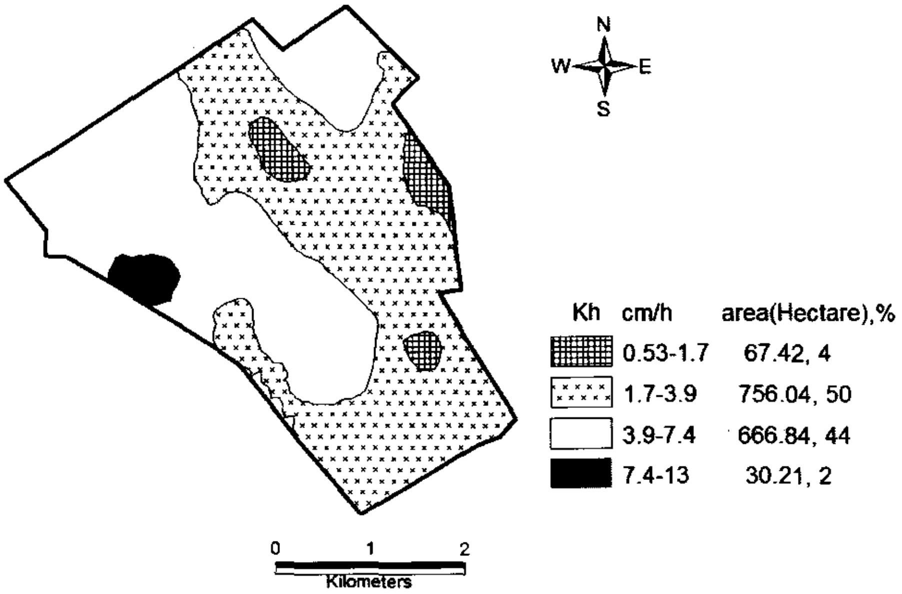
Map (3): Kriged map for available water



Map (4): Kriged map for field capacity



Map (5): Kriged map for wilting point



Map (6): Kriged map for saturated hydraulic condactivity

To check for the goodness of fit of the interpolation method and accuracy of the obtained Semi-Variogram models, a cross validation was carried out to test the reability of this model against other models available. Table (4) shows the results of cross validation, the root mean square standardized close to 1 and the mean close to zero (Webster, R. and M.A. Oliver. 2007).

Table (4): Cross validation calculated statistics for the the moisture constants and the hydraulic conductivity.

Variable	Mean	Root Mean square	Average standard Error	Mean standardized	Root Mean square standardized
AW	-0.018	6.518	6.413	0.0004	1.02
FC	-0.037	1.677	1.741	-0.011	0.96
WP	-0.034	1.137	1.137	-0.015	1.005
Kh	0.051	2.347	2.382	0.014	0.9954

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الملخص العربى

إستخدام التحليل الجيو احصائى لعمل الخرائط وتقدير ثوابت الرطوبة والتوصيل الهيدروليكى لمنطقة بنجر السكر،غرب الإسكندرية،مصر

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3 قسم الموارد و الهندسة الزراعية كلية الزراعة جامعة دمنهور مصر

4 قسم التربة و المياة كلية الزراعة جامعة عمر المختار ليبيا

م عمل دراسة فى منطقة بنجر السكر سنة 2009 حيث تم قياس بعض خصائص التربة الفيزيائية للطبقة السطحية و ذلك بأخذ 90 عينة تغطى قرية الزهور. وتم تحليل النتائج بالإحصاء الكلاسيكى و الإحصاء المكانى (الجيو احصائى) لتقييم درجة الاختلاف المكانى لبعض خصائص التربة الفيزيائية ، حيث أوضح الإحصاء الكلاسيكى أن معامل التوصيل الهيدروليكى ذو معامل اختلاف عالى 0.68 بمتوسط قدره 3.97 سم /ساعة، ونقطة الذبول بمعامل اختلاف 0.28 وبمتوسط قدره 5.56 سم/متر، والسعة الحقلية بمعامل اختلاف 0.22 وبمتوسط قدره 10.37 سم/متر، و الماء المتاح بمعامل اختلاف 0.17 وبمتوسط قدره 48 سم/متر. وقد أيدت هذه النتائج بنتائج التحليل الجيو احصائى حيث كان التباين ايزوتروبكIsotropic ، وكان Semivariogram يتبع نموذج spherical لكل من (معامل التوصيل الهيدروليكى ، السعة الحقلية ، نقطة الذبول) و Gaussian للماء المتاح. وكانت مساحة الفترات للماء المتاح (489.5، 855.11، 156.49، 19.41) هكتار للفترات (36-45،45-55،55-64،64-73) على التوالى و للسعة الحقلية (350.32، 906.90، 237.59، 25.71) هكتار للفترات (6-9،9-12،12-15،15-18) على التوالى، ولنقطة الذبول (285.89، 850.09، 355.66، 288.7) هكتار للفترات (3-4 ، 4-6، 6-8، 8-10) على التوالى، و لمعامل التوصيل الهيدروليكى (67.42، 756.04، 666.84، 30.21) هكتار للفترات (0.53-1.7 ، 1.7-3.9، 3.9-7.4، 7.4-13) على التوالى.