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A TRIAL OF ENHANCING REGIONAL SOIL MAP RESOLUTION AT EAST EL-OWIENAT AREA USING GEOSTATISTICAL ANALYSES

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ABSTRACT

Geostatistics provides quantitative indicators to characterize the spatial distribution of soil attributes which follow the regionalized variable theory. The present study aimed at applying Geostatistics to enhance the resolution of a regional soil map at East El-Owienat area which surveyed by one profile for each four kilometers. Studied area was extracted over 71 thousand feddans where six soil units were distinguished varying in profile depth and gravels properties. Studied area was covered using 23 sampled locations with 4 km lag spacing in which profile depth, gravels and salinity were determined in addition to 56 un-sampled locations forming a total of 79 sites with 2 km lag spacing. Variation of profile depth and gravels were best fitted to Exponential semivariogram model with 0.96 and 0.93 estimation coefficient, respectively, while salinity was best fitted by Spherical model with 0.95 estimation coefficient. Punctual kriging was processed to estimate soil properties at non sampled location. Estimated soil properties were mapped and overlayed to generate kriged soil map which contains ten soil mapping units and includes more interpolated details than in original regional soil map. High similarity was realized when kriged soil map was compared with actual map which produced based on 79 sampled sites, due to high regression coefficients between measured and estimated data which are 0.99, 0.89 and 0.92 for the studied properties, respectively. Standard error of estimation was also low and varied between 0.12 and 0.26. This study

recommends the application of Geostatistics to condense soil data for detailed maps production.

Keywords: Geostatistical analysis, Kriging, Semivariogram, Soil map.

INTRODUCTION

Soil properties vary in the space according to repeated pattern rules, although their spatial variation can be considerable over short distances, there are often regular patterns also (Lagacherie et al., 1995). The spatial relationship between the values of the attribute is governed by the regionalized variable theory, which states that observations close to each other are more correlated than observations taken at a further distance (Journel and Huijbregts, 1978). This means that points spatially close to the estimation points should be given higher weights than those further away (Cressie, 1993).

Geostatistics has been applied intensively during the last dedicate to describe the spatial variability using the variogram model which predict the values of soil attributes at un-sampled locations through different kriging techniques for data interpolation (Trangmar et al., 1985; Warrick et al., 1986; Webster and Oliver, 1989; Burrough, 1989; Webster, 1991; Goovaerts, 1992, 1998 and 1999). Goovaerts (1998) used different methods of kriging to model the spatial distribution of pH and electrical conductivity in two transects in forest and pasture soils.

The central tool of regionalized variable theory is what called "semi-variogram" (Trangmar et al., 1985) which defined as a plot of variance (one-half the mean squared difference) of paired sample measurements as a function of the distance between samples (Oliver and Webster, 1991). Kriging is a weighted local average interpolation method used to predict spatially the soil properties, which is computed as a function of fitted variogram model, locations of samples to each other, and to the point or block being estimated. (Oliver and Webster, 1991)

Lots of local investigations were carried out at different Egyptian regions for soil spatial variability assessment and mapping (Bahnassy et at. 1995; Bahnassy and Morsy, 1996 and El-Zahaby et al. 1999). The application of geostatistical techniques in most of the

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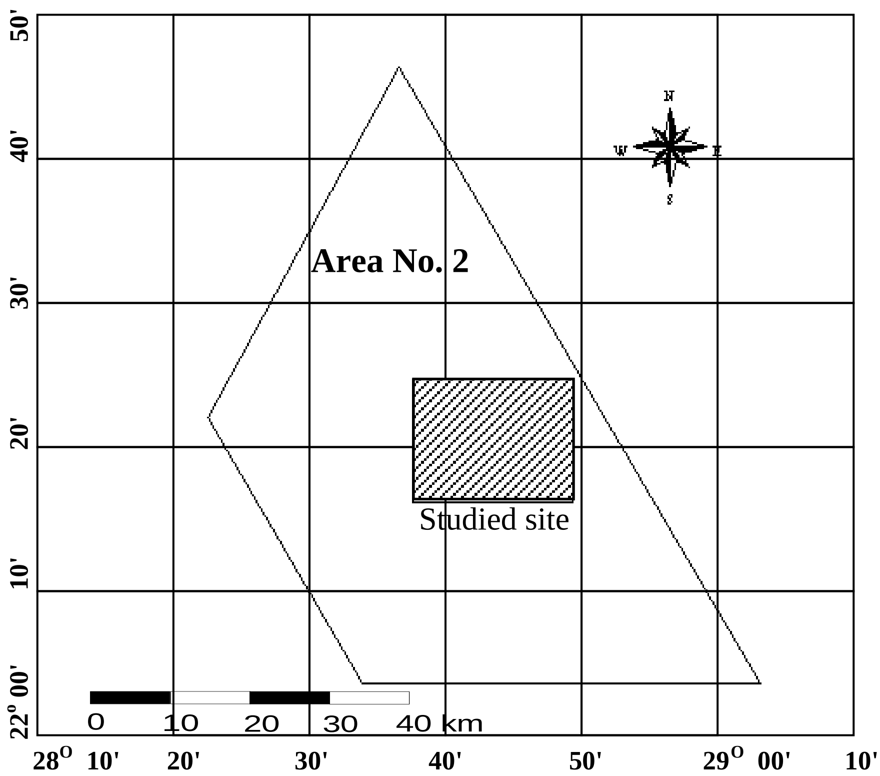
previous studies focused on data of relatively small spatial scale. There is still a lack of case studies on large-scale soil survey data (Yi-Ju Chien et al., 1998).

The purpose of this study aimed at using the geostatistical procedure in enhancing soil map resolution at East El-Oweinat area which have sampled regionally by one profile for each four square kilometers

STUDY AREA

1- The study location

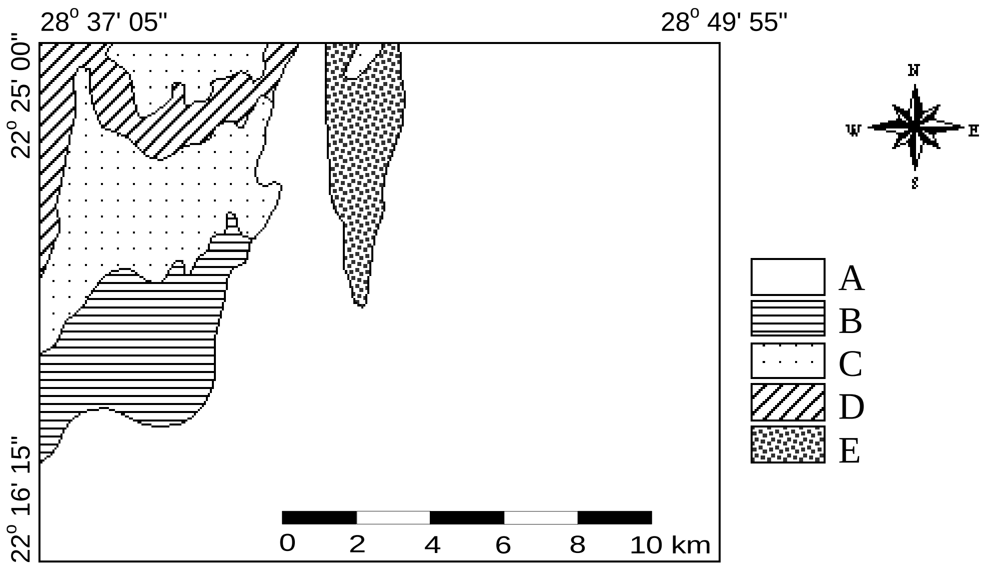
Studied area is an extracted clip as reference area to explain soil variation illustrated in Area no. 2 over 500 thousand feddans at East El-Oweinat area. The study site comprises part of sandy soils located over about 71 thousand feddans between latitude 22^o 16' 15" and 22^o 25' 00" Northing and longitude 28^o 37' 05" and 28^o 49' 55" Easting (map 1).



Map (1) Location of the study area.

2- Geomorphology

Studied area could be classified into five geomorphic units; (A) undulating gravely sandy terrain, (B) deflated terrain, (C) rock out crop, (D) leveled sandy terrain, and (E) sand dune (map 2).



Map (2) Geomorphologic forms of the study area.

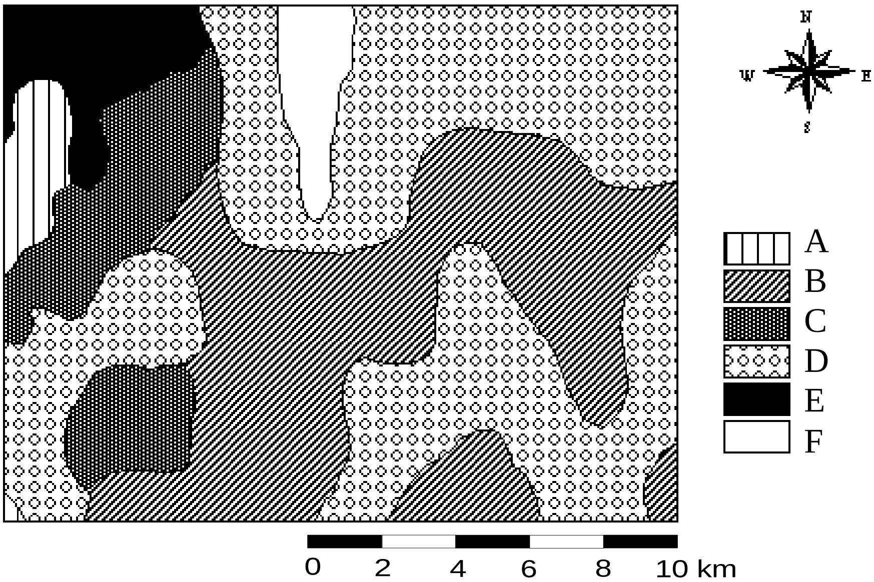
3- Regional soil map

Studied area was surveyed regionally by one profile for each four kilometers where sex soil mapping units were identified as seen in table 1 and map 3. 78.3 % of the total area had deep profile depth, while 48.9% of the area was gravelly sandy soils.

Table (1) Regional soil mapping units based on 4 km lag spacing in the studied area.

Unit	Soil Mapping Unit	Area (%)
A	Moderately deep sandy soils	4.2
B	Deep sandy soils	33.5
C	Moderately deep gravelly sandy soils	8.1

D	Deep gravelly sandy soils	40.8
E	Very shallow to shallow sandy to gravelly sand soils with rock exposures	7.6
F	Sand dune	5.8



Map (3) Regional soil map in the study area based on 4 km lag spacing.

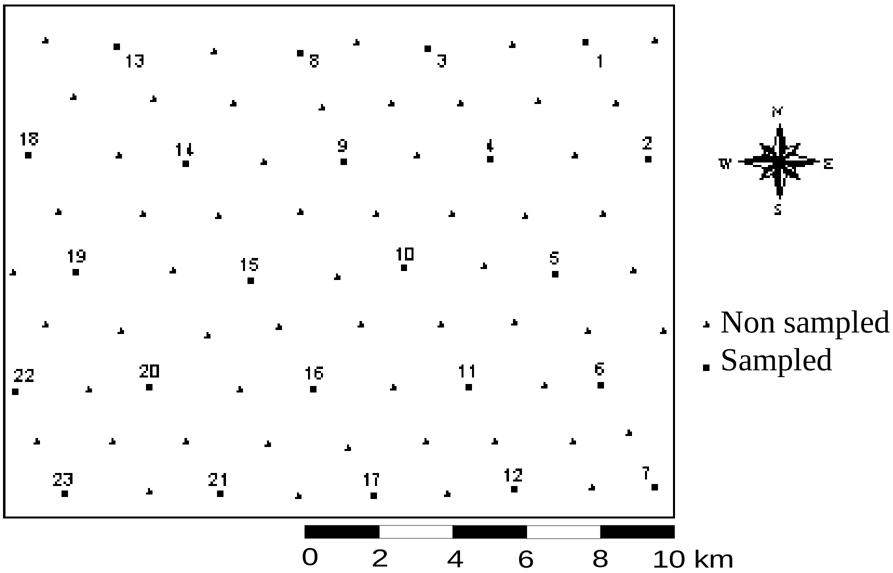
METHODOLOGY

1- Description of Spatial Patterns

Map (4) shows the spatial distribution of sampled locations over 23 sites in addition to 56 non sampled sites forming a total of 79 locations over the study area with 2 km network resolution used through the geostatistical analysis. The samples locations were georeferenced to the UTM coordinate system

2- Descriptive Statistical Analysis

Reported data associated to regional soil map was related to soil depth, soil texture and gravels. Soil salinity data also was incorporated to generate estimated soil map. Soil properties were analyzed for basic statistics including mean, variance, standard deviation, minimum, maximum, skewness, and kurtosis.



Map (4) Spatial locations of soil observations in the studied area

3- Semivariogram

The semivariogram is defined as half of the average squared difference between two attribute values separated by vector **h**, for one variable (Burrough and McDonnell, 1998):

$$\gamma(\mathrm{h}) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} \{Z(x_i) - Z(x_i + h)\}^2$$

Where $N(h)$ is the number of pairs at lag **h**, $Z(x_i)$ is the value of the attribute at location (x_i) and $Z(x_i + h)$ is the value of the attribute at location $(x_i + h)$ separated by distance **h**. The separation vector **h** is specified with some direction and distance (lag) tolerance. This semivariogram is used to model the variation of analyzed soil parameters by fitting them to one of the known semivariogram functions like Linear, Gaussian, Exponential or Spherical models.

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Each variogram has three main parameters; Nugget variance which describes the positive intercept with the Y-axis and estimates the non-spatially inherited variance, Range which is a critical distance for maximum sample spacing and Sill variance which describes the value of semivariance beyond the range (Burrough, 1991). Isotropic semivariograms were calculated and best fitted (Gamma D. I., 2001)

4- Kriging

A kriged estimate is a linear sum of the analyzed data with given weights associated to each location depending on fitted semivariogram (Rogowski and Wolf, 1994). If there are some measured values of a property (Z) at some sampling point, X1, X2..., Xi, the estimated value of that property at a non-sampled point (X0) is estimated based the associated weights of sampling points (λ) according to the following equation:

$$(X_0) = \lambda_1(X_1) + \lambda_2(X_2) + ... + \lambda_i(X_i)$$

Kriging was undertaken using punctual kriging method which aims to estimate the values according to the fitted semivariogram model, at non-sampled locations. Estimations of soil attributes were calculated and exported to Surfer 8 package (Golden software, Ins. 2002) to generate contour estimated maps.

5- Cross Validation

Cross validation is a technique which is used to compare estimated and true values, where estimation method is tested at the sampled locations using the information of estimation model. Correlation coefficients were calculated between true and estimated values. The error of prediction could be expressed according to Issaks and Srivastava, (1989) as:

$$Error = r = v' - v$$

Where *v'* is the estimated value and *v* is the true or measured value

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6- Linking Geostatistics to Geographic Information Systems (GIS)

The estimated kriged data were exported to Arc GIS software (ESRI, 2006) for mapping.

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RESULTS AND DISCUSSIONS

1- Descriptive Statistical Parameters

The statistical analysis of soil profile depth, gravels and salinity is shown in table (2). There is greater number of soil samples with high profile depth values, which raised the mean compared to the standard deviation. The distribution of gravels and salinity variables are positively skewed, indicating the dominance of low values.

Table (2) Descriptive statistical analysis for studied soil properties

Statistical Parameter	Profile depth	Gravels	Salinity
Mean	115.0	26.8	1.35
Minimum	15	1.0	0.3
Maximum	150	71.4	3.8
Standard Deviation	36.16	16.32	0.72
Variance	1308	266.3	0.52
Skewness	-1.61	0.06	1.69
Kurtosis	1.59	-0.33	3.02

2- Semivariograms

Semivariogram curves for both soil profile depth and gravels were best fitted to the Exponential model, while soil salinity was best fitted to Spherical model. Table 3 shows the parameters of fitted semivariograms for studied properties including the coefficient of determination (r^2) which exceeds 0.90 for whole fitted models indicating the goodness of estimation (Burrough and McDonnell, 1998).

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Table (3) Fitted semivariogram models and associated parameters for studied soil properties.

Variable	Model	Nugget (Co)	Sill (Co+C1)	Range (Ao)	r^2
Profile depth	Exponential	166	2308	20.5	0.962
Gravels	Exponential	41.9	274	9.2	0.926
Salinity	Spherical	0.14	2.46	39.8	0.947

It is obvious that profile depth has the highest nugget variance (166) which reflects their strong and high inherited variability. The sill variance which describes the structural variance between analyzed sample pairs was 2308, 274 and 2.5 for profile depth, gravel and salinity, respectively. The range represents the spatial dependence over specific lag distance, or by another word it could describe the maximum distance between a pair of samples in which the correlation between variance and distance is valid for optimum sampling strategy. Range values are 20.5, 9.2 and 39.8 for profile depth, gravel and salinity, respectively. The high range value of salinity reflects the high correlation between distance and the variance of salinity.

Fitted semivariograms curves for soil profile depth, gravels and soil salinity described in figure 1 according to the following equations:

For profile depth:

$$\gamma(h) = 166 + 2308\ [1 - \exp(-h/20.5)]$$

For gravels:

$$\gamma(h) = 41.9 + 274\ [1 - \exp(-h/9.2)]$$

For soil salinity:

$$\gamma(h) = C_o + C\left[\frac{3h}{2a} - \frac{1}{2}\left(\frac{h}{a}\right)^3\right]$$

$$\gamma(h) = 0.14 + 2.46\ [3h/79.6 - h^3/\ 63044.8]$$

Where h is the separation distance (lag) in meters

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3- Kriging

The spatial distribution of kriged estimated values of profile depth, gravels and salinity were generated based on the information content of corresponding semivariograms (map 5). Kriging did not aggregate the values in a contiguous group due to the estimated information in the areas between samples. Kriged estimates were overlayed to produce estimated soil mapping units based on 4 km lag spacing (map 6).

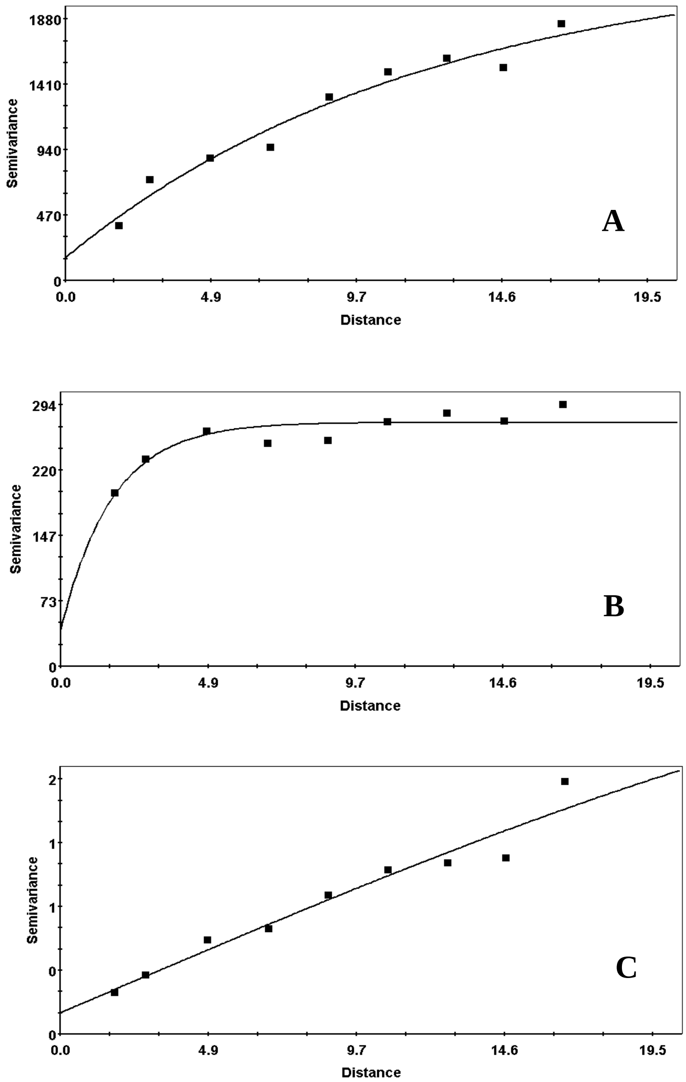
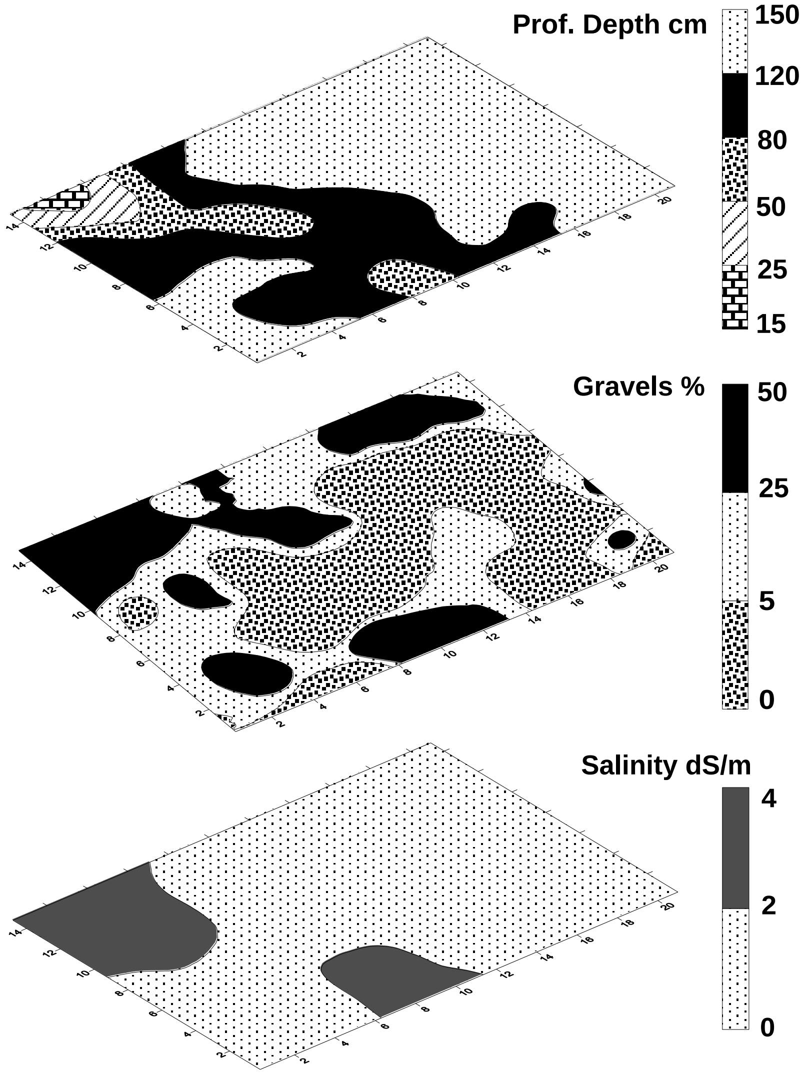


Fig. (1) Isotropic semivariograms for (a) profile depth, (b) gravels and (c) salinity.



Map (5) Spatial distribution of Krigred estimated values for soil profile depth, gravels and salinity in the studied area.

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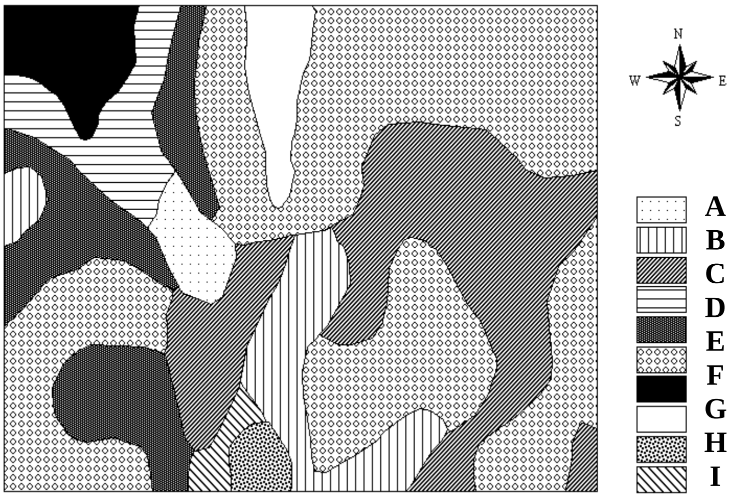
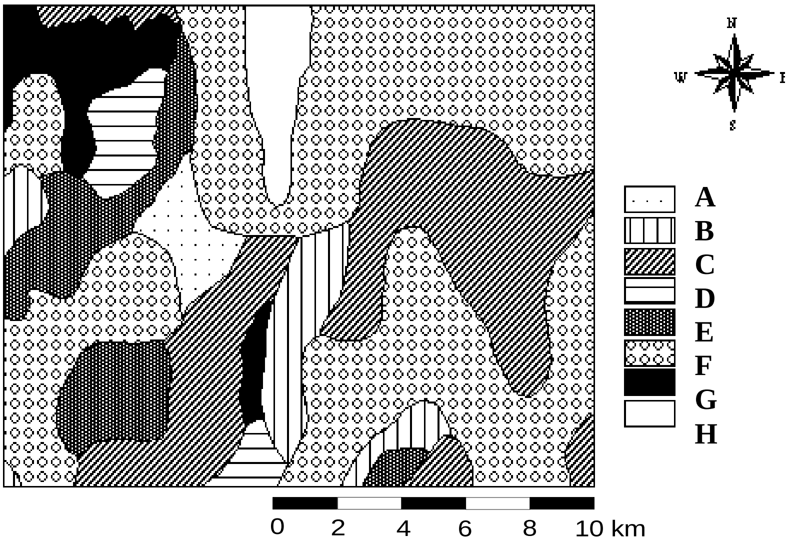
4- Cross Validation of Kriging

The process of cross validation between the estimated and the true value permits the evaluation of kriging performance, where estimated soil units (maps 6) compared with actual units (map 7). Table 4 shows the differences between estimated and actual unit areas.



Map (6) Estimated soil mapping units based on 4 km lag spacing in the studied area.



Map (7) Soil mapping units based on 2 km lag spacing in the studied area.

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Table (4) Actual and estimated soil mapping units based on 2 and 4 km lag spacing, respectively in the studied area.

U.	Soil Mapping Unit	Area (%)	
		Actual	kriged
A	Shallow sandy soils	4.2	3.8
B	Moderately deep sandy soils	6.2	7.5
C	Deep sandy soils	18.3	16.8
D	Shallow gravelly sandy soils	3.8	5.1
E	Moderately deep gravelly sandy soils	9.1	9.3
F	Deep gravelly sandy soils	47.5	42.3
G	Very shallow to shallow slightly saline sandy to gravelly sand soils with rock exposures	5.2	4.4
H	Sand dune	5.8	5.8
I	Shallow slightly saline gravelly sandy soils		2.9
J	Deep slightly saline sandy soils		2.1

Ten soil units were distinguished as seen in map 6 varying in profile depth, gravel percentage and soil salinity. High degree of similarity could be obviously noticed between the spatial distribution of true soil map based on 2 km resolution and estimated soil map based on 4 km resolution, with some differences due to salinity incorporation. Therefore, kriging has proven successfulness in estimation soil properties. Results of formalized semivariograms and associated kriging estimation may be extrapolated over the whole area.

Figure (2) shows the linear regression between kriged and actual values for profile depth, gravels and salinity, respectively. High correlation was achieved between actual and estimated values, where regression coefficients were 0.99, 0.89 and 0.92 for studied properties, respectively. Associated standard error of prediction were 0.12, 0.26 and 0.22 respectively for the studied properties which indicating reasonable accuracy results.

Results emphasized on geostatistics as a hermeneutic key may be useful in enhancing soil maps resolution and details condensation. This study recommends the application of such processing procedure to enhance regional map resolution.

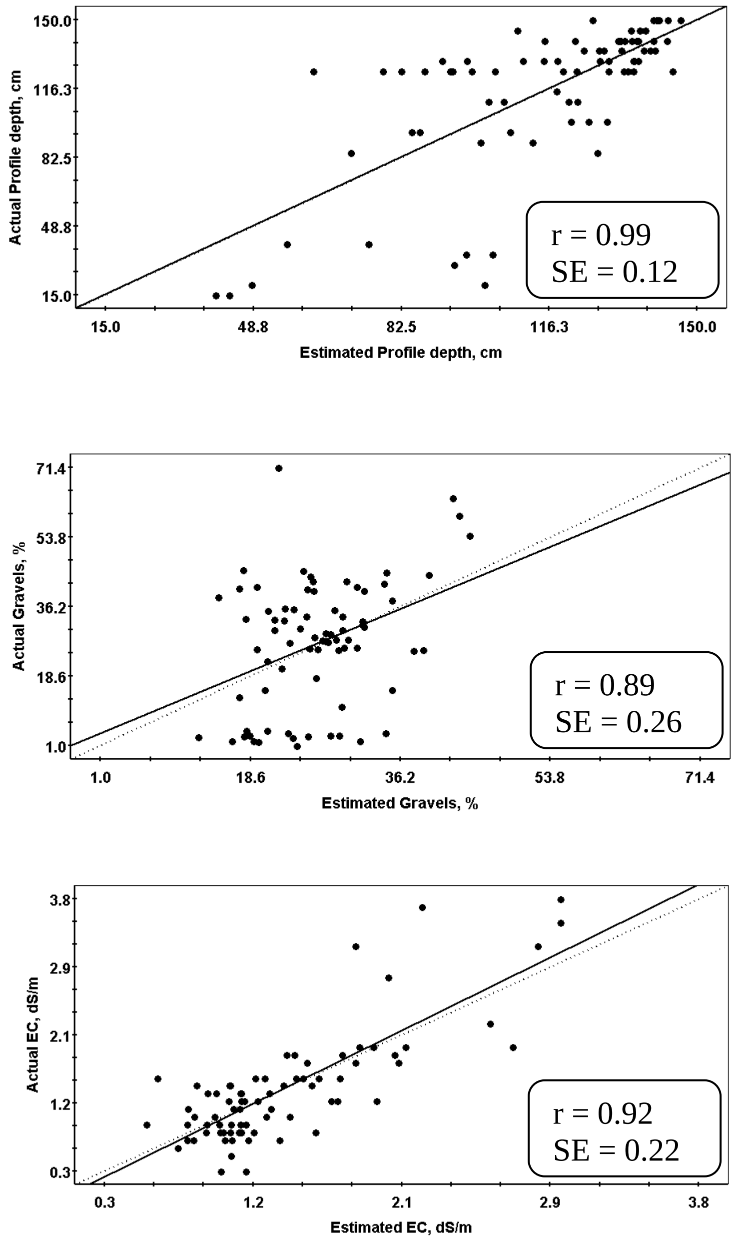

Fig. (2) Regression between kriged and actual values of (a) profile depth (b) gravels (c) soil salinity. (The solid line is the regression line, the dot-dash line is for r = 1)

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الملخص العربى

محاولة لزيادة دقة خريطة التربة الإقليمية بمنطقة شرق العوينات بإستخدام التحليل الجيوإحصائى

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تقدم الإحصاء الأرضية مؤشرات كمية لتوصيف التوزيع المكانى لخواص التربة والذى يتبع نظرية التغير المحلى والتى مؤداها أن صفات التربة لا تتوزع عشوائيا وإنما هى فى ذلك تتبع نمطا مميزا ومتكررا وفقا لعوامل وعمليات تكوين الأراضى. ويهدف البحث إلى إستخدام طرق الإحصاء الأرضية فى زيادة درجة الإيضاح وقدر التفاصيل بخريطة التربة المنشأة على المستوى الإقليمى والتى حصرت بواقع قطاع أرضى لكل أربعة كيلومترات على إمتداد مساحة 500 ألف فدان بمنطقة شرق العوينات فى محاولة لإستغلال إسهام التكنيك الإحصائى فى تحديد تغيرات صفات التربة بداخل كل وحدة أرضية متجانسة جاءت بخريطة التربة الإقليمية للمنطقة. منطقة الدراسة أستخلصت على مساحة بلغت حوالى 71 ألف فدان حيث تم تمييز عدد 6 وحدات تربة إختلفت فيما بينها فى صفات عمق القطاع الأرضى ونسب الحصى. أجريت الدراسة بإستخدام 23 موقع ممثل حصرت على مسافات فاصلة تقدر بـ 4 كم تم حصر بيانات عمق القطاع ونسبة الحصى ونسبة الملوحة عندها، إضافة لـ 56 موقع غير ممثل بإجمالى 79 موقع حددت على مسافات فاصلة بلغت 2 كم. أوضحت دراسة توافق نماذج التباين الموزون أن توزيع صفات عمق القطاع الأرضى ونسبة الحصى حقق أفضل توافق مع النموذج الأسى فى حين توافق توزيع الملوحة كأفضل ما يكون مع النموذج الكروى حيث بلغ معامل التقدير 0.96 – 0.93 – 0.95 لصفات عمق القطاع ونسبة الحصى والملوحة على الترتيب. ثم أستخدمت طريقة الإستيفاء النقطى لتقدير الصفات المدروسة عند المواقع الغير ممثلة بدلالة نماذج التباين المتوافقة مع رسم خرائط توزيعاتها. تم مطابقة الخرائط التقديرية الناتجة لإنشاء خريطة تربة جديدة إختلفت عن الخريطة الأصلية فى زيادة عدد وحدات التربة لعدد 10 وحدات إضافة لقدر التفاصيل الجديدة والتى أدرجت ما بين المواقع الممثلة. ولإختبار صحة خريطة التربة التقديرية والمنشأة بإستخدام مواقع تفصلها مسافات 4 كم تم مقارنتها بخريطة التربة الحقيقية والمنشأة بناءا على حصر 79 موقع ممثل تفصلها مسافات 2 كم، حيث بدا أن هناك تقارب كبير فى التوزيع المكانى لوحدات التربة بكلتا الخريطتين تم تأكيده كميا من خلال إرتفاع معامل الإرتباط بين قيم الصفات الحقيقية والتقديرية والذى بلغ 0.99 – 0.89 – 0.92 على الترتيب لصفات عمق قطاع التربة ونسبة الحصى والملوحة، إضافة لتدنى قيم الخطأ المعيارى لتقدير ذات الصفات والذى بلغ 0.12 – 0.26 –0.22 على الترتيب. وتأتى أهمية البحث التطبيقية من خلال إمكانية إستخدام ذلك الأسلوب الإحصائى فى زيادة درجة إيضاح تفاصيل التوزيع المكانى لصفات التربة والذى يتحقق معه أصدق تمثيل للإختلافات الأرضية تزامنا مع إستهلاك أقل وقت وجهد وتكاليف مصاحبة لعملية الحصر.