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VARIABILITY OF SOME SIWA OASIS SOILS USING PRINCIPAL COMPONENT ANALYSIS

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ABSTRACT

A survey of some Siwa oasis area soils was carried out in 2001-2002. Measurements of topsoil properties were made at 36 grid system (350×350m.) sites. The results have been statistically and geostatistically analyzed to assess the degree and nature of spatial variability and spatial dependence in the soil properties. Classical statistical analysis showed that the coefficients of variation (C.V.) were 2.09, 2.07, 1.54, 1.50, 1.47, 1.43, 1.40, 1.18, 1.13, 1.06, 0.90, 0.78, 0.76 and 0.73 for K^+, SO_4^{--}, Cl^-, Na^+, EC, HCO^-_3, gravel, Mg^{++}, Ca^{++}, V.F.S., SAR, $CaCO_3$, fine sand and very coarse sand, respectively. Principal component analysis (PCA) was carried out to reduce data redundancy and interpretation. The first sex PC's were selected as each of them explained more than 4.55% of the total variance. These six PC's explained 80.26% of the total variance. This is confirmed by the coefficient of variation (C.V.). Geostatistical analysis showed that the semi-variogram model was Spherical for depth and $CaCO_3$%, Gaussian for EC and SAR, and Exponential for O. M. and tatol sand. The only variables that showed the EC, SAR, depth and total sand has the highest nugget variances of 2460, 324, 167 and 122.1 which indicate their strong spatial dependence and high inherited variability. The maximum interpolation distances for $CaCO_3$, depth EC, SAR, O.M and total sand, are 540.1, 531.0, 275.3, 124.4, 619 and 616 m., respectively. Highly variable soil properties were used to produce kriging maps, using Punctual kriging method. The information taken from the semi-variogram model for each property was used in drawing the isarithmic maps for these properties, indicating their spatial distribution.

Keywords: Siwa oasis, Geostatistical, Principal component analysis, spatial variability, coefficient of variation, semi-variogram, nugget, kriging.

INTRODUCTION

The agricultural development of oases offers great opportunities to move out of the crowded Nile valley and delta and start new life on these freshly reclaimed productive farm lands. Siwa Oasis is among the famous of the western desert oases, as it has certainly the most intersting touristic attraction due to its famed temple and the largest naturally flowing springs, however, it suffers from several problems that strictly affect its development. The main problem is the continous deterioration of its cultivated lands and changing most of them to very low productive ones.

Variations in soil properties tend to be correlated over space-both vertically and horizontally. Estimates for a property at an unsampled location will be principally determined by measurements made close by, rather than by assuming a class (or plot) average (Warrick *et al.*, 1986). If the frequency distribution for a soil property follows a normal probability density function (PDF), its position and dispersion are easily and conveniently described by the arithmetic mean and the variance (Webster, 1977). The principal component analysis (PCA) is a method used to reduce the number of soil properties without losing important information. PCA was used as an unbiased method to make the selection (Ovalles and Collins, 1988 and Theocharopoulos *et al.*, 1997). The basic idea of PCA is to create new variables called PC's (Afifi and Clark, 1989). 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 and Lark and Beckett, 1998). 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 that the variation is isotropic in soil pH, sand, organic matter, nitrogen, phosphorus, and potassium. Also, El-Menshawy (1994 and 2000), Ramadan and Abdel-Kader (1995), Bahnassy (1996), and El-Menshawy *et al.*,(1998) applied the geostatistical technique to find out the optimum sampling distance of different soil properties, both at different scale and spatial extent.

Many investigators have studied the Siwa oasis from pedological aspects, (Harga et al. 1975, Balba 1992, Shatanawi 1991, Abdel-Samie, 2000 and Ahmed 2001). These studies have resulted in an accumulation of a great amount of information related to different disciplines. These Studies provide the basis for land management recommendations towards a better utilization and conservation of nataral resources and the enhancement of their sustainable production.

The aims of the present study are to 1- determine the descriptive statistical indices of some surface soil properties, 2- identify the differential soil characteristics using principal component analysis and 3- investigate and quantify the spatial distribution and spatial dependence of the surface properties using geostatistical analysis.

MATERIALS AND METHODS

Location :

Siwa oasis is a natural depression situated in the north western portion of the western deseret between Longitudes 25° 18`and 26° 06` E, and Latitudes 29° 05` and 29° 20` N. It is located at about 300km. southwest of the capital of Marsa Matruh governorate, Fig. (1). Though the total area of Siwa depression is about 1100km^2, about 5% of this area is now under cultivation, while the remaining area is mainly saline, rocky or occupied by salty lakes. The only source of water for irrigation used in siwa depression is ground water.

Spatial Extent and Sampling :

The area under study is a part of Siwa oasis (Western Desert) with an estimated area of about 1500 fed. Fig. (1). A detailed soil survey was carried out, using topographic map (1:25000). Thirty six soil samples were taken according to grid system with interval 350m. The location of the area and soil surface samples are shown in Fig. (1).

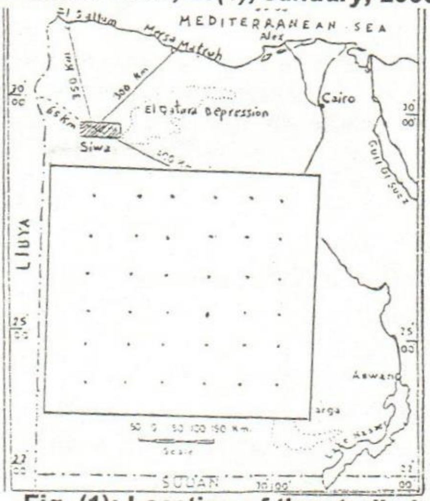

Fig. (1): Location of the studied area.

Laboratory analysis:

The soil samples were air dried, crushed with a wooden pestle, and sieved through 2 mm sieve. Chemical and physical analyses were carried out according to Page *et al.*, (1982). Particle size distribution was determined by using dry sieving.

Statistical analysis:

Mean, minimum, maximum, variance, standard deviation, skewness, kurtosis and coefficient of variance were calculated using Systat statistical version 5.1 (Systat, 1990).

Principal component analysis (PCA):

The principal component analysis technique is concerned with the explanation of the variance-covariance structure through a set of linear combinations of the original variables. Its general objectives are data reduction and interpretation. The principal components were derived as the eigenvectors associated with each of the eigenvalues of correlation matrix of the studied variables. In general, each principal component can be represented in the form:

$$PC_n = A_{11} X_1 + A_{12} X_2 + \dots\dots\dots\dots + A_{in} X_n$$

Where A_n is the correlation between each variable X, and principal component PC_i; and is referred to as loading. (Johnson and Wichern, 1982).

Spatial variability methods:

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 contour maps or isarithms, (Burgess & Webster, 1980 a).

The semi-variogram γ (h) is defined as:

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

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. The quantity γ (h) can be estimated for integer values of h from the data. If the mean of the observations remains constant over distances d, then provided h less than d the semi-variance is half the expected squared difference between values at that lag:

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

An estimate semi-variance function is given by:

$$\gamma^{*}(h) = \frac{1}{2n(h)} \sum_{i=1}^{n(h)} [Z(X_1+h)-Z(X_1)]^2 \qquad (3)$$

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

The obtained semi-variogram values for each lag were fitted to one of the semi-variogram functions using the GS^{+} geostatistical analysis software, Gamma Design (1990). A spherical, (a), Gaussian, (b), and exponential (c) semi-variogram, models are given by the following equations respectively:

(a) i-

$$\gamma(h) = C_{\circ} + C[1.5\frac{h}{A_{\circ}}) - 0.5(\frac{h}{A_{\circ}})^3], \qquad for \qquad h \le A_{\circ}$$

ii-

$$\gamma(h) = C_{\circ} + C \qquad (4)$$

(b)

$$\gamma(h) = C_{\circ} + C[1 - \exp(\frac{3h^2}{A_{\circ}^2})] \qquad (5)$$

(c)

$$\gamma(h) = C_{\circ} + C[1 - \exp(\frac{-h}{A_{\circ}})] \qquad (6)$$

where γ is the semi-variogram, C_0 is the nugget variance, C_0+C is the sill variance, A_0 is the range distance, and h is the lag distance.

The nugget (C_0) is the semi-variogram values due to short scale or inherited variability. The range (A_0) is the distance at each of the semi-variogram reaches its maximum, after which there is no spatial dependence among the samples occurs, and within it interpolation is worthwhile; and the sill (C_0+C) is the plateau (constant value) which the semi-variogram reaches, (Issaks and Srivastava 1989, and Warrick *et al.*, 1986).

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 give values $z(x_i)$, i =1,2, ….,n; then the estimate at point β will be the linear sum, so that,

$$Z(\beta) = \lambda_1 Z(X_1) + \lambda_2 Z(X_2) + \ldots\ldots\ldots\ldots + \lambda_n Z(X_n) \qquad (7)$$

Where the λ_i are the weights associated with the sampling points. The estimate is unbiased since.

$$E[Z(\beta)-Z(\beta)] = 0 \qquad (8)$$

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

$$\sum_{i=1}^{n} \lambda_i = 1 \tag{9}$$

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

$$\sigma_E^2(\beta) = E[|\bar{Z}(\beta)|^2]$$

$$\sigma_E^2(\beta) = 2\sum_{i=1}^{n} \lambda_i \bar{\gamma}(X_i, \beta) - \sum_{i=1}^{n} \sum_{j-1}^{n} \lambda_i \lambda_j \gamma(\beta_i \beta_j) \tag{10}$$

where: $\gamma^{-}(X_i\text{-}\beta)$ is the average semi-variance between x_i and the point to be estimated β, and γ (β_i, β_j) is the average semi-variance within the block. In punctual kriging, the last term = 0. Kriging maps were produced and drawn using the software, Surfer (1994).

RESULTS AND DISCUSSION

Descriptive classical statistical:

Table (1) summarizes the descriptive statistical analysis for all the variables, and shows that the highest coefficients of variation (c.v.) were 2.09, 2.07, 1.54, 1.50, 1.47, 1.43, 1.40, 1.18, 1.13, 1.06, 0.90, 0.78, 0.76 and 0.73 for K^+, SO_4^-, Cl^-, Na^+, EC, HCO_3^- gravel, Mg^{++}, Ca^{++}, V.F.S., SAR, $CaCO_3$, F.S. and V.C.S. respectively.

Table(1): Descriptive statistics for surface soil properties.

Variable		Mean	Sta. Dev.	Min.	Max.	Variance	C.V.	Sk.	Ku.
No.	Description								
1	Depth (cm)	87.29	19.15	40.00	110.00	366.68	0.22	- 0.64	- 0.03
2	pH	7.73	0.34	7.00	8.50	0.11	0.04	0.17	- 0.22
3	EC((dS/m^{-1})	43.99	51.50	1.30	185.00	2652.39	1.47	1.95	2.44
4	Ca++(meq/l)	53.46	60.49	4.10	286.10	3659.19	1.13	2.18	5.03
5	Mg++(meq/l)	39.37	46.56	3.70	155.60	2168.01	1.18	1.51	0.87
6	Na+(meq/l)	184.35	276.99	2.90	1180.20	76721.68	1.50	2.18	4.04
7	K+(meq/l)	15.26	31.86	0.70	125.00	1015.18	2.09	2.77	6.20
8	HCO_3	28.37	40.61	1.40	140.00	1649.07	1.43	1.72	1.35
9	Cl^-	185.28	285.90	10.00	1220.00	81739.25	1.54	2.09	3.73
10	$SO_4^=$	213.91	441.69	0.10	2278.00	195093.07	2.07	3.35	12.05
11	SAR	20.99	18.94	1.40	79.40	358.53	0.90	1.64	2.14
12	$CaCO_3$%	16.97	13.21	1.80	42.10	174.59	0.78	0.63	- 1.10
13	O.M%	0.45	0.33	0.06	1.25	0.11	0.73	1.20	0.14
14	Gravel %	6.22	8.70	0.22	37.90	75.69	1.40	2.29	4.79
15	V.C.S.%	13.89	10.18	2.08	41.50	103.54	0.73	0.99	0.39
16	C.S.%	18.02	8.74	4.28	38.22	76.31	0.49	0.35	- 0.64
17	M.S. %	24.88	11.31	10.11	53.71	127.86	0.46	0.73	- 0.35
18	F.S. %	14.86	11.29	0.15	33.28	127.44	0.76	0.31	- 1.33
19	V.F.S. %	7.85	8.30	0.05	33.89	68.86	1.06	1.35	1..55
20	T.S. %	78.75	15.11	28.48	97.70	228.41	0.19	- 1.11	1..90
21	Silt. %	10.51	6.03	1.18	22.31	36.36	0.57	- 0.01	- 0.76
22	Clay %	9.21	6.59	1.10	29.86	43.27	0.71	0,93	1.00

V.C.S. = Very Coarse Sand (2-1 mm), C.S.= Coarse Sand (1-0.5 mm)
M.S. = Medium Sand (0.5- 0.25 mm), F.S.= Fine Sand (0.25- 0.125 mm)
V.F.S. = Very Fine Sand (0.125-0.063 mm), T.S.= Total Sand
C.V. = coefficient of variation, Sta. Dev. =standard deviation
SK. = Skewness, Ku. = Kurtosis

Principal component analysis (PCA):

Table (2) shows that there are 22 principal components. The first 6 PCA's were selected as their eignvalues (component loading) are larger than 4.55 (100/No. of variables = $\frac{100}{22}$ = 4.545), which explain 80.26% of the total variance.

Eigenvectors reflect the loading of each variable in each component. Only the variables that had an absolute value more than selection criterion S.C (S.C = 0.182, 0.233, 0.263, 0.293, 0.444, and 0.470) were indicated within the first sex PAC's, (Afifi and Clark, 1984).

Table (2): Proportion of total variance explained by each principal component for surface data.

Principal comp. No.	Eigenvalue	Proportion %	Cumulative. Proportion %
1	7.521	30.565	30.565
2	4.610	18.672	49.237
3	3.601	13.052	62.289
4	2.911	7.001	69.290
5	1.269	6.328	75.618
6	1.134	4.642	80.260
7	0.967	3.202	83.462
8	0.865	3.106	86.568
9	0.744	2.036	88.604
10	0.515	2.081	90.685
11	0.423	1.861	92.549
12	0.288	1.456	94.005
13	0.261	1.365	95.370
14	0.202	1.243	96.613
15	0.190	0.906	97.519
16	0.125	0.810	98.329
17	0.084	0.521	98.850
18	0.061	0.396	99.246
19	0.053	0.298	99.544
20	0.040	0.286	99.930
21	3E-5	0.048	99.978
22	3E-6	0.022	100.000

Component loading = 100/22 = 4.545

Data in Table (3) show very high variability for gravel, Na^+ SAR and EC, and high variability for Ca^{++}, K^+, Cl^-, very fine sand and coarse sand. These results agreed with the descriptive statistical analysis.

Semi-Variogram of the variables:

Three semi-variograms were mainly fitted to the individual soil properties, namely, spherical for Soil depth and Ca CO_3%, Gaussian for EC and SAR, and Exponential for O.M% and Sand %. The parameters of these models for different soil properties are shown in Table (4). It 'is clear that EC, SAR, depth and total sand has the highest nugget variance of 2460, 324, 167 and 122.11 which indicate their strong spatial dependence and high inherited variability, (Warrick *et al.*, 1986).

Table (3): Eigenvectors of the correlation matrix for parameters of samples.

Soil Property		Principal Components					
		1	2	3	4	5	6
1	Depth	0.601	-	-	-	-	-
2	PH	0.589	-	0.389	-	-	-
3	EC	0.652	0.593	0.442	-	-	-
4	Ca^{++}	0.796	0.802	-	-	0.462	-
5	Mg^{++}	-	0.523	0.441	-	-	-
6	Na^{+}	0.356	-	0.459	-	0.561	0.569
7	K^{+}	-	0.482	0.336	0.542	-	-
8	HCO_3^{-}	0.467	0.582	-	-	-	-
9	Cl^{-}	0.660	0.488	-	0.530	-	-
10	SO_4^{--}	0.367	-	-	0.486	-	-
11	SAR	0.450	0.553	0.480	-	0.612	-
12	$Ca\ CO_3$	0.782	-	0.665	-	-	-
13	O.M	0.371	0.286	-	-	-	-
14	Gravel	0.467	0.389	0.411	-	-	0.541
15	V.C.S	0.510	0.428	-	-	-	-
16	C.S	0.651	-	0.428	0.383	-	-
17	M.S	0.481	0.291	-	-	-	-
18	F.S	-	0.330	0..371	-	-	-
19	V.F.S	0.283	-	0.411	-	0.446	-
20	T.S	0.364	-	-	-	-	-
21	Silt	0.461	-	-	-	-	-
22	Clay	0.581	-	-	-	-	-
S.C*		0.182	0.233	0.263	0.293	0.444	0.470

* Selection Cariterion = $\frac{0.5}{\sqrt{\Pr incipal..component..eigenvalue}}$

Table (4): Semi-variogram parameters of the investigated soil properties.

Soil properties	Model	Co Nugget	Co+ C Sill. Var.	Ao Range	r^2
Depth (Cm)	Spherical	167.00	443.4	531.0	0.67
$Ca\ CO_3$ (%)	Spherical	0.01	191.0	540.1	0.91
EC (ds.m^{-1})	Gaussian	2460.00	457.0	275.3	0.36
SAR	Gaussian	324.00	534.9	124.4	0.60
O.M (%)	Exponential	0.05	0.1	619.0	0.37
Sand (%)	Exponential	122.10	205.9	616.0	0.48

Co+C = Sill variance

Fig. (2) illustrates the semi-variogram models for some soil properties. From the above discussion we can concluded that, if we want to study the variability of this area in the future, the maximum interpolation distance for $CaCO_3$, depth, EC, SAR, O.M and sand are 540.1, 531.0, 275.3, 124.4, 619 and 616 meters, respectively.

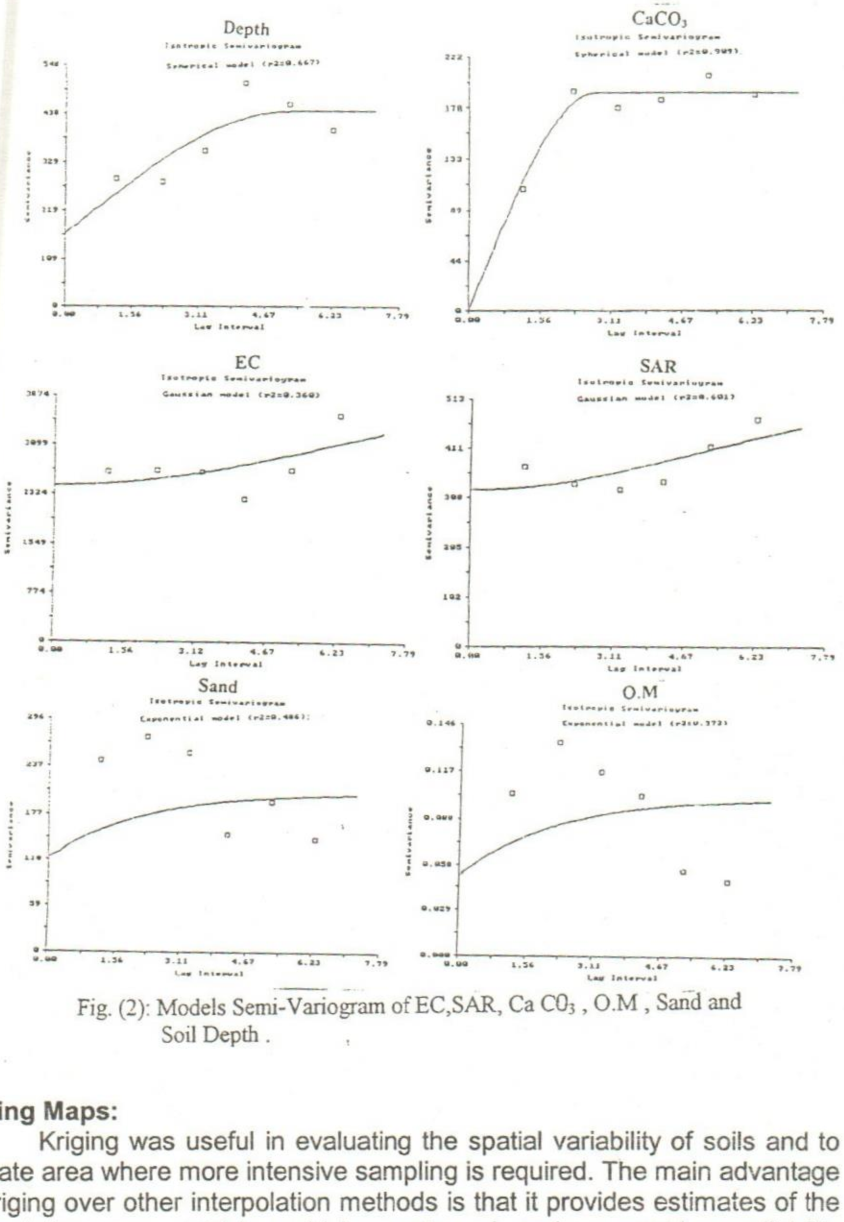

Fig. (2): Models Semi-Variogram of EC,SAR, Ca $C0_3$, O.M , Sand and Soil Depth .

Kriging Maps:

Kriging was useful in evaluating the spatial variability of soils and to indicate area where more intensive sampling is required. 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). Studied soil properties variables were used to produce Kriging maps. Punctual Kriging method was used in this analysis Fig. (3) show the kriged spatial distribution of studied soil properties. The information taken from the semi-variogram model for each property was used in drawing the isarithmic maps for these properties, indicating its spatial distribution.

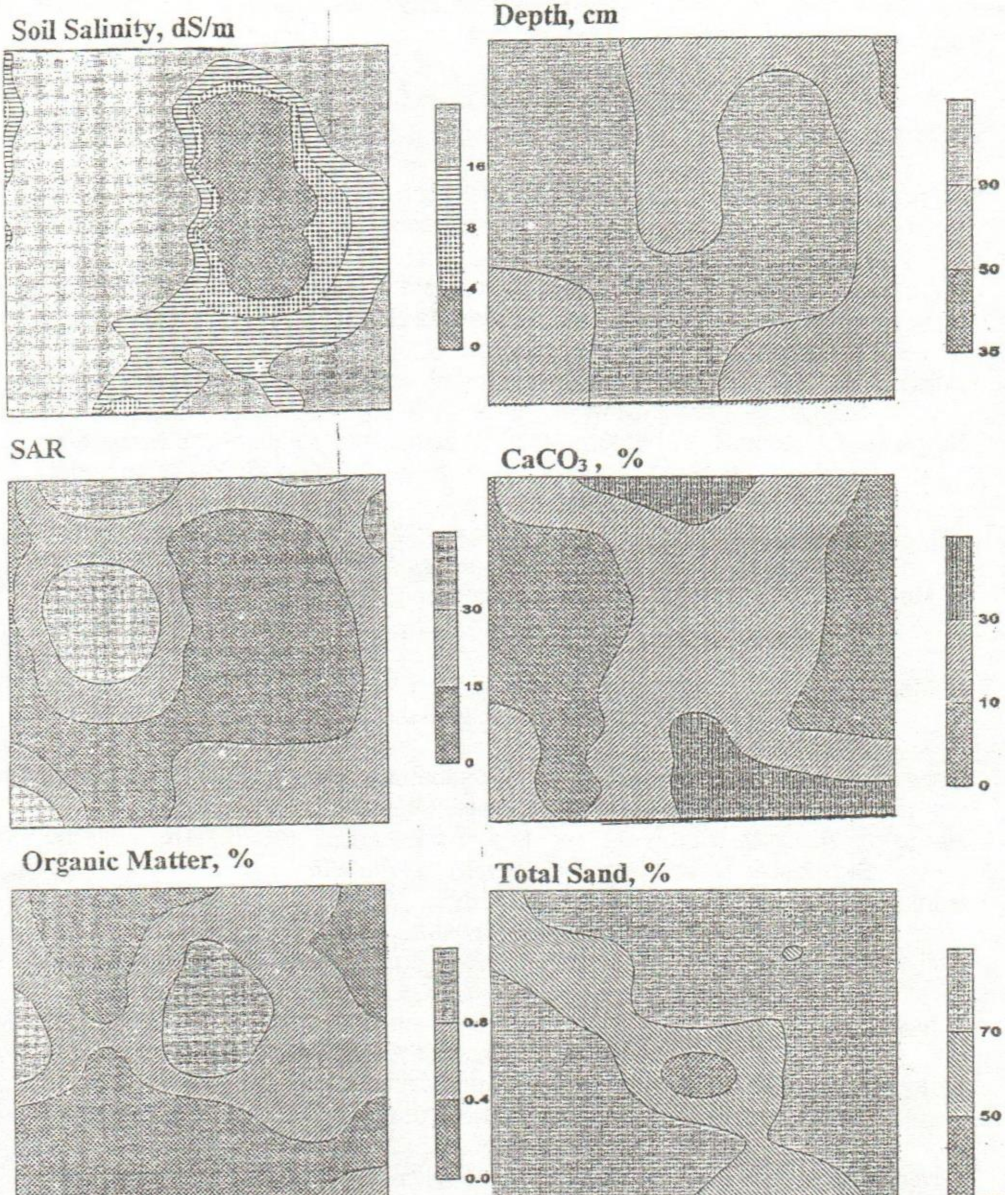

Fig. (3): Kriged spatial distribution of soil salinity, SAR, CaCO$_3$, total sand, depth and organic matter for studied area

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تحليل الاختلافات لبعض أراضى واحة سيوة باستخدام تحليل المكونات الأساسية

عبد العزيز بسيونى المنشاوى
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أجرى حصر لبعض أراضى واحة سيوة (١٥٠٠ فدان) خلال الفترة من (٢٠٠١ إلى ٢٠٠٢م). تم قياس خواص العينات الأرضية السطحية لـ٣٦ عينه سطحية والتى اختيرت على نظام شبكى بفاصل رأس ٣٥٠ متر . تم تحليل النتائج إحصائيا وإحصائى مكانى لتحديد درجة وطبيعة الاختلافات الفراغية فى خواص التربة . وأوضح التحليل الإحصائى التقليدى أن معامل الاختلاف كان (٢,٠٩ ، ٢,٠٧ ، ١,٥٤، ١,٥٠، ١,٤٧، ١,٤٣، ١,٤٠، ١,١٨ ١,١٣ ، ١,٠٦ ، ٠,٩٠ ، ٠,٧٨ ، ٠,٧٦ و ٠,٧٣) للبوتاسيوم والكبريتات والكلوريد والصوديوم والتوصيل الكهربى والبيكربونات والحصى والكالسيوم والمغنسيوم ومكون الرمل الناعم جداً ونسبة الصوديوم المدمص وكربونات الكالسيوم ومكون الرمل الناعم ومكون الرمل الخشن جداً على التوالى . وقد تم أجراء تحليل المكونات الأساسية (PCA) ووجد أن السته مكونات الأولى تساهم بحوالى ٨٠,٢٦% من التباين الكلى . وقد تم عمل اختزال الخواص المقاسة للوصول إلى الخواص الأرضية ذات التباين العالى وقد توافقت هذه النتائج مع نتائج معامل الاختلاف . وكان شكل الـ Semi-variogram للخواص الأرضية كالتالي :-

- Spherical لعمق القطاع الأرضى ومحتوى الأرض من كربونات الكالسيوم الكلية.
- Gaussian للتوصيل الكهربى ونسبة الصوديود المدمص.
- Exponential لمحتوى الأرض من المادة العضوية وكذلك مكون الرمل الكلى.

وقد أظهر التوصيل الكهربى ونسبة الصوديوم المدمص وعمق القطاع الأرضى ومكون الرمل الكلى أعلى Spatial dependence حيث كان Nugget variance مساويا ٢٤٦٠ و ٣٢٤ و ١٦٧ و ١٢٢,١ على التوالى . ولدراسة هذه الخواص مستقبلا لهذه المنطقة تكون المسافات المناسبة لأماكن أخذ العينات على النحو التالي ٥٤٠,١ و ٥٣١,٠ و٢٧٥,٣ ١٢٤,٤ و ٦١٩,٠ ٦١٦ متر على الترتيب لكل من محتوى الأرض من كربونات الكالسيوم الكلية وعمق القطاع الأرضى والتوصيل الكهربى ونسبة الصوديوم المدمص ومحتوى الأرض من المادة العضوية وكذلك مكون الرمل الكلى. وقد تم رسم خرائط الـ kriging لبعض الصفات السابقة مستخدما النتائج المتحصل عليها من الـ Semi-variogram .