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Soil Salinity Mapping in North and South Bahariya Oasis Using Geostatistics

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BAHARIYA OASIS faces a sever constraint in availability of good agricultural land. It is obvious that land use planning has to be adapted. It is recognized, that the major limitations were associated to high salinity of the soil. Estimating spatial variability of soil salinity is an important issue in precision agriculture. Geostatistical methods provide a means to study the heterogeneous nature of spatial distributions of soil salinity. Block kriging was applied to estimate EC measurements in the fields north and south of Bahariya. These EC salinity spatial data were analyzed for autocorrelation and then used this information to make optimal, statistically rigorous maps of the area sampled. In kriging, more easily measured data sets of electrical conductivity (EC) were incorporated to improve the estimation of salinity state. The estimated spatial distributions of EC using the geostatistical methods with various reduced data sets were compared with the extensive salinity measurements in the large field. There are different original factors have influenced the final output of the kriging logarithm technique especially in the southern study area. Improving those factors would play a good role for obtaining more accurate results. The results suggest that sampling cost can be dramatically reduced and estimation can be significantly improved using kriging technique. Based on the results of salinity mapping, improvement of land use should be assessed (*i.e.*, leaching requirements).

Keywords: Soil salinity, Spatial variability, Nugget effect, Semivariograms, Ordinary kriging.

Bahariya Depression is located nearly in the middle of the Western desert of Egypt and comprising a total area of approximately 2250 km^2 (Fig.1). The depression is surrounded by plateau escarpment. The floor of the depression consists of sandstone, clays and marls. The area falls under the arid condition as the total rainfall is (3-6) mm/year. Springs and wells are the main two groundwater resources for irrigation and civic purposes (Salem, 1987). Based on US Soil Taxonomy (1999) six taxonomic units (at great group level) were identified in the study areas; Torripsamments, Pasmmaquents, Torrifluvents, Torriorthents, Salorthids, Calciorthids (Darwish, 2004).

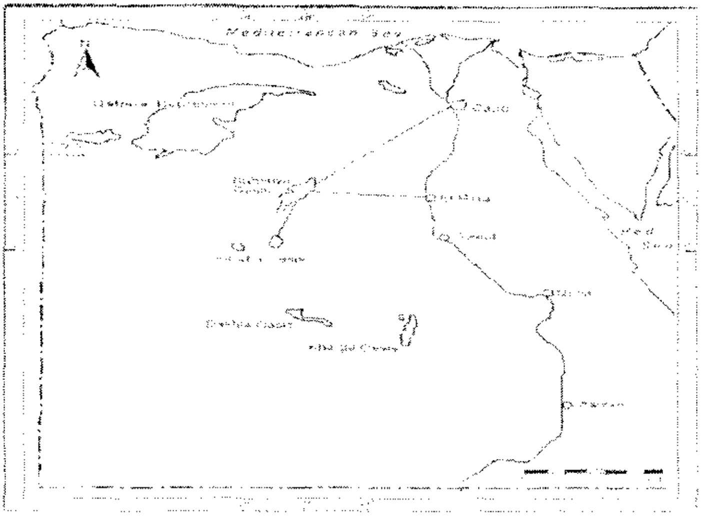


Fig. 1. Location of Bahariya Oasis.

In Bahariya, it is found that the main unsuitability criteria restricting and eliminate more extend of additional areas for cultivation is the excess of salts. A salt-affected soil is a major soil degradation process affecting the agricultural productivity in the Egyptian soils (Darwish, 1998). Accumulation of salts in the soils can be caused by natural processes "primary salinity" human action "secondary salinity" or effects of "fossil salts" (Hinrich & Bohn, 1985). In Bahariya, although irrigation has greatly increased the agricultural production potential, a rise in water table results when irrigation-induced recharge is greater than the natural discharge. In many irrigated areas rising water tables have subsequently led to water-logging and associated salinity problems.

Detection, delineation and mapping of saline and alkaline soils are the first steps for the amelioration processes of salt-affected soils. The heterogeneous distribution of the soil characteristics was called the soil spatial variability. The spatial variability of soil makes it difficult to get precise information from soil. More detailed and accurate information of soil were asked due to the requirement of management and sustainable utilization for agricultural soil. Therefore, more attention was paid to studying the spatial variability of soil as an important component part of precision agriculture (Paz-Gonzalez, 2000).

Lesch *et al.* (1992) mapped spatial variation of soil salinity on the field scale using geostatistical approaches. However, where there is a lack of spatial autocorrelation, a statistical calibration technique based on multiple-linear regression for predicting multiple depths, field scale spatial distribution of soil ECe is more appropriate (Lesch *et al.*, 1995).

This study aims to delineate and map the salinity limiting factor pronounced by EC (dS/cm) measurements that rating some areas as unsuitable for crop production in Bahariya, using geostatistics. It will be important for soil management and enhancement of crop yield to study the spatial variability of soil salinity measurements, to draw the precise map with soil information (Beckett & Webster, 1971) and to make the regime of the spatial variability of soil characteristics quite clearly, especially for carrying out precision agricultural in the future.

Material and Methods

General situation of experimental area(s)

In this research, two study areas were selected. One is in the north of Bahariya covering an area of about 118.3km^2 and the second is covering partly the southern part of it with an area of 77.5km^2 (Fig.2).

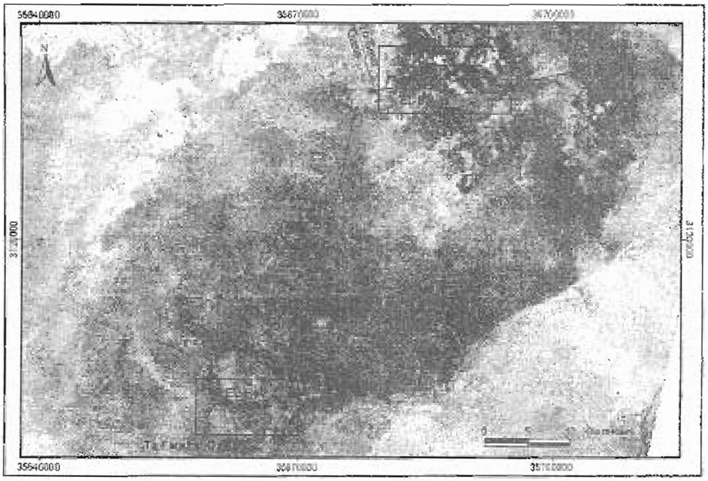


Fig. 2. The study areas in N and S Baharyia.

Based on the pre-field and information obtained, 45 soil profiles and 71 soil augers were examined in different locations. Some proposed observations were added at the edge of the study areas to reduce the error of missing information.

Figures 3a and 3b show the location of the observation sites where soil samples were taken. Four transects in area1 and two in the southern one. Soil salinity measurements (ECe) dS/cm were determined in the soil water extract out of the saturated soil paste.

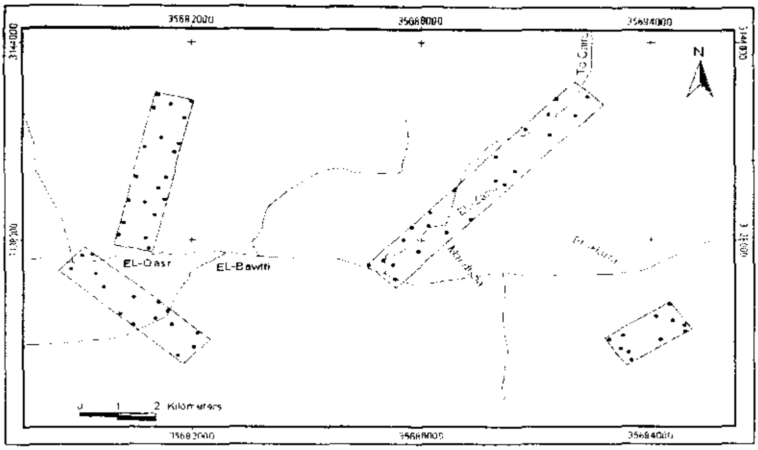


Fig. 3a. Location of sample points in study area 1 (North).

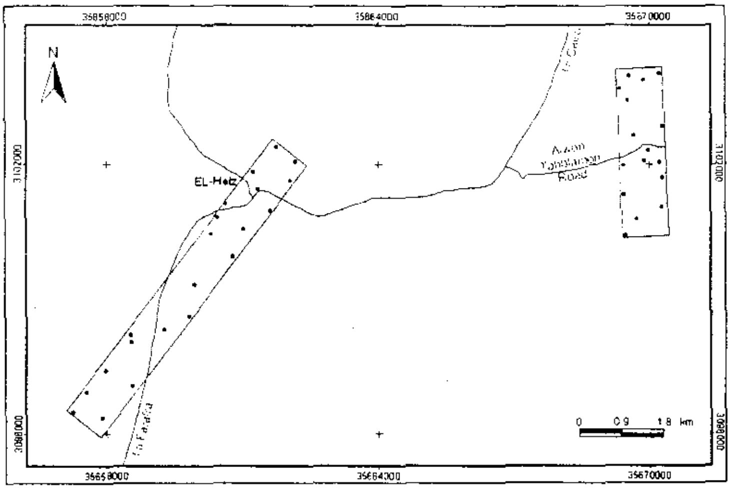


Fig. 3b. Location of sample points in study area 2 (South).

The determination of the sampling pattern

Total of six sample areas were selected and distributed over the study areas with a fixed wide of 1km for each. The exact locations of the soil profiles and auger points were precisely defined in the field by using the DGPS "System Cooperation MAGELLAN"-GPS NAV DLX-10 TM, and plotted on the maps.

Briefly, the steps in a geostatistical study include: (a) exploratory data analysis (b) structural analysis (calculation and modeling of variograms) (c) making predictions (kriging or simulations).

Figures 4a and 4b show the frequency distribution of EC (dS/cm) values in study area 1 and 2 respectively. The first one exhibit abnormal distribution, while the second is normally distributed, which does not deemed *Ln* transformation prior to kriging. Although the *Ln* transformation EC semivariogram can give a better fitting, when using it for kriging purposes the problem of back transformation of the kriged estimated is limiting its usability.

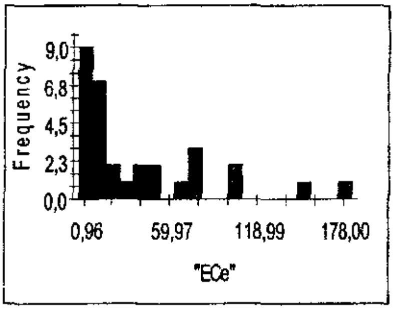


Fig. 4a. Frequency distribution of ECe values in area 1.

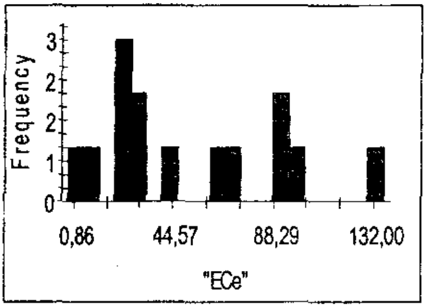


Fig. 4b. Frequency distribution of ECe values in area 2.

Method of geostatistical analysis

The spatial variability of EC data was analyzed using semi-variance function. The correlation lag range of soil salinity EC values was determined according to the sill of semivariogam and the spherical models were set up. And then, the spatial distribution maps of EC in the two areas were drawn by using Kringing interpolation.

Semi-variance function method

Semivariance function is used to measure the degree of variation in soil characteristics ECe between sampling points and to determine the reasonable space of sampling.

Semivariance is an autocorrelation statistic defined as:

$$\gamma(h) = [½\, N(h)]\, \Sigma\, [\, z_i - z_{i+h}\,]^2 \qquad (1)$$

where

$\gamma(h)$ = Semivariance for interval distance class *h*;

z_i = measured sample value at point *i*;

z_{i+h} = measured sample value at point *i+h*; and

N(*h*) = total number of sample couples for the lag interval *h*.

Semivariance is evaluated by calculating γ (h) for all possible pairs of points in the ECe data set and assigning each pair to an interval class *h*. The Lag Class Distance Interval defines how pairs of points will be grouped into lag classes.

It is found that the distribution of the ECe measurements in spatial for area 1 and 2 is isotropic or direction-nondependent geometric model. The isotropic model can be described based on three parameters:

- Nugget Variance or C_0
- Sill or C_0+C – the model asymptote
- Range or A – the separation distance over which spatial dependence is apparent. Sometimes this is called the effective range in order to distinguish range (A) from a model's range parameter (A_0).

Spherical isotropic model

The spherical isotropic model is a modified quadratic function for which at some distance A_0 pairs of points will no longer be autocorrelated and the semivario-gram reaches an asymptote. The formula used for this model is:

$$\gamma(h) = C_0 + C\,[1.5(h / A_0) - 0.5(h / A_0)^3] \qquad (2) \qquad \text{for } h \leq A_0$$

$$\gamma(h) = C_0 + C \text{ for } h > A_0 \qquad (3)$$

where

$\gamma(h)$ = semivariance for interval distance class h,

h = the lag distance interval,

C_0 = nugget variance ≥ 0,

C = structural variance $\geq C_0$, and

A_0 = range parameter. In the case of the spherical model, the effective range $A = A_0$.

Sill $C_0 + C$ and correlation lag range h of soil characteristics can be got relying on the semivariograms based on the formula (2). The semivariogams showing the spatial variability of soil salinity data characteristics may be drawn be semi-variance function according to the information obtained from the ECe measurements.

Kriging

Kriging is the technique of making optimal, unbiased estimates of regionalized variable at unsampled locations using the structural properties of the semivariogram and the initial set of data values (Davis, 2003). In this research the ordinary block kriging method was used. Block kriging provides an estimate for a discrete area around an interpolation point. In environmental work block kriging is usually more appropriate. The block is defined as the rectangular area around a point that is not included in an adjacent block.

Results and Discussion

Spatial variability of ECe values in study areas

The statistical results of the ECe measurements for area 1 & 2 are listed in Table 1. The statistical analysis can just explain the sample difference of ECe characteristics in volume and in homogeneity, but it cannot describe the spatial variability difference of the salinity data. So, it is necessary to analyze the spatial variability of the data above by semivariance function.

TABLE 1. Statistical summary of ECe (dS/cm) data.

Items	Mean	Standard Deviation	Sample variance	Min.	Max.
Area 1 (N)	37.27	46.51	2163.06	0.96	178.0
Area 2 (S)	51.26	39.41	1552.79	0.86	132.0

Figures 5a and 5b illustrate the semivariance value of area1 and 2. The sill of ECe in area 1 and 2 are 2622,00m and 1845.00m and their correlation lag range 3960.0m and 1150.0m respectively.

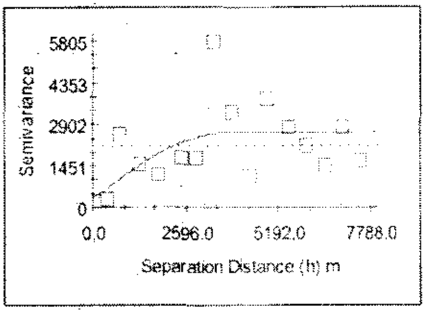


Fig.5a. Isotropic variogram (spherical model) of ECe (dS/cm) in area 1.

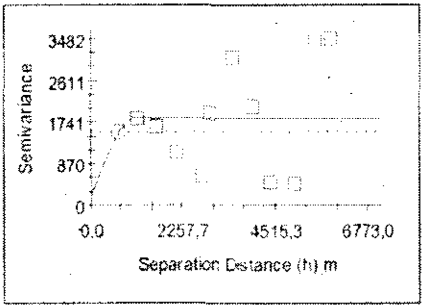


Fig.5b. Isotropic variogram (spherical model) of ECe (dS/cm) in area 2.

The sampling interval can be determined based on the semivariograms. This proves the existence of correlation between spatial variability of the soil salinity data, which belongs to nugget effect.

The variogram shows a relative nugget effect of 11.7% for study area 1 and 10.0% for area 2, which cloud be calculated through this ratio $[(C_0/(C_0 + C)) \times 100]$ between nugget variance and sill. This variability caused by random factors. The nugget effect looks more significant in study area 2 than area 1. The correlation lag range of area 2 was obviously smaller than that of area 1 in the north of Bahariya.

According to the forgoing discussion, the salinity status in the study areas is closely related to the position in the landscape. Thus, the variogram analysis can be used to investigate the spatial structure of this primary variable. This analysis, based on samples distributed over the investigated areas, is essential before the actual spatial estimation by kriging can be performed. As mentioned before the experimental variograms calculated on the EC data were well fitted to the spherical variogram model. Both variograms show some impotent facts:

-They are rising gradually for study area 1 and rapidly for area 2 and then levels off to become constant for larger distances.

-The sill is reached asymptotically as a character of the spherical model.

As a conclusion, the results obtained from the variogram analysis of the EC data indicate that the salinity data show an identical spatial structure. The reason for less fitting of the EC variograms is due to the quite limitation of number of the EC data available, the uneven spatial distribution of the sample localization's and the effect of some extreme EC values.

Spatial interpolation of EC data using kriging

After calculating the semi-variogram parameters and choosing the best variogram model with its building parameters that fit with spherical isotropic model, the ordinary block kriging algorithms was applied to interpolate the EC data using GS^+ program.

The resulting block-kriged maps of EC values for the study areas 1 & 2 are illustrated in Fig. 6a and 6b.

Normally, the smoothness of spatial distribution map illustrated the degree of spatial variability in soil salinity data characteristics. If the degree of spatial variability is small, that means the spatial distribution of soil salinity data is even and less sampling points are needed to draw an accurate soil salinity map; otherwise, more sampling points are needed.

The complicated and less smooth spatial distribution of EC data in study area 1 (Fig. 6a) suggested higher spatial variability of salinity data EC (dS/cm), while, the simple and smooth spatial distribution indicated lower spatial variability of EC data in study area 2 (Fig. 6b).

To assess the accuracy of the kriging estimated maps, there is a cross validation analysis for evaluating effective parameters for kriging. In cross-validation analysis each measured point in a spatial domain is individually removed from the domain and its value estimated via kriging as though it were never there. In this way a graph can be constructed of the estimated vs. actual values for each sample location in the domain. The cross validation analysis of study areas 1 and 2 are presented in Fig. 7a and b.

The regression coefficient, which is describing the linear regression equation is for area1 = 0.1 and for area 2 = -2.2. The standard error of the regression coefficient (SE = 0.39, 1.07 for area 1 & 2 respectively). The r2 value is the proportion of variation explained by the best-fit line (in case of area 1= 0.1% and 27.0% for area 2); and the y-intercept of the best-fit line is also provided. The SE Prediction term is defined as SD x (1 - r2) 0.5, where SD = standard deviation of the actual data (46.5 and 33.7 for areas 1 & 2 respectively).

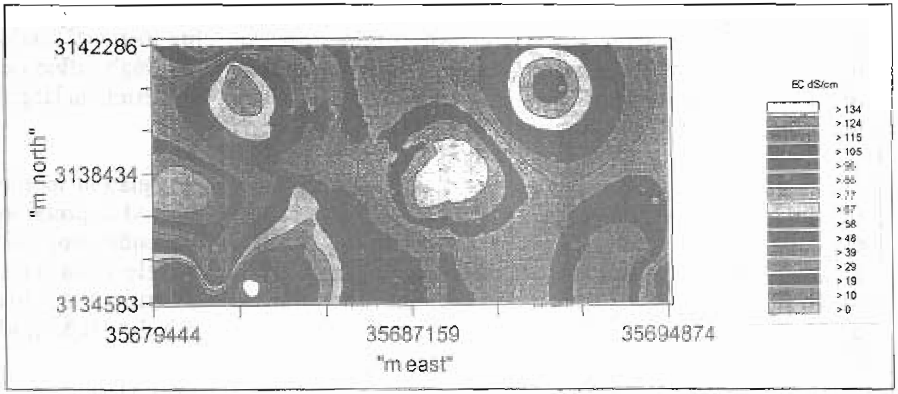


Fig. 6a. Interpolate-Kriging map of the study area 1 north of Bahariya.

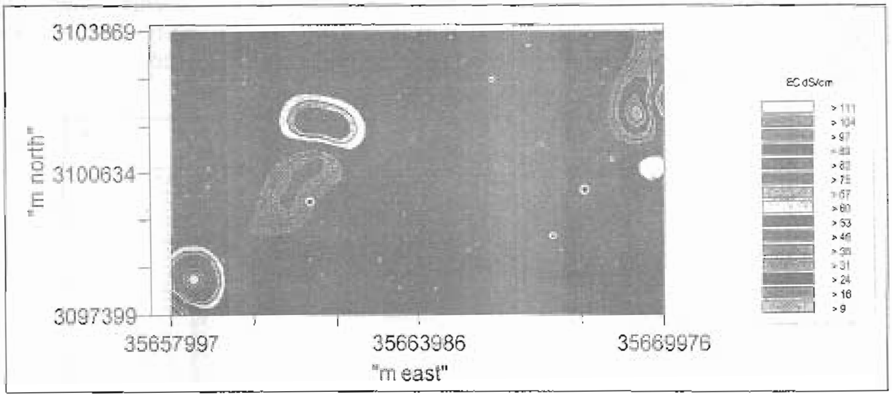
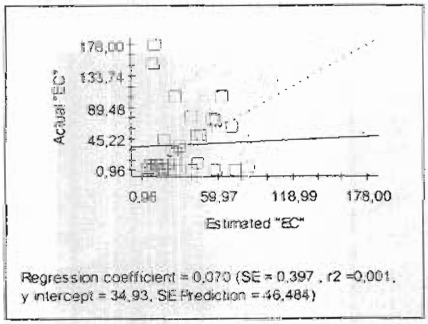
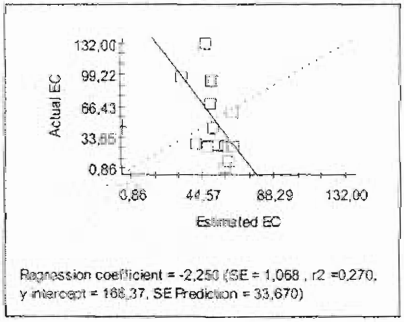


Fig. 6b. Interpolate-Kriging map of the study area 2 south of Bahariya.



Regression coefficient = 0,070 (SE = 0,397 , r2 =0,001, y intercept = 34,93, SE Prediction = 46,484)

Fig. 7a. Cross Validation (Kriging) of study area 1.



Regression coefficient = -2,250 (SE = 1,068 , r2 =0,270, y intercept = 168,37, SE Prediction = 33,670)

Fig. 7b. Cross Validation (Kriging) of study area 2.

It is clear that the spatial variability of area 2 is comparatively less than that in area1. The main reason for this weakness of spatial variability in area 2 could be referred to the lack of EC sampling points available and to the high influence of the EC (dS/cm) extreme values on neighboring locations. This results in larger tendency of the kriged estimates to higher salinity categories.

However, the visual interpretation of both kriged maps in relation to the DEM (digital Elevation Model) grid image of each area give a good impression that the estimation of salinity values is logical, taken into consideration the location from the salt effected soils (playa), the relatively lower elevation units (depressions) and the position in landscape in the Oasis. To demonstrate this quite simply is by overlaying the interpolated kriged maps with the DEM grid image of each area (Fig. 8a1-2 & 8b-1).

Figures 8a-2 and 8b-2 illustrate obviously how the 2D interpolated maps geographically and geomorphologic-ally overlapped. The relatively high EC values that are pronounced and presented as connected counter lines are overlapping the areas where low elevation and much salinity features are available. This quite validating the estimated kriged maps obtained.

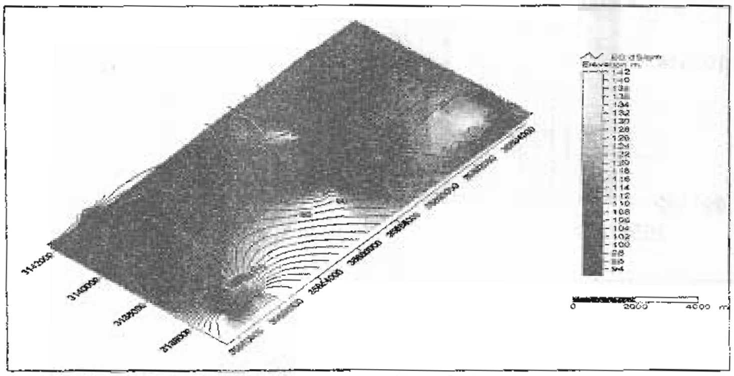


Fig. 8a-1. The kriged map overlaying the DEM of area 1 (North of Bahariya).

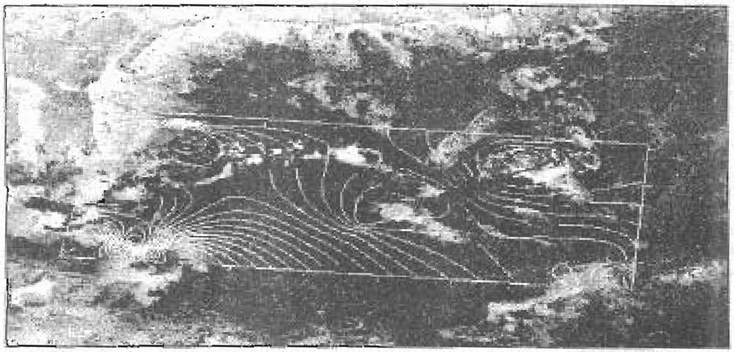


Fig. 8a-2. The kriged map overlaying the DEM grid image of area 1 (North of Bahariya).

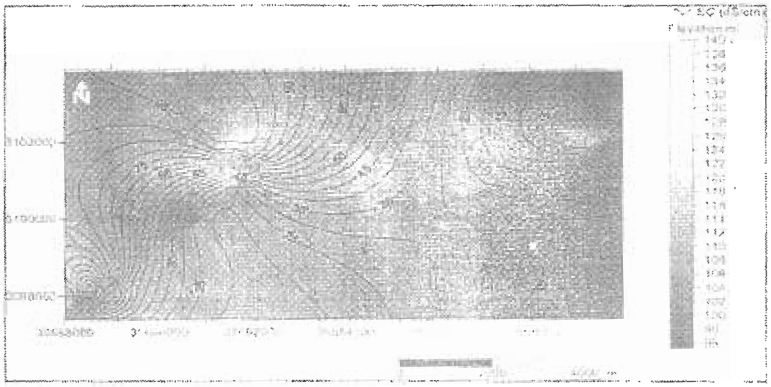


Fig. 8b-1. The kriged map overlaying the DEM of area 2 (South of Bahariya).

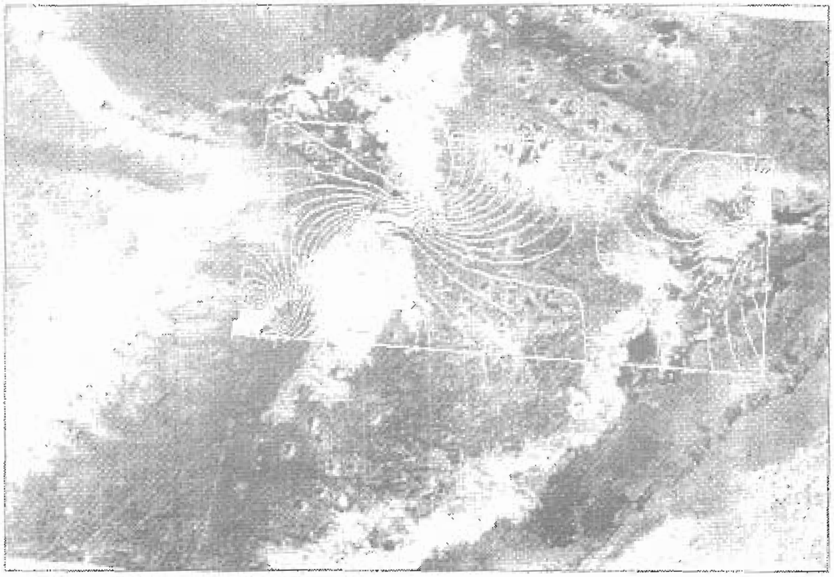


Fig. 8b-2. The kriged map overlaying the DEM grid image of area 2 (South of Bahariya).

Also, the spatial distribution pattern and isotropic variogram model (spherical) of the estimations of both interpolated maps were quite similar.

Conclusion

The spatial distribution maps drawn based on kriging interpolation method explain clearly the spatial variability of soil salinity measurements in north and south study areas of Bahariya oasis.

Indeed, there are different original factors have influenced the final output of the kriging logarithm technique. Those factors can be related to the issues of sampling, the spatial distribution of the soil salinity measurements in the space, the total number of the observation points and the variability of the EC data set obtained.

Improving those factors especially in the south study area 2 would play an important role for receiving more accurate results out of this interpolation method.

The spatial distribution characteristics not only related to the processing of formation, but also related to the result of the specific agricultural production system and mode in Bahariya.

It is worth to mention, that the results suggest that sampling cost can be dramatically reduced and estimation can be significantly improved using kriging technique. Of course, the cost vs. benefit balance of such a detailed approach still needs to be explored.

In addition, consequent studies are recommended relying on the current results including cokriging geostatistical technique.

At the end of the whole procedure, it is still manage successfully to use the obtained interpolated EC salinity maps and to suggest better resource management practices for the selected study areas of Bahariya Oasis.

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استخدام تقنية الأحصاء الجغرافية Geostatistics فى رسم خرائط لحالة ملوحة التربة فى شمال وجنوب الواحات البحرية

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تواجه الواحات البحرية تحديا كبير في توافر الأراضى الزراعية الجيدة الصفات. ومن الهام أعادة النظر فى تخطيط أستغلال الأراضى الزراعية. حيث اتضح ان ملوحة التربة الزراعية تعتبر من المحددات الرئيسية لزيادة انتاجية الأرض بالمنطقة. ويعتبر الأستدلال على التوزيع المكانى السطحى spatial variability لملوحة التربة من الخطوات الهامة لمعالجة هذه المشكلة . فى هذه الدراسة تم الأستعانة بأحدى الطرق الأحصائية وهى Block Kriging للتنبؤ بالتوزيع الفراغى المكانى لقيم التوصيل الكهربى EC الدالة على ملوحة التربة فى المناطق شمال وجنوب الواحات البحرية . بأستخدام Kriging تم دمج قيم EC للتنبؤ ورسم خرائط أفضل لحالة الملوحة بالمنطقة . ثم تم مقارنة النتائج بقيم الملوحة الحقلية المتوفرة ، وقد وجد أن هناك أكثر من عامل أساسى يلعب الدور فى التأثير على النتيجة النهائية لتقنية Kriging اللوغارتمية خصوصا فى منطقة الدراسة الجنوبية و تعديل هذه العوامل من الأهمية فى الحصول على خرائط أكثر دقة.

فى ضوء هذه الدراسة يتضح أن تكلفة تجميع العينات الأرضية يمكن أختزالها بشكل ملحوظ بالأستعانة بتقنية Kriging وكذلك أستنادا على خرائط ملوحة التربة المتحصل عليها من هذه الدراسة أصبح من الضرورى تطوير أستخدام الأرض (ممثلا فى تقدير الأحتياجات الغسيلية الضرورية لمنطقة الدراسة).