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SITE-SPECIFIC RECLAMATION MAPS OF A SALT AFFECTED SOIL IN ISMAILIA GOVERNORATE

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ABSTRACT: Delineation of soil management zones is essential for precision agriculture applications, to know agricultural inputs added to soil. Geostatistics provides an effective tool for soil spatial variability and delineating management zones. Spatial variability was done on soil properties to prepare prescription maps for leaching and gypsum requirements (GR) of a salt affected soil. The performance of the spatial model was evaluated by calculating two different statistics. Mean error (ME) as a measure of precision and mean square standardized error (MSSE) as a measure of accuracy were calculated. The developed spatial maps of investigated soil parameters [electrical conductivity (ECe), exchangeable sodium percentage (ESP) and cation exchange capacity (CEC)] were used to specify 4 zones-prescription maps that need leaching and gypsum requirements. Results showed that the three models were precise and accurate with ME and MSSE values (-0.110, -0.210, 0.002 and 0.937, 1.033, 1.010), respectively. Applying site-specific management for leaching proved cost-effective and beneficial effects compared with traditional management which is based on an average value over the experimental field. The (GR) on basis of traditional management was cost-effective but was not more beneficial because zones 1 and 2 showed GR more than needed and *vice versa* for zones 3 and 4. The high cost in this case could be counterbalanced by the expected increased production in zones with high ESP.

Key words: Kriging, salt affected soils, management zones.

INTRODUCTION

Salt affected soils are found in both arid and semi-arid regions affecting negatively plant growth and consequently low yield (**Eilers *et al.*, 1997**). In Egypt, salt-affected soils are located in the Northern-Central part of the Nile Delta and its Eastern and Western areas. They are also found in Wadi El-Natroun, El-Tal El-Kebeir, the Oases, many parts of the Nile Delta and Valley and Fayoum Governorate. In Egyptian irrigated lands, about nine hundred thousand hectares suffer from salinization, distributed as follows: 60% is in Northern Delta, 20% in Southern Delta and Middle Egypt and 20% in Upper Egypt (**FAO, 2007**). **Herrero and Pérez-Coveta (2005) and Benyamini *et al.* (2005)** affermed the importance of spatial variability of salt affected soil which allow to map and delineate management of zones of saline soils and how much agricultural inputs should be added to such soils. The problem of soil salinity can be solved by leaching soluble salts out of the root zone. Conventionally, data of soil properties are based on averages of soil analyses collected soil samples with no consideration of the spatial variations either at macro or micro scales within-field (**Navarro-Pedreño *et al.*, 2007; Webster and Oliver, 2007**). Geostatistics is an effective tool to assess within field spatial variations of soil analyses used to delineate different management zones (**Oliver and Webster, 2015**). However geostatistical methods are time as well as money saving compared with the traditional methods since they provide a fine-scale information on soil variables. Spatial distribution of soil properties has been evaluated by several

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researchers (**Burgess and Webster, 1980; Warrick *et al.*, 1986; Odeh *et al.*, 1992; Juang and Lee, 2000**). The most common geostatistical prediction method was used to interpolate spatial distribution maps of the different soil properties is the ordinary kriging method (**Meul and Van Meirvenne, 2003; Sumfleth and Duttmann, 2008; Lopez-Granados *et al.*, 2015**).

The current study aimed at evaluating the spatial distribution of soil salinity, sodicity, cation exchange capacity over a field in Ismailia Governorate using ordinary kriging for preparing site-specific management maps of leaching and gypsum requirements.

MATERIALS AND METHODS

Site Description, Sampling and Laboratory Work

This study was conducted on a 1.8-ha field (30°25'47.42''N, 31°39'24.49E) located in El-Kassasseen, Ismailia Governorate, Egypt (Fig. 1). One hundred soil samples from the 0 - 30 cm surface were taken based on a regular grid 20 m x 20 m, for analyses. Analyses included electrical conductivity (EC) which was measured on soil paste extract according to **Jackson (1973) and Slavich and Petterson (1993)**. Cation exchange capacity (CEC) was measured according to the barium chloride (pH 8.2) method, while soluble ions and SAR were measured according to **Jackson (1973)**.

Exchangeable sodium percentage (ESP) was calculated using the following equation:

$$ESP = \frac{100\,(-0.0126 + 0.01475\,SAR)}{1 + (-0.0126 + 0.01475\,SAR)}$$

Cited by **USDA (1954)**.

Geostatistical Analysis

The geostatistical analysis was implemented using ArcMap software 10.1 (USA), which consisted of the following steps:

1. Exploratory data analysis with the purpose of finding out whether the studied soil variables are normally distributed or not.
2. Calculation of the experimental semi-variogram for determining the spatial auto-correlation.
3. Fitting a model to the experimental semi-variogram.
4. Interpolation using ordinary kriging.

Prediction Assessment

For evaluating the performance of prediction, cross validation was used (**Isaaks and Srivastava, 1989**) calculating two statistics to assess the precision and accuracy of estimation of the studied soil variables. The first statistic was the mean error (ME) as a bias indicator and the second was the mean standardized squared error (MSSE) (scaled by the predicted standard deviation of estimation), as an accuracy measure. The equations were as follows:

$$ME = \frac{1}{N}\sum_{i=1}^{N}(z_i - z^*)$$

$$MSSE = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{z_i - z^*}{\sigma}\right)^2$$

Where N is the number of active observations, σ the kriging standard deviation, Z* is predicted value, Zi is measured value.

The first statistic should be close to zero implying that the estimation is unbiased whereas the second statistic should approximately equal 1 because it corresponds to the ratio between an experimental variance and a theoretical one (**Carroll and Cressie, 1996**).

Calculations of Leaching Requirements for Delineated Zones

Reclamation requirement was calculated using **Reeve equation (1975)**, as follows:

$$\frac{D_{iw}}{D_s} = \frac{EC_{ei}}{5EC_{ef}} + 0.15$$

Where D_{iw} is the depth of leaching water (cm), D_s is the depth of soil (cm), EC_{ei} and EC_{ef} are soil salinity (in dSm^{-1}) before and after leaching, respectively. Leaching requirement was calculated to reduce soil salinity to be 2 dS m^{-1} for only zones having a mean value of ECe higher than 4 $dS.m^{-1}$ for 0.20m depth. The mean value and area of each delineated zones were calculated.

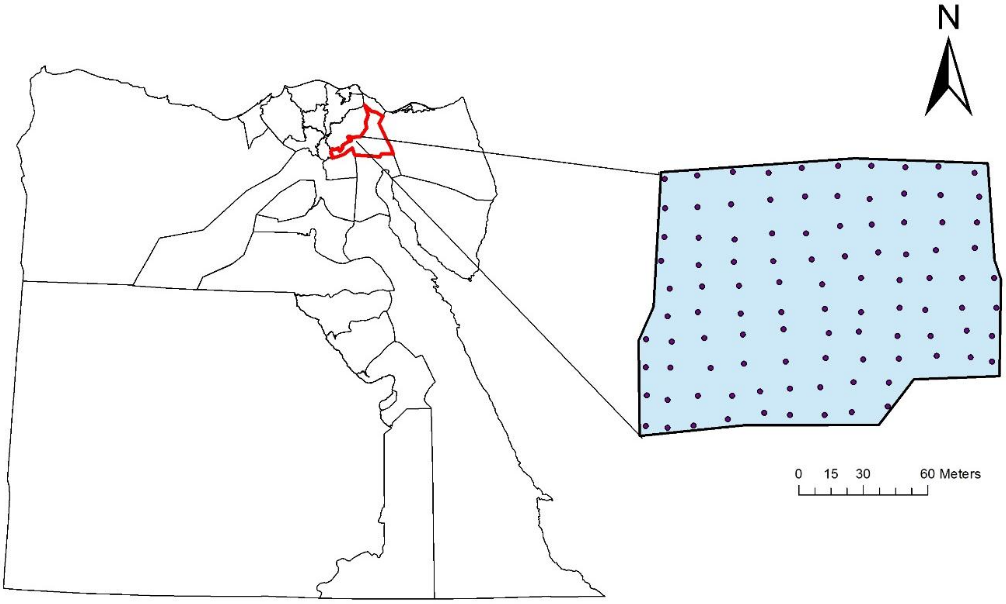

Fig. 1. Site location and soil sampling scheme

The leaching requirements was also calculated based on the average value of all samples (100) to quantify the water saved and make a reliable comparison between the two geostatistical and traditional methods.

Calculation of the Gypsum Requirements (GR) of Each Delineated Zone

GR was calculated based on the average value of ESP and CEC in each delineated zone using the following equation according to (**USDA, 1954**):

$$GR = \frac{ESP_i - ESP_f}{100} \times C_{EC} \times 4.09$$

Where ESP_i is the initial value and ESP_f is the desired value to be reached. The GR is expressed as megagram per hectare (Mg ha^{-1}) for a depth of 30 cm of soil surface.

RESULTS AND DISCUSSION

Results of the descriptive statistics are summarized in Table 1 where the studied soil variables are approximately symmetric since the skewness of ECe, ESP and CEC are 0.42, -0.32 and 0.56, respectively. Then, geostatistical analysis is applied directly without transformation.

Three different models were fitted to the experimental variograms of ECe, ESP and CEC. These were stable, gaussian and spherical models for the soil variables, mentioned above, respectively (Table 2). The nugget to sill ratios indicates a moderate spatial dependence for ECe with a value of 0.312 and a strong spatial dependence for ESP and CEC with values of 0.226 and 0.057, respectively.

Cross-validation results (Table 3) indicated that the three models were precise with ME values of -0.011, -0.210 and 0.002 for ECe, ESP and CEC, respectively. MSSE values were rather different from one but still within the tolerance interval ($\pm 3\sqrt{2/N}$, N is number of observations) (**Chiles and Delfiner, 1999**). However the three studied soil variables showed that the three models were accurate.

Mapping

Soil salinity

The spatial map of ECe shows four delineated zones with different ECe average values (Fig. 5). Zone 1 is characterized as non-saline soil and there is no need to apply leaching process since the ECe average value is less than 4 dSm^{-1}. The other three delineated zones had different mean values of ECe. These were 4.5, 5.93 and 7.64 dSm^{-1} for zones 2, 3 and 4, respectively. Most of zone 1 area was in the Western part of the field which might be due to the close of that area to the drain located in the Western part of the field.

Table 1. Descriptive statistics of soil variables

Statistic	ECe	ESP	CEC
Mean	5.84	32.71	24.34
Standard Deviation	2.07	9.92	4.59
Kurtosis	-0.37	0.48	-0.81
Skewness	0.42	-0.32	0.56
Minimum	2.16	7.46	17.40
Maximum	11.11	52.84	33.00
Count	100	50	50

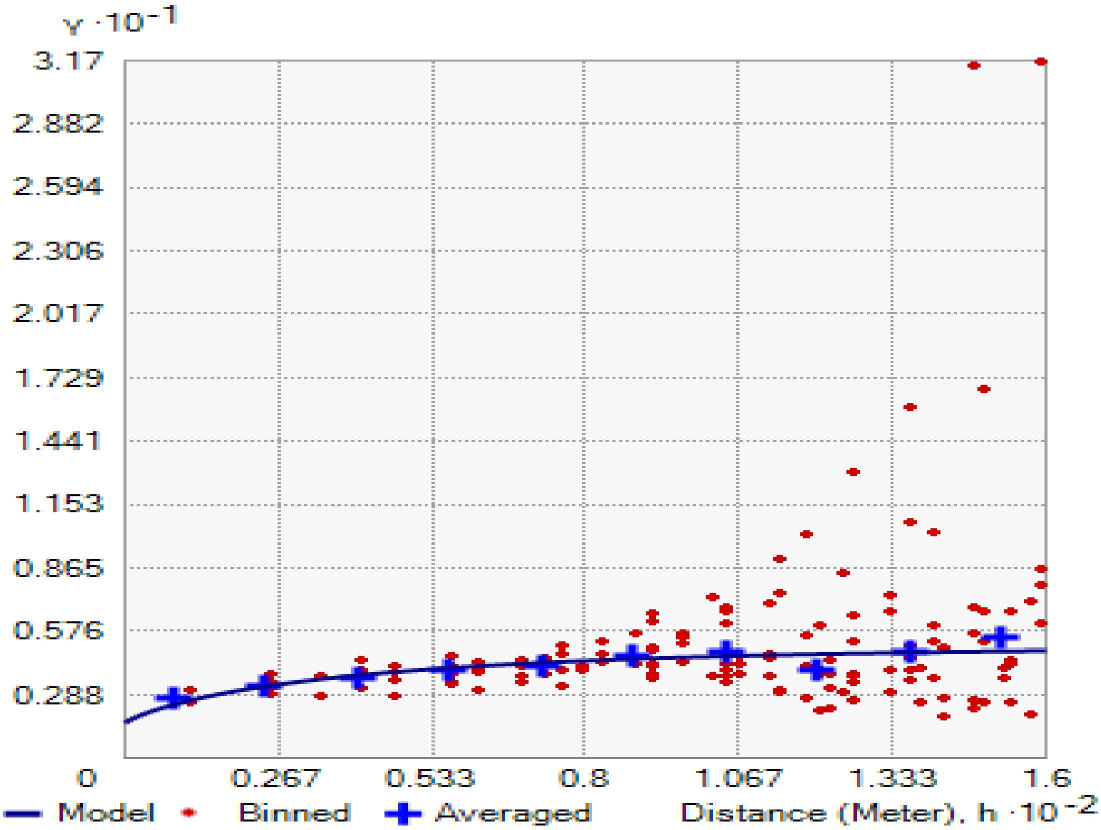

Fig. 2. Variogram model of ECe

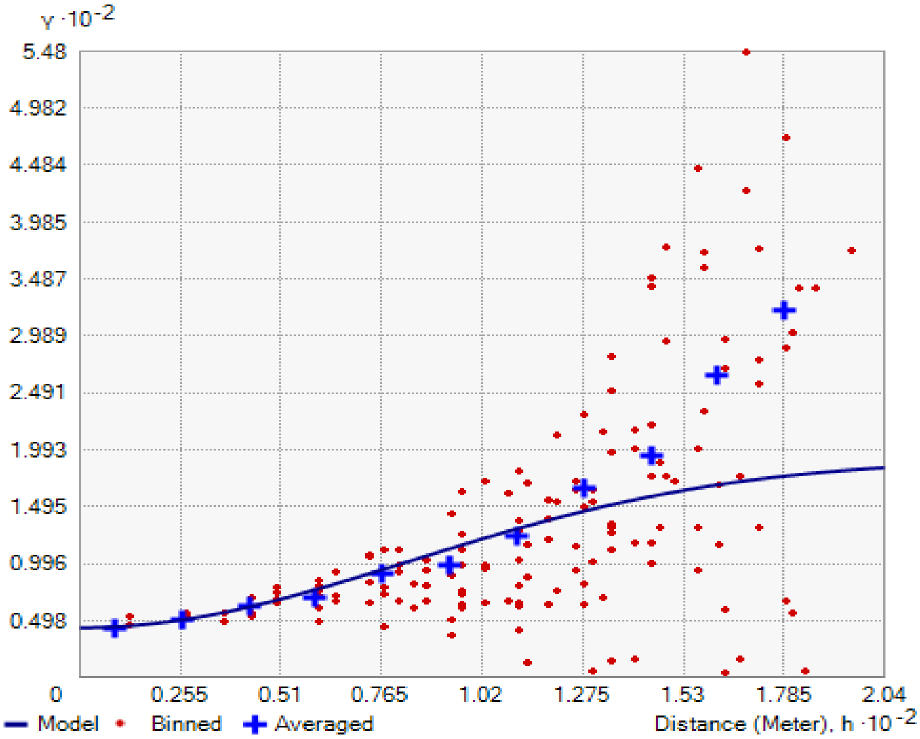

Fig. 3. Variogram model of ESP

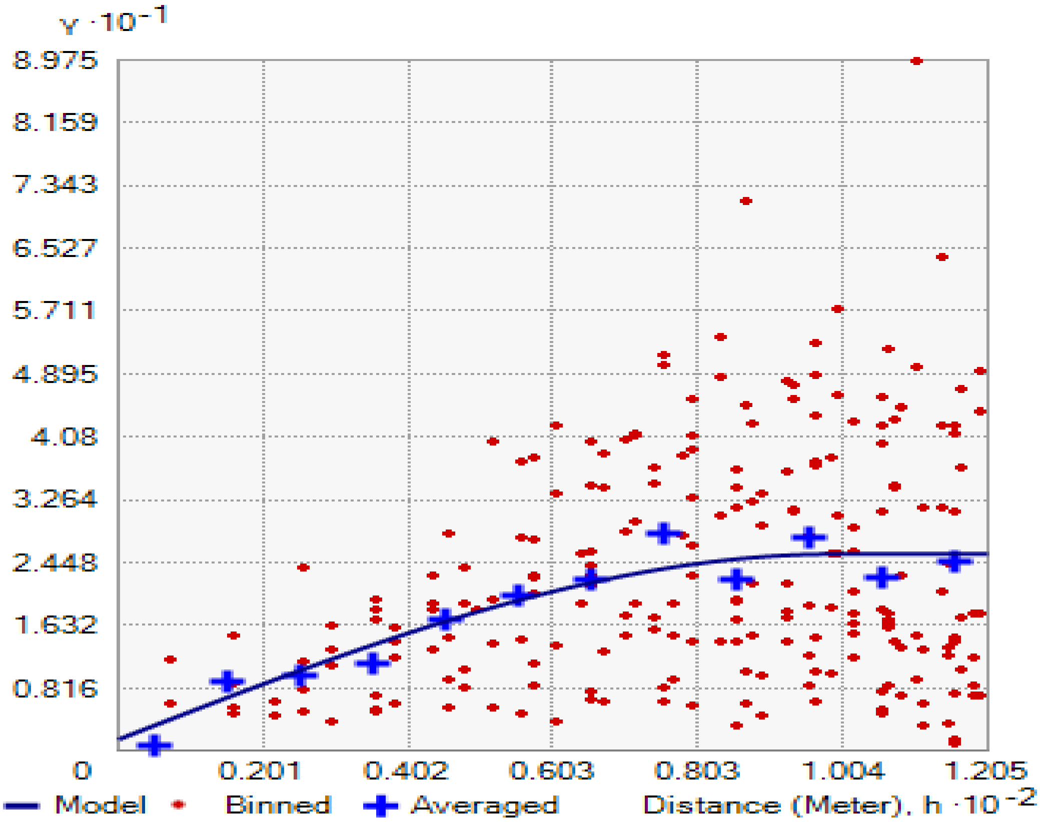

Fig. 4. Variogram model of CEC

Table 2. Variogram model parameters of the studied soil variables

Variable	Model	Nugget effect	Partial sill	Range (m)	Nugget/sill
EC (dS m^{-1})	Stable	1.581	3.471	160	0.312
ESP	Gaussian	43.319	147.597	204	0.226
CEC (cmolc kg^{-1})	Spherical	1.459	24.116	99.29	0.057

Table 3. Cross-validation results

Variable	Count	ME	MSSE	Tolerance intervals
EC (dS m^{-1})	100	-0.011	0.937	0.575 – 1.425
ESP	100	-0.210	1.033	0.575 – 1.425
CEC (cmolc kg^{-1})	50	0.002	1.010	0.400 – 1.600

Leaching requirements (Table 4) revealed that no leaching is needed for zone 1 whereas leachings (for 30 cm soil depth) for zones 2,3 and 4. Leaching water amounts were 646.47, 2009.88 and 1170.28 m^3 for zones 2, 3 and 4, respectively. Such calculations are based on the ECe mean value for 100 soil samples (5.84 dSm^{-1}). Without geostatistical interpolation, a water amount of 4134.91 m^3 of water should be added to reduce salinity of the total area to 2 dSm^{-1}. Thus, 308.28 m^3 can be saved and then used for irrigation. These results emphasize the importance of geostatistical techniques in detecting within field variability and hence applying site-specific management.

Soil sodicity

Fig. 6 shows the spatial map of exchangeable sodium percent (ESP) over the area. Sodicity decreased towards the Southern West diagonal of the area. This may be attributed to the constructed drain network on the Western part of the field which is similar to the spatial distribution of ECe over the field.

A comparison between site-specific and traditional management for gypsum requirements (Table5) was calculated to find out which of them is cost effective or more efficient. Results showed that under site-specific management a total of 53.24 Mg of gypsum are needed to reach an ESP of 5 for the whole field, while under traditional management a total of 49.65 Mg of gypsum are needed to reach an ESP of 5 for the whole field. This means that in this case, traditional management is apparently cost-effective compared with site-specific management. However, the site-specific management is more efficient than the traditional management as the former allows to add the needed amount of gypsum where it is needed. Table 5 shows that zones 1 and 2 under traditional management would receive an amount of gypsum of 2.582 and 15.057 Mg, respectively each of which being more than needed. On the other hand, zones 3 and 4 would receive an amount of gypsum of 19.855 and 12.141 Mg, respectively which being less than needed under site-specific management. Such results indicate that applying site-specific management is more efficient even if traditional management is more economic. The high amount of gypsum under site-specific management could be counterbalanced by the increased production because of remediating soil sodicity especially in zones 3 and 4 which would receive gypsum less than needed.

Conclusions

Reclamation of salt affected soils is usually applied without taking spatial variation of soil salinity and sodicity into consideration. It may be cost-effective and more efficient to manage this on basis of management zones. This needs to recognize soil spatial variability and then delineate management zones. In this study, ordinary kriging was used to develop spatial maps of three soil properties of (ECe, ESP and

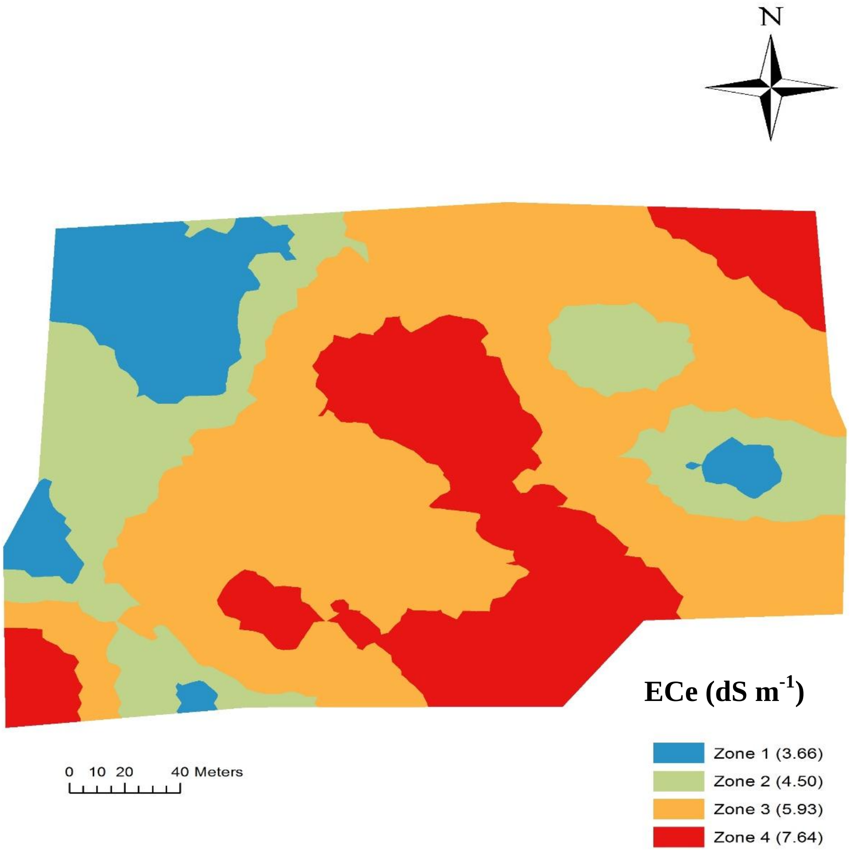

Fig. 5. ECe kriged map with mean value of each zone

Table 4. Leaching requirements for the delineated zones

Zone	Area	ECe (dSm^{-1})	LR (m^3)
1	1901	3.66	------
2	3593	4.50	646.47
3	9017	5.93	2009.88
4	4268	7.64	1170.28
Average		5.84	4134.91
Amount of water saved (m^3)			308.28

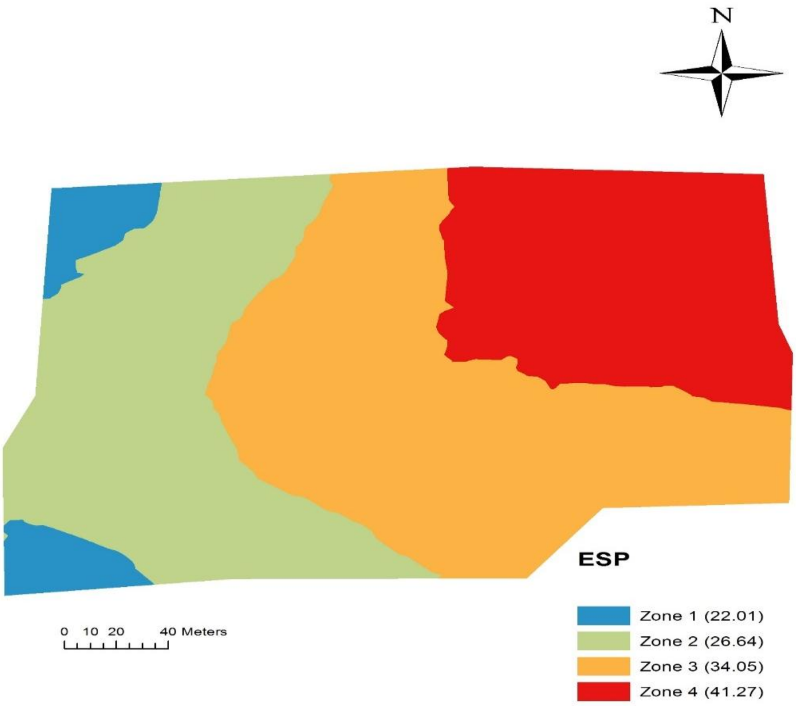

Fig. 6. ESP kriged map with mean value of each zone

Table 5. GR based on both site-specific and traditional management

Zone	Area (m^2)	ESP (%)	CEC ($cmol_c\ kg^{-1}$)	GR Mg/zone based on site-specific management	GR Mg/zone based on traditional application
1	977	22.01	24.00	1.63	2.582
2	5696	26.64	23.12	11.67	15.057
3	7511	34.05	23.14	20.68	19.855
4	4593	41.27	28.23	19.26	12.141
Total samples average	18778	32.71	24.34	53.24	49.65

CEC). A comparison between site-specific management and traditional management was carried out to verify which approach is more beneficial. Results showed that under site-specific management a quantity of water was saved and can be used for irrigation. For gypsum requirement, traditional management was apparently cost effective. However this could be counterbalanced by increased production in zones with high level of sodicity.

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خـــرائـط اســـتصلاح نطاقية لأرض متأثـــــرة بالأمـــــلاح فــي محـافظـــة الإسـماعيليـــة

ريم عبدالرؤف محمد - سامح محمد شداد - عطيات السيد نصرالله - كرم فؤاد موسى

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إن دراسة التباين المكاني لصفات التربة وتحديد مناطق الخدمة ذو أهمية كبرى في تطبيقات الزراعة الدقيقة، حيث يمكن من خلاله تحديد المكان والكمية التي يجب إضافتها من المدخلات الزراعية إلى التربة بهدف رفع إنتاجيتها وتحسين خواصها، حيث تلعب تقنيات الجيواحصاء دور كبير في تقدير التباين المكاني لصفات التربة وتحديد المناطق المتجانسة، يهدف هذا العمل إلى دراسة التباين المكاني لبعض صفات تربة متأثرة بالأملاح وكذلك إنتاج خرائط وصفية للاحتياجات الغسيلية والاحتياجات الجبسية، تم تقدير درجة التوصيل الكهربي، الايونات الذائبة، نسبة الصوديوم المتبادل والسعة التبادلية الكاتيونية، تم استخدام الكرجنج العادي لإنتاج الخرائط المكانية للملوحة، نسبة الصوديوم المتبادل والسعة التبادلية الكاتيونية، أداء النموذج المكاني تم تقييمه باستخدام الـ Cross-validation وذلك بحساب مؤشرين الأول هو متوسط الخطأ mean error كمقياس للانحياز Bias والثاني هو متوسط مربع الخطأ القياسي mean squared standardized error كمقياس لواقعية التنبؤ، قسمت الخرائط المكانية لملوحة التربة ولنسبة الصوديوم المتبادل إلى أربعة مناطق ثم تم إنتاج خرائط وصفية للاحتياجات الغسيلية وللاحتياجات الجبسية، أظهرت نتائج تقييم أداء النماذج المكانية المستخدمة في التنبؤ أنها دقيقة وواقعية، جدير بالذكر أن إدارة الأرض إدارة موقعية في حالة غسيل الأملاح يؤدي إلى تقليل التكاليف مقارنة بالإدارة التقليدية المعتمدة على قيمة المتوسط العام، على العكس في حالة التخلص من صودية التربة فقد كانت الإدارة التقليدية للتربة اقل في تكاليفها عنها في الإدراة الموقعية إلا أن الإدارة الموقعية أكثر كفاءة وبالتالي سوف يؤدي ذلك إلى زيادة الإنتاج والذي بدوره قد يغطي الفرق في التكاليف بل قد ينتج عنه ربح.

المحكمــــــون:

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