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# SPATIAL PREDICTION OF SOIL SALINITY USING ELECTROMAGNETIC INDUCTION TECHNIQUES

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## ABSTRACT

The ability to diagnose and monitor field scale salinity condition has been considerably refined and improved through the use of electromagnetic induction survey instruments. The EMI 400 prediction technique was made using salinity survey data from three separated fields. Three frequencies were used during collecting the measurements (14 KHz, 15 KHz, and 16 KHz). The zigzag orientation was used for measurements distribution. Simple correlation and multiple liner regression models were combined with ordinary kriging to construct field average salinity estimates to produce spatial salinity map. From the multi regression analysis, the EMI 400 reading values at frequency 14KHz justified 74.7% and 89.5% of the variations that existed in the measured EC values for plot 1 and 2, respectively. While the EMI 400 reading values at frequency 15KHz, justified 68.1% of these variation for plot 3.There is a general spectral pattern similarity between EMI 400 readings maps and the estimated ECe maps. This confirms that EMI 400 readings are appropriate for reconnaissance survey to provide a priori spatial information about salinity; allowing allocation of the most and least saline areas. The study shows the usefulness of using electromagnetic sensor (EMI 400) to assess, predict and map soil salinity at field scale.

**Keywords:** Soil salinity, electromagnetic induction, EMI400, EMI400, Beni Suif.

## INTRODUCTION

Soil salinity assessment represents an important component in land reclamation. The need for rapid, cost effective appraisal technique has become critical. The ability to monitor field scale salinity has been improved through the use of electromagnetic induction survey instruments. Sudduth *et al.* (2003), reported that the differences in ECa data collected with different sensors have been more noticeable over soils with highly contrasting layers. Corwin and Lesch (2005), reported that surveys of ECa provide one of the most reliable and comprehensive means for obtaining spatiotemporal information. The development of mobile ECa equipment has made it possible to characterize spatial variability of a variety of electromagnetic properties both rapidly and cost effectively. Amezketa (2007), concluded that there is strong correlation between EMI readings and the measured EC values. The electromagnetically estimated EC values may improve the mapping details, as compared to those maps obtained from the few measured EC values. The detailed salinity map proves very helpful in displaying the spatial patterns of soil salinity and identifying sources/causes of salt-loading. Corwin (2008), noted that the major advantage of EMI is its capacity to produce a large number of georeferenced, quantitative measurements that can be associated with the spatial variability of salinity and sodicity at field and landscape scales. Rongjiang and Jingsong (2010), found that the relationship between soil salinity and electromagnetic induction measurements was calibrated by using GIS and geostatistical technique. Herrero *et al.* (2011), indicated that EMI can be an effective tool for future salinity assessments. Attention should be given to highly saline sites to determine if intensive EMI readings or soil samplings are needed. The good calibrations of the EMI with simultaneous soil samplings could be reduce the number of sites needed to validate the EMI values. Moore *et al.* (2011), converted the electromagnetic induction instrument readings to salinity using a regression derived from field data, and mapping the spatial salinity gradients. Brevik (2012), reported that the electromagnetic induction has been increasingly used to support soil surveys and site-specific management at field and landscape scales. Xiao-ming *et al.* (2012), concluded that EM survey provided enough data for spatial analysis of soil salinity. They added that geostatistical technique and Kriging interpolation were introduced to predict the spatial distribution of soil salinity in the study area. Ganjegunte *et al.* (2013), used the multiple linear regression model to produce the calibration equations to estimate ECe from EC samples values and indicated that the EMI technique can be used to delineate site specific spatial distributions of salinity and sodicity in salt affected turf areas at depths close to the surface (0–15 cm) and at depths below the root zone (15–30 cm).

This work aims to use the electromagnetic sensor (EMI 400) to assess, predict and map soil salinity at field scale.

## MATERIALS AND METHODS

**a. Materials:**

- Electromagnetic induction (Profiler EMI400).
- GPS to locate the EMI400 measurements.
- SPSS software, ArcGIS software.

**b. Methods**

**1) Field work experimental design**

The plot area was selected for the study because of the high salinity and variability defined in the previous reconnaissance survey. The plot area includes three locations (Fig. 1).

The EMI readings were made in a grid system. The Grid Configuration of measuring points were in orthogonal grid of an area (25 X 25) meters in plot 1 and plot 2 and (25 X 35) meters in plot 3. The distances between points were (5 X 5) meters with total number of measurements of 25 points (in 5 lines and 5 rows) in plot 1 and plot 2, and 35 points (in 5 lines and 7 rows) in plot 3. In each plot area the points were measured using EMI 400. The process of EMI 400 measurements were repeated three times in each point. Nine, eight and ten surface soil samples were collected as shown in Fig. 2.

The time interval between readings is 2 seconds from plots 1, 2 and 3, respectively. This is also the only rate at which GPS data can be collected. The measuring height was collected using pallet on shoulder (1meter above the surface).

Three frequencies were used during collecting the measurements (14 KHz, 15 KHz, and 16 KHz). The zigzag orientation was used for measurements distribution.

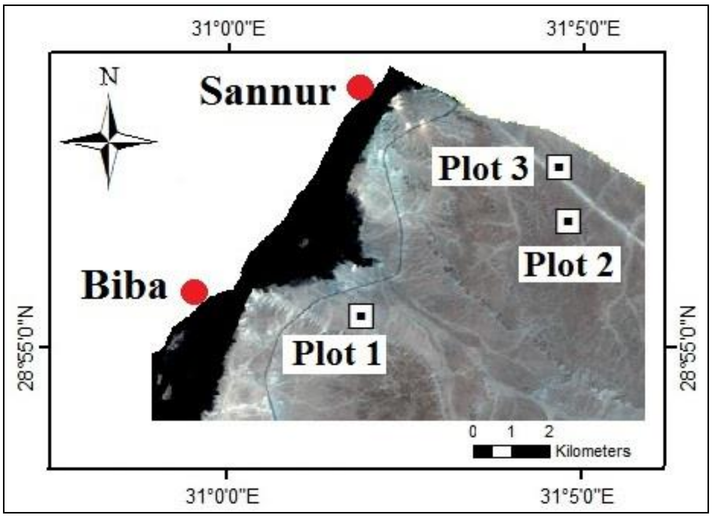


**Fig. 1. Location of the selected fields.**

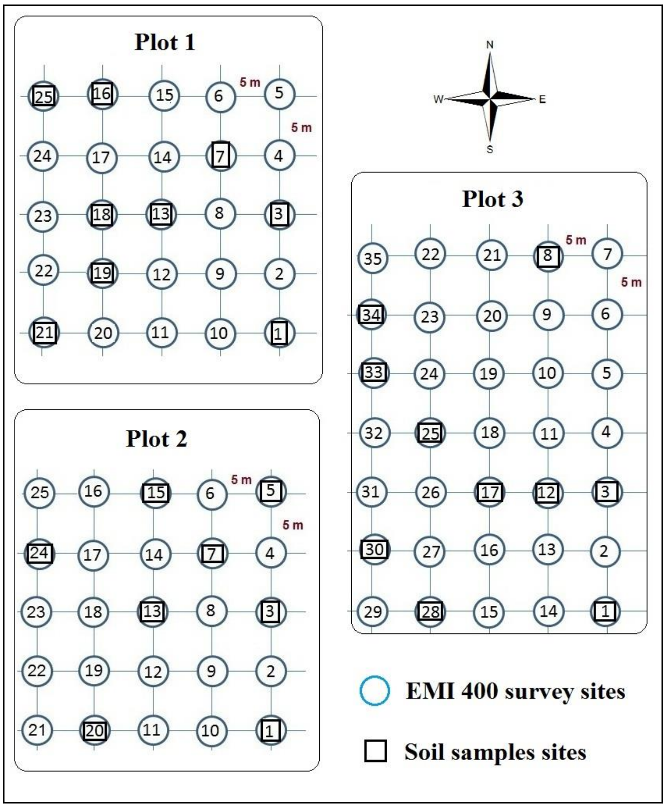


**Fig. 2. Locations of EMI 400 survey sites and soil samplesites in selected fields.**

**2)Data analysis**

**a)Calculate the relation between reading and soil samples analyses**

SPSS, version 17.0 (2008) was used for the statistical analysis. The system provides a selection of top quality statistics and a high resolution graphics. The correlation operation in SPSS software was used to calculate the relation between the reading of the EMI400 of each plot area and the EC of soil samples in lap of each plot area. Different correlations were done as following:

- All Reading of the EMI400 of plot 1 with EC values of soil samples determined in the lap.
- All Reading of the EMI400 of plot 2 with EC values of soil samples determined in the lap.
- All Reading of the EMI400 of plot 3 with EC values of soil samples determined in the lap.

**b) Calculate the multi regression formula**

The simple linear regression operation was used to determine the formula for each plot area based on the significant of the relation analysis. The simple linear regression model applied on this study assumes that the M mean of the response variable Y depends on the explanatory variable X according to a linear equation. The mean response is a linear function of the explanatory variables

$$\mathbf{M\ Y = B_0 + B_1X_1 + B_2X_2 + \ldots + BpXp}$$

**c) Produce EC values maps**

The interpolation operation of Arc GIS software was used to create the EC values maps of different layers using the parameters of multi regression model of each plot area.

## RESULTS AND DISCUSSION

**1) Location of the study area**

The three plots were located in the newly reclaimed area of Beni Suif governorate between Sannur and Biba. The plots are located between latitude $28^0$ 55' and $29^0$ 00' north and between longitudes $31^0$ 05' and $31^0$ 00' east.

Three separate fields location were selected for this study. The tested points were 25 in plot 1 and plot 2 and 35 points in plot 3. The distance between tested points were (5 × 5) meters (Fig. 2).

Nine, eight and ten soil samples were collected from plot 1, 2 and 3, respectively. EC value for each soil sample was determined.

**2) Statistical analysis**

The EMI 400 prediction technique was made using salinity survey data from three separated fields. Correlation analysis is widely used in statistical evaluation and it shows efficiency of relationship between variables (Ozdamar, 1999). Simple correlation and multiple liner regression models are combined with ordinary kriging to construct field average salinity estimates to produce spatial salinity map.

The simple correlation coefficients between the measuring EC values and the EMI 400 instrument readings at 16KHz, 15KHz, and 14KHz were calculated and presented in Table 1.

**Table 1.Simple correlation coefficients between EMI 400 measurements and EC values**

| Frequency | Plot 1 | Plot 2 | Plot 3 |
|---|---|---|---|
| 14KHz | -0.864** | -0.951** | -0.838** |
| N | 9 | 8 | 10 |
| 15KHz | -0.859** | -0.945** | -0.859** |
| N | 9 | 8 | 10 |
| 16KHz | -0.860** | -0.922** | -0.820** |
| N | 9 | 8 | 10 |

****. Correlation is significant at the 0.01 level.**
***. Correlation is significant at the 0.05 level.**

Table 1 data prove that there are high negative significant correlations at the level 0.01 between the measured EC values and the EMI 400 instrument readings of 16KHz, 15KHz, and 14KHz for all locations. The strong correlation between EMI 400 readings and the measured EC values demonstrate that salinity accounted for most of the response of EMI 400 sensor.

Stepwise multi regression analysis is a multiple statistical method that can screen or select the most important variables through the independent variable such as the EMI 400 instrument readings at 16KHz, 15KHz, and 14KHz. The data analysis was used by considering the measuring EC values as a dependent variable and the EMI 400 instrument readings at 16KHz, 15KHz, and 14KHz as independent variables.

From the multi regression analysis, the EMI 400 reading values at frequency 14KHz justified 74.7% and 89.5% of the variations that existed in the measured EC values for plots 1 and 2 ,respectively. While the EMI 400 reading values at frequency 15KHz, justified 68.1% of these variation for plot 3.

These results are in agreement with those of the simple correlation (Table 1), as the measured EC values show the highest significant correlation with the readings of 14KHz for plot 1 and plot 2 and readings of 15Kz for plot 3. Therefore, these readings were considered as the main effective EC independent variable. The unexplained variation (25.3 %, 10.5% and 31.9% of the total) for plots 1, 2 and 3, respectively, may be due to the effect of other variables. The multi regression analysis (Fig. 3) shows that the fitting equation is a liner regression model describing the relationship between the measuring EC values and the instrument readings at frequency 14KHz for plots 1 and 2 and frequency 15KHz for plot 3.

**The results could be summarized in the following equations:**

$EC_{estimated}$ **for plot 1 = 6.15 + (-0.371 * 14 KHz reading)**

$EC_{estimated}$ **for plot 2 = 1.622 + (-0.054 * 14 KHz reading)**

$EC_{estimated}$ **for plot 3 = -3.957 + (-0.905 * 15 KHz reading)**

**3) Calculate the relation between the estimated values and soil samples analyses (observed values)**

It is evident from the statistical analysis of the data (Table 2) that there are negative and high significant correlations existed between the estimated EC values and the instrument reading at 14 KHz, 15 KHz and 16 KHz for the three locations. The estimated EC values have higher significant correlation with the instrument readings than the measured EC values.

**Table 2. The relation between the instrument readings, the measured EC and estimated EC values**

| Frequency | Plot 1 | | Plot 2 | | Plot 3 | |
|---|---|---|---|---|---|---|
| | EC Observed | EC Estimated | EC Observed | EC Estimated | EC Observed | EC Estimated |
| 14KHz | -.864** | -1.000** | -.927** | -.964** | -.838** | -.996** |
| N | 9 | 25 | 8 | 25 | 10 | 35 |
| 15KHz | -.859** | -.999** | -.945** | -.960** | -.859** | -1.000** |
| N | 9 | 25 | 8 | 25 | 10 | 35 |
| 16KHz | -.860** | -.999** | -.946** | -.842** | -.820** | -.998** |
| N | 9 | 25 | 8 | 25 | 10 | 35 |

****. Correlation is significant at the 0.01 level (2-tailed).**

**4) Produce EC values maps**

The calibration equations for soil samples were used to predict and constructs field average EC estimates of all the remaining non sampled sites from the EMI 400 readings. Then, the kriging spatial analysis using Arc GIS was used to produce soil salinity raster maps for the three locations as shown in Fig. 4.

The data presented in Figure 4 show the usefulness of the hand held electromagnetic sensor EMI 400 to assess, predict and map soil salinity at field scale. There is a general spectral pattern similarity between EMI 400 readings maps and the estimated ECe maps. This confirms that EMI 400 readings are appropriate for reconnaissance survey to provide a priori spatial information about salinity; allowing allocation of the most and least saline areas.

The resulted estimated salinity map (Fig. 5) show that 100% of plot 2 has salinity level less than 4 dS/m. In plot 1, soil with EC values 8-16 dS/m represents 10.7% of the tested field, and strongly saline soils >16 dS/m represents 89.3%. In plot 3, the salinity classes of strongly saline, moderately saline, slightly saline and non saline covers 42.5%, 21.2%, 12.5% and 28.8% of the study area, respectively.

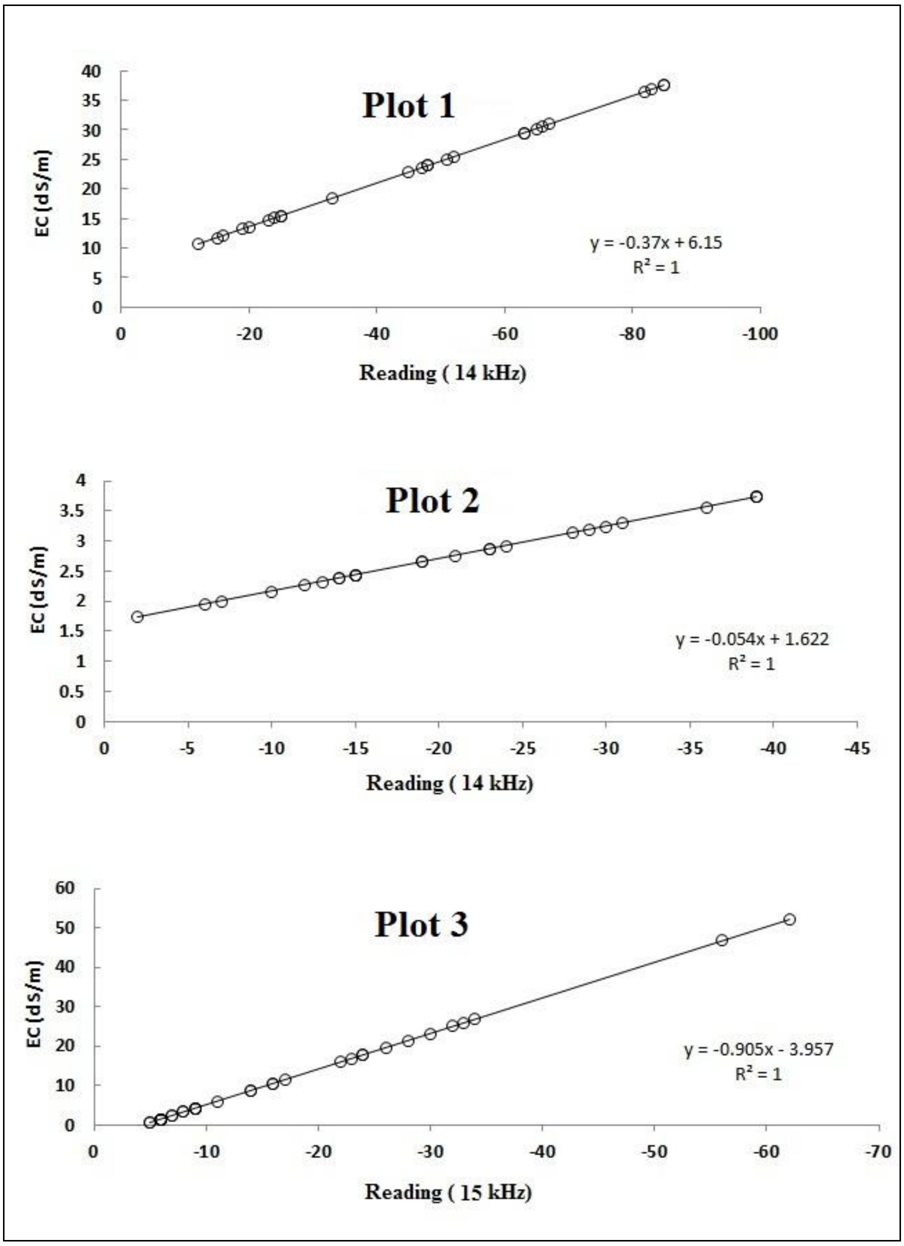


**Fig.3. The relation between the estimated EC and the EMI 400 readings.**

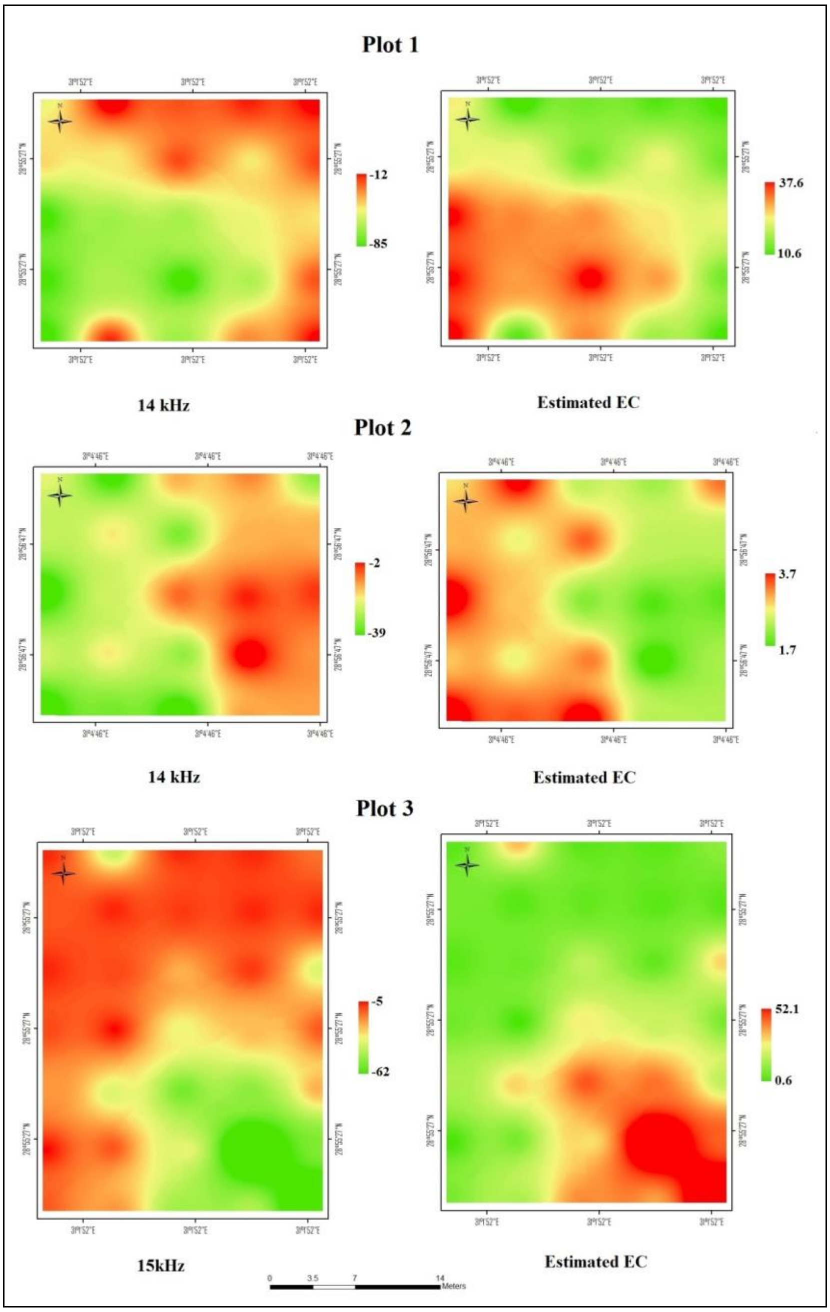


**Fig. 4. The spatial distribution of the EMI400 readings and the estimated EC values.**

## CONCLUSION

Estimating EC values may improve the salinity mapping compared to those maps obtained from the few measured EC values. The detailed salinity map proves very helpful in displaying the spatial patterns of soil salinity and identifying sources/causes of salt-loading. While controlling the soil salinity levels, salt-tolerant crops should be grown in this field.The electromagnetic induction sensor EMI400 and the ArcGIS software package have been proved to be very useful for assessing, estimate and mapping the soil salinity in the studied area. The rapidity and ease of use of the EMI400 and the customized ArcGIS software package quickly enabled the estimation of the spatial distribution of the soil salinity.

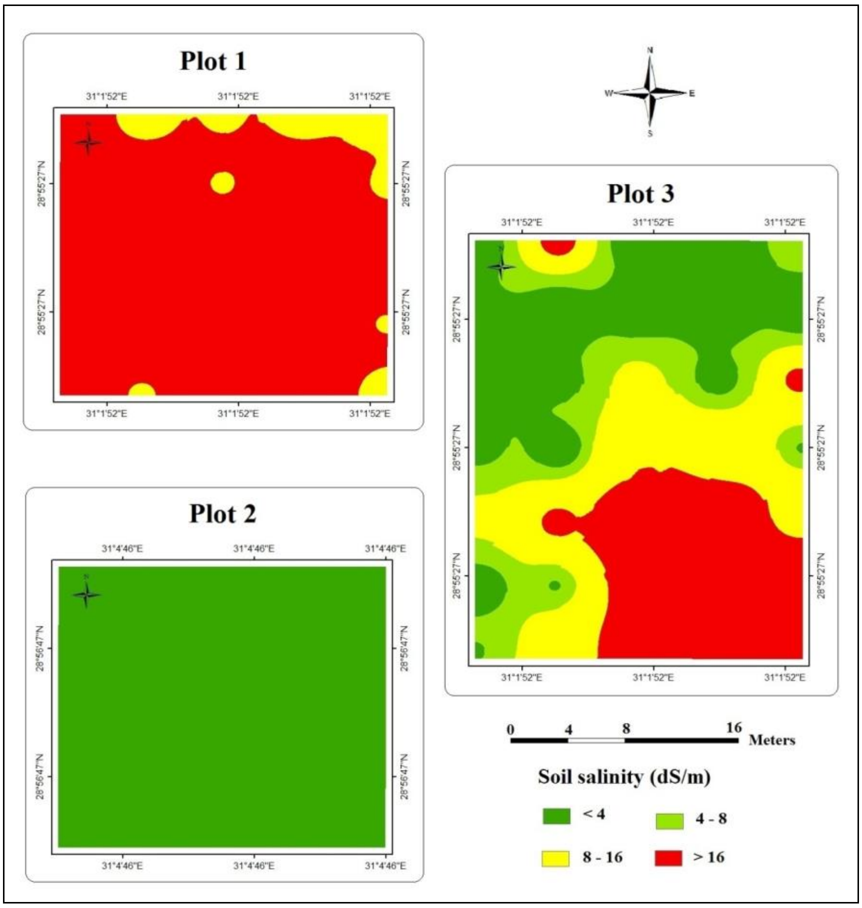


**Fig. 5. Soil salinity classes maps of the estimated EC values.**

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**التنبؤ المكاني لملوحة التربة بإستخدام تقنية الحث الكهرومغناطيسي**

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أستخدمت اجهزة الحث الكهرومغناطيسي لتحسين القدرة على التنبؤ بملوحة التربة. وقد استخدم لذلك جهاز EMI 400 لثلاث مناطق بمحافظة بني سويف. وقد استخدامت الترددات الثلاث (١٤ كيلوهرتز، ١٥ كيلوهرتز، و ١٦ كيلوهيرتز) لعمل القياسات المطلوبة و جمعت العينات بطريقة الزجزاج. تم استخدام الارتباط البسيط والانحدار المتعدد و ordinary kriging لتقدير متوسطات الملوحة في المنطقة لإنتاج الخرائط المكانية لتوزيع الملوحة. وقد وجد من نتائج تحليل الانحدار المتعدد و قراءة الجهاز EMI 400 عند تردد ١٤ كيلوهرتز أن ٧٤.٧٪ و ٨٩.٥٪ من الاختلافات في قراءة الجهاز كانت متأثرة بملوحة التربة للموقعين ١ و ٢ على التوالي. و أن ٦٨,١٪ من الإختلافات في قراءة الجهاز عند تردد ١٥ كيلوهرتز كانت متأثرة بملوحة التربة في موقع ٣, و ان هناك تشابه في النمط الطيفي العام بين قراءة الجهاز EMI 400 وخرائط الملوحة المقدرة. وهذا يؤكد أن قراءة جهاز EMI 400 مناسبة لعمل مسح استطلاعي لتوفير المعلومات المكانية حول ملوحة التربة. وتظهر الدراسة فائدة استخدام جهاز الحث الكهرومغناطيسي (EMI 400) لتقييم والتنبؤ وعمل خريطة ملوحة التربة على النطاق التفصيلي دون الحاجة لإجراء تحليلات معملية.