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# ASSESSMENT OF SOIL VARIABILITY USING ELECTRICAL RESISTIVITY TECHNIQUE FOR NORMAL ALLUVIAL SOILS, EGYPT

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## Abstract

Spatial information on soils could be resulted from direct measurements that are destructive, expensive, effort and time consuming. Methods of geophysics can be an effective, fast, economic and non-destructive tool for soil mapping for large areas. Electrical resistivity could be effective in studying soil variability as it relied on many soil characteristics. This paper was designed to study soil spatial variability using electrical resistivity technique. The Experimental Western Farm (EWF) in the faculty of agriculture, Cairo University at Giza was chosen for the present study. A GPS outlined grid points 40X40 m were initiated to cover an area of about 160 by 400 m. At each point (40 nodes) resistivity was measured using 4-electrodes Wenner array in a line perpendicular to the path direction. Soil resistivity data from a 2-depth profiling mode was considered to produce two apparent resistivity maps.using ArcGis software. Soil resistivity taxa were sampled and analyzed for soil moisture, EC and bulk density. The resistivity data were geostatistically investigated. Krigged soil resistivity maps were produced for depths (i.e. 30 and 60 cm). Kriging and Semivariogram interpretation was conducted to find out the spatial dependency of top- and subsoil (Nugget / sill %).

The spatial dependency of the top and subsoil resistivity were moderate (48.4% and 68.6% respectively). Highly significant negative correlations were recorded in the topsoil between apparent or true resistivity and soil moisture, EC or bulk density for the different units of the produced soil resistivity map. The best fitting relationship models ranged between linear, power, logarithmic and exponential models. In subsoil weak or insignificant relationships were recorded. The obtained models were used to produce conjugated moisture, EC and bulk density maps. The conjugated soil moisture and salinity maps were geostatistically investigated. The spatial dependency of the top and subsoil moisture contents were moderate (47.5% and 60.4% respectively), while it was for soil salinity 68.5% and 62.5%, respectively.

The multiple linear regression analysis that includes moisture, EC and bulk density, showed highly significant model ($R^2$= 0.885). The obtained factorial analysis showed that soil moisture had the highest contribution percent on soil resistivity reaching 54.99% followed by electrical conductivity by 25.92% and the least factor affecting ER was bulk density as its contribution was 18.06%. However, it could be concluded that soil moisture and EC are the most significant factors that controlling soil electrical resistivity of the investigated surface layer (0-30 cm). For the subsurface layer (30-60), the obtained linear multiple regression model was insignificant ($R^2$=0.540). This technique can compete the other methods of soil surveys, and facilitate the development of semi-automatic soil mapping from electrical resistivity data.

***Key words :*** Soil resistivity, Wenner profiling, soil moisture, soil salinity, mapping, spatial dependency.

## Introduction

Because a huge number of soil sampling and laboratory analysis work are wasting time and money in the ordinary survey methods, alternative methods to investigate spatial variability of soil properties are desirable. Soil electrical resistivity could be considered as a proxy for the spatial and temporal variability of soil physical and chemical properties (*i.e.* soil structure, water content, salinity or fluid composition). This non-destructive and sensitive method is an unique tool for assessing the soil subsurface properties without digging (Samouëlian *et al*., 2005). Electrical resistivity method had been applied in different studies such as : groundwater exploration, landfill delineation and solute transfer, agronomical management of soil compaction or soil and watertable depths, and also assessing the soil moisture status.

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**Fig. 1 :** Geo-referenced soil resistivity data acquisition grid.

The electrical resistivity surveys, depending on the soil variability can be made in 1-, 2- or 3-dimensions and also at different resolutions from the small to the regional scales. Soil electrical resistivity (ER) is increasingly used in near-surface soil applications because it is related to many soil characteristics and electrical survey information; it therefore represents a rapid and flexible tool to predict spatial soil variability at the field or local scale (Panissod *et al*, 1998; Lund *et al*., 1999 and Dabas *et al*., 2001). The soil bulk electrical resistivity technique offers the following advantages: (i) widely used to characterize soil physical and chemical properties, (ii) ER measurements can be taken as quickly, (iii) Low cost, (iv) Two persons can cover large area,(v) Monitoring of soil variability,(vi)Exploring soil subsurface without digging and (vii) Minimize the number of soil samples.

Soil bulk resistivity depends on multiple variables, including soil texture, and structure, porosity, soil moisture content (Besson *et al*., 2010), pore water salinity, temperature, and sometimes on the presence of root biomass. Several studies have been performed using this technique, with the aim of delineating field zones for managing specific crops in the context of digital agriculture (Heiniger *et al*., 2003; Kitchen *et al*., 2003; Corwin *et al*., 2006), mapping soil texture (Jung *et al*., 2005; McCutcheon *et al*., 2006) and describing soil structure of different soil horizons (Tabbagh *et al*., 2000) and soil salinity variability (Rhoades, 1993; Omonode and Vyn, 2006).

The objectives of the present study are to: (i) survey the electrical resistivity on an alluvial soil farm using Profiling Model in two depths to describe its spatial variability. (ii) Correlate Profiling resistivity values in the alluvial farm with its correspondent physical and chemical properties and (iii) Produce the soil map of the studied farm by correlating ER units with their physical and chemical properties.

## Materials and Methods

### Principals of Electrical Resistivity measurement

Electrical resistivity methods introduce an electrical current into the soil through current electrodes at the soil surface and measure the drop in current flow potential at inner electrodes. Wenner array of electrode configuration is described by four electrodes placed at equal distances in a straight line. The outer two electrodes working as the current or transmission and the inner two electrodes working as the potential or receiving ones (fig. 2).

The extent of electrical current penetration and the depth and volume of measurement depend on the inter electrode spacing. The larger the spacing is, the deeper the measurement the larger the volume of measurement. The resistivity, measured with the Wenner array (Burger, 1992) is

$$\rho = 2\pi a \Delta V / i = 2\pi a R$$

One and two meters spacing between probes were chosen so as to detect metric contrasts in the soil properties at two depths (US-EPA, 2011). Soil resisitivity reading were converted to apparent resistivity using the relation

$$\rho_a = k_i \frac{\Delta V}{I}$$

With i =1,2m for each array and where I = is the injected current in mA, ΔV is the electrical potential difference (Volt) measured between electrodes Mi and Ni and the geometrical parameter for each array is

$$k_i = \frac{\pi}{\frac{1}{AM_i} - \frac{1}{AN_i}}$$

### Site description

The experimental western farm (EWF) in the faculty of agriculture, Cairo University at Giza was chosen for the present study. The geo-reference coordinates of the investigated rectangle area (@ 6.1 hectares) are

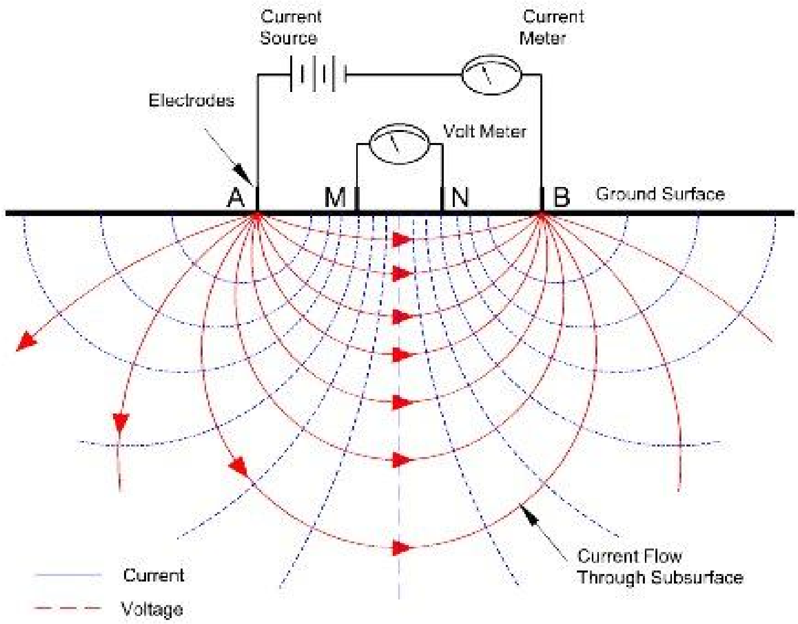



**Fig. 2 :** Geo-referenced soil resistivity data acquisition grid.

N=30.02.25.40 to 30.02.57.90 and E=03.11.97.41 to 03.11.96.77 (fig. 1).

### Acquisition of the Resistivity Data

For the farm survey, a GPS defined grid points 40×40 m were initiated. Data were acquired on the nodes of regular grids extended across an area of about 160 by 400 m (Fig. 1). At each point (40 nodes) resistivity was measured using 4-electrodes Wenner array in a line perpendicular to the path direction (Sudha *et al*, 2009). The readings were collected by a resistivity meter (KYORITSU-KEW-4106). All measurements (40 points) were geo-referenced using a Germin-550 differential GPS and recorded on a PC.

### Data preprocessing

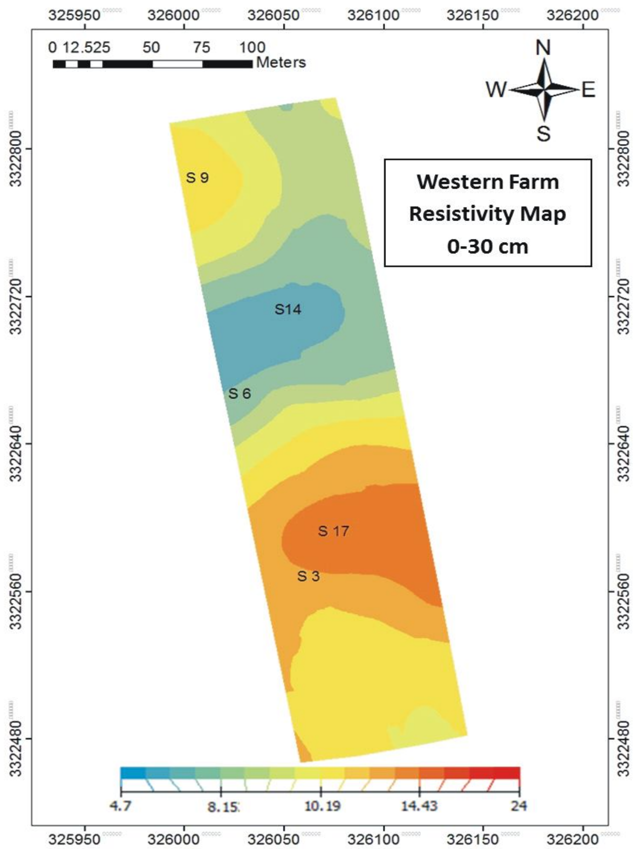
Data processing is simple and consists of: i) Inversion of the apparent resistivity values (Ra) into true resistivity (Rt) using IPI2win software, then ii) generating an iso-line distribution map of the inverted electrical resistivity data to report the spatial distribution of the true resistivity values. The maps were generated using ArcGis Software (ESRI, 2011). The results are presented in the form of two maps corresponding to thetwo targeted depths of soil layers. These maps represent the contribution of the cumulativesoil volume, from the surface down to the two depths of investigation, 0.3 and 0.6 m for arrays 1 and 2 m, respectively.

### Determination of soil properties

Ten taxa were resulted from the resistivity maps. Composite disturbed soil samples were collected at two depths (0-30 and 30-60cm) to represent each soil resistivity taxa. The collected samples were analyzed for soil moisture content (Gardner, 1986) and electrical conductivity EC at 1:2.5 soil:water ratio (Rhoades, 1982). In addition, undisturbed soil samples for each resistivity taxa were collected to determine soil bulk density (Blake and Hartge, 1986).

**Table 1 :** Apparent and true resistivity, soil moisture content, EC and bulk density of the main topsoil and subsoil resistivity taxa units.

| Taxa Unit | Apparent R(Ω m) | True R (Ω m) | θ % (w/w) | $EC_{2.5}$ (dS/m) | Bulk Density $g.cm^{-3}$ |
|---|---|---|---|---|---|
| | **Topsoil (0-30 cm)** | | | | |
| I | 12.90 | 17.59 | 25.0 | 1.09 | 1.35 |
| II | 9.20 | 10.76 | 26.0 | 0.63 | 1.17 |
| III | 6.20 | 6.36 | 33.7 | 1.48 | 1.24 |
| IV | 4.80 | 5.04 | 31.7 | 0.94 | 1.32 |
| V | 4.70 | 5.57 | 35.0 | 1.63 | 1.33 |
| VI | 18.00 | 18.16 | 23.5 | 1.33 | 1.18 |
| VII | 24.00 | 20.42 | 23.3 | 1.49 | 1.14 |
| VIII | 14.20 | 15.62 | 30.9 | 1.13 | 1.38 |
| | **Subsoil (30-60 cm)** | | | | |
| I | 8.00 | 4.11 | 24.0 | 0.89 | 1.36 |
| II | 7.40 | 5.57 | 26.7 | 0.65 | 1.18 |
| III | 6.00 | 5.73 | 33.2 | 1.49 | 1.22 |
| IV | 4.50 | 4.11 | 30.8 | 1.13 | 1.32 |
| V | 3.70 | 2.72 | 32.2 | 1.61 | 1.30 |
| VI | 17.80 | 17.51 | 21.3 | 1.02 | 1.26 |
| VII | 29.10 | 41.17 | 23.3 | 1.20 | 1.31 |
| VIII | 12.50 | 10.53 | 26.3 | 0.86 | 1.45 |



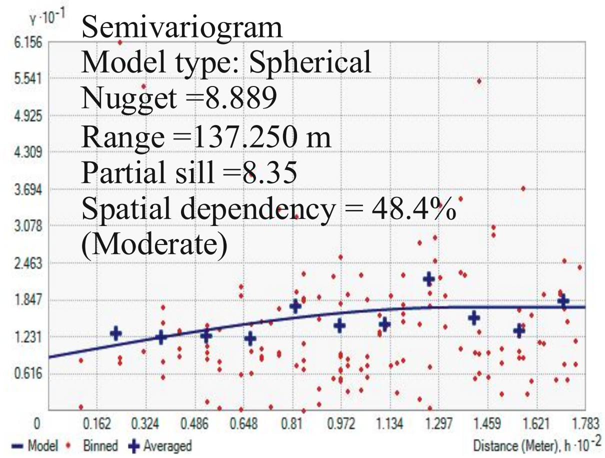




**Fig. 3 :** Topsoil (0-30 cm) soil resistivity krigged map and its semivariogram interpretation.

**Table 2 :** Statistical relationship models between apparent or true resistivity with soil moisture, EC and bulk density for both top- and subsoils.

| Soil Property | Apparent Resistivity | True Resistivity |
|---|---|---|
| | **Topsoil** | |
| Moisture | $y = 62.391e^{-0.072x}$ | $y = -36.57\ln(x) + 133.66$ |
| | $R^2 = 0.8184$ | $R^2 = 0.8884$ |
| EC | $y = -3.4348x2 - 5.9874x + 23.21$ | $y = -14.019x + 28.96$ |
| | $R^2 = 0.9946$ | $R^2 = 0.839$ |
| Bulk Density | $y = 64.161x^{-9.499}$ | $y = 54.169x^{-8.475}$ |
| | $R^2 = 0.8262$ | $R^2 = 0.845$ |
| | **Subsoil** | |
| Moisture | $y = 142.04e^{-0.106x}$ | $y = 36960x^{-2.635}$ |
| | $R^2 = 0.7243$ | $R^2 = 0.4653$ |
| EC | $y = 16.851e^{-0.889x}$ | $y = 5.0998x^{-0.862}$ |
| | $R^2 = 0.7508$ | $R^2 = 0.484$ |
| Bulk Density | $y = 24.652\ln(x) + 0.5019$ | $y = 19.614x - 18.588$ |
| | $R^2 = 0.3295$ | $R^2 = 0.3593$ |

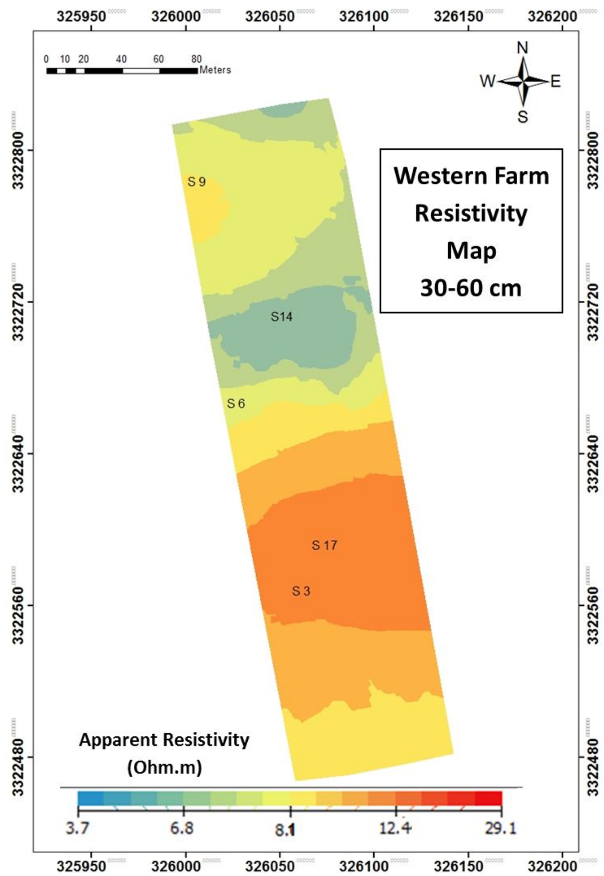
## Results and Discussion

Soil resistivity values for the surface layer (0-30 cm) were mapped using ArcGis software. Kriging and Semivariogram Interpretation was conducted to find out the spatial dependency of top soil (Nugget/sill%) and the resulted out put is presented in fig. 3.

The weighted least square method was used to estimate the auto- and cross-variogram parameters (i.e., nugget, sill, and range). From fig. 3, it is clear that the spatial dependency of the topsoil resistivity is moderate (48.4%). Generally, a semi-variogram may reach its sill at a finite distance calledthe range. The range of the semi-variogram represents distance limit beyond which the data are no longer correlated and it was found to be 137.3 m for the resistivity of the investigated topsoil.Eight soil taxa units were resulted to cover resistivity range between 4 and 24 Ohm.m were resulted from the krigged map.

Another krigged resistivity map was produced for the subsoil layer (fig. 4). The spatial dependency of the subsoil resistivity is also moderate (68.6%).

The soil physical properties of the composite soil samples that representing the resistivity taxa units of both topsoil and subsoil are showed in table 1. The number of sampling sites represented 20% of the total grid points



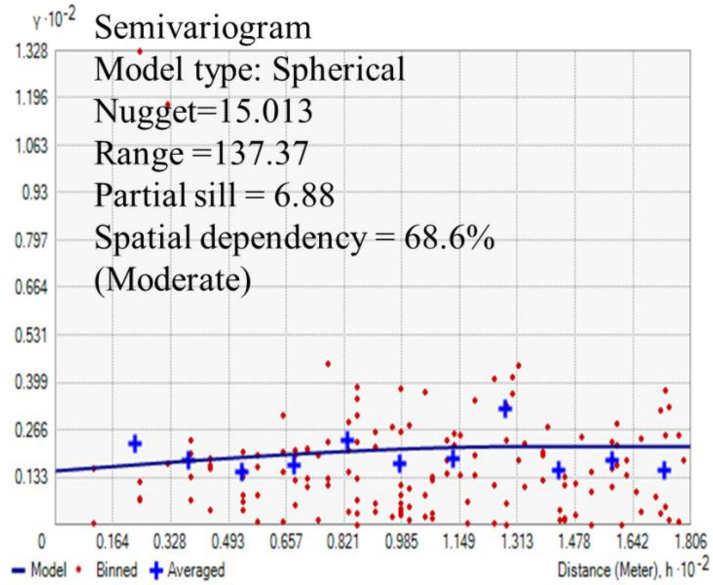




**Fig. 4 :** Subsoil (30-60 cm) soil resistivity krigged map and its semivariogram interpretation.

**Table 3 :** The relative contribution percentage of variance for each factor in the value of electrical resistivity of the soil surface layer (0-30 cm).

| | Initial Factors | | Significant Factors | |
|---|---|---|---|---|
| Component | % of Variance | Cumulative % | % of Variance | Cumulative % |
| 1 SM | 54.988 | 54.988 | 54.988 | 54.988 |
| 2 EC | 25.918 | 80.905 | 25.918 | 80.905 |
| 3 BD | 18.061 | 98.966 | | |
| 4 ER | 1.034 | 100.000 | | |

that normally sampled in an ordinary soil survey.

Simple regression analysis was developed between both apparent / true resistivities and each of soil moisture content, EC and bulk density. Fig. 4 represent the best fitting relationships of each property for both top- and subsoil.

Highly significant negative correlations were recorded in the topsoil between apparent or true resistivity and soil moisture, EC or bulk density. The best fitting relationship models (table 2) ranged between linear, power, logarithmic and exponential models. In subsoil weak or insignificant relationships were recorded. These findings indicated that present array of soil resistivity measurement could be more useful for detecting efficiently topsoil variability. It is suggested that changing the array of soil resistivity measurement couldfocus on the subsoil layer in the future work.

**Production of maps for soil properties**

The obtained models were used to produce conjugated moisture, EC and bulk density maps. The regression equations were used to calculate the value of soil moisture and salinity for each resistivity value of the 40 points of the investigated grid. The resulted moisture and EC values were used to produce conjugate soil Moisture and soil-EC maps (figs. 5 and 6).

The spatial dependency of the top and subsoil moisture contents were moderate (47.5% and 60.4%, respectively), while it was for soil salinity (68.5% and 62.5%, respectively). These maps could be used for better management of the farm irrigation system to reduce uneven distribution of both soil moisture and salinity.

**Multiple Regression analysis**

From the obtained data, it is clear that soil resistivity (ρ) is a function of soil moisture (θ), salinity (EC) and bulk density (BD) and other properties could be added:

$$\rho = \int(\theta, EC, BD, ...)$$

The Multiple Regression analysis showed that this model is highly significant ($R^2 = 0.885$) for the surface layer (0-30 cm). The obtained multiple linear regression model is:

$$ER_{30} = 16.88739536 - 1.535769677\ SM$$

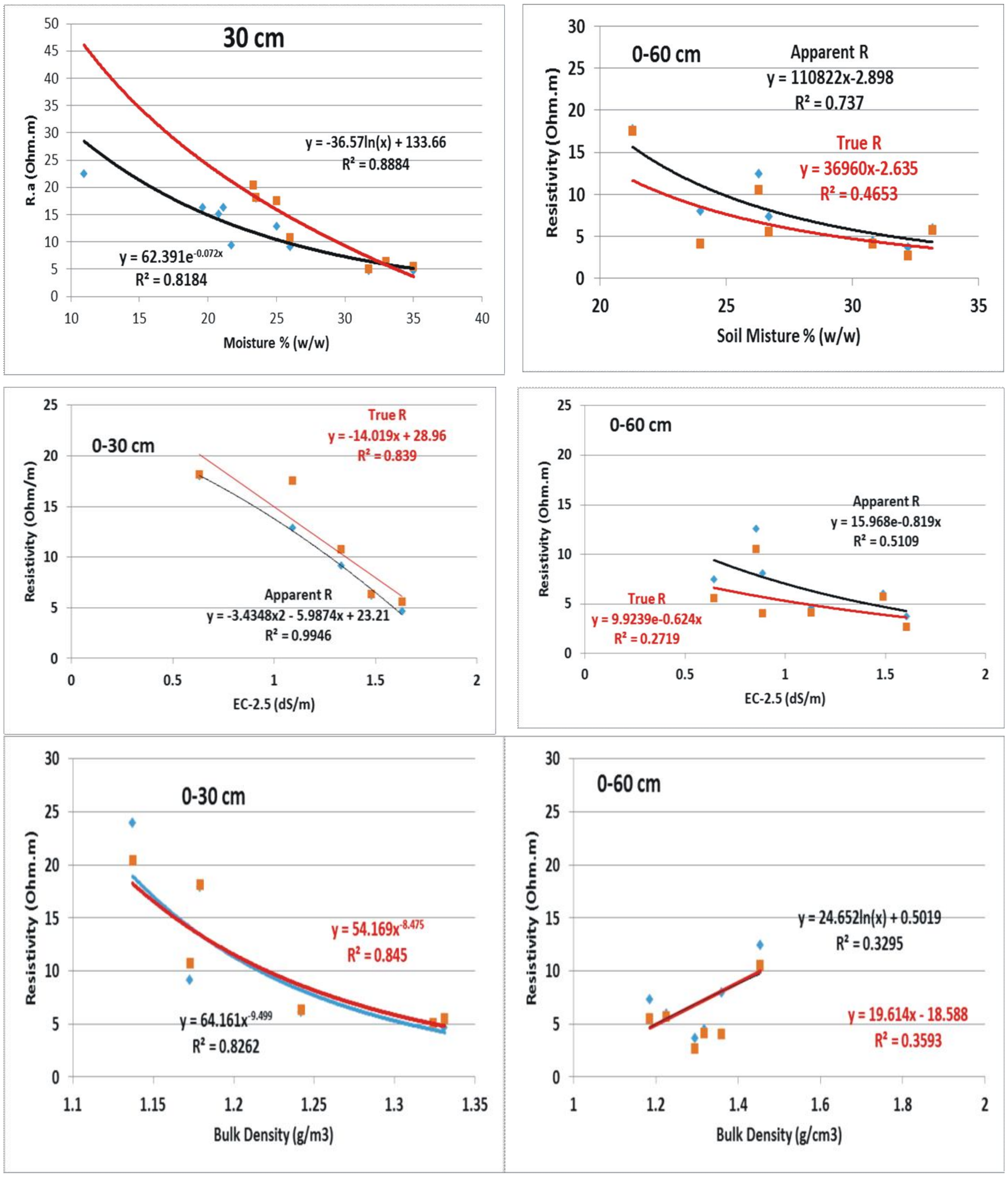



**Fig. 5 :** The best fitting relationships of each soil property and apparent or true resistivity for both top- and subsoil.

$$+ 6.503447218\ EC + 25.02988756\ BD$$

Where, $ER_{30}$= Soil electrical resistivity of 0-30 layer, SM=Soil moisture (w%), EC= EC of 1:2.5 (soil:water extract) and BD = Bulk density (g/cm$^3$). The statistical parameters of this model are as follows:

Residual Sum of Squares: RSS = 31.49547841

Mean square error MSE = 1.984171

Coefficient of Determination: $R^2$=8.853790407×$10^{-1}$

In order to estimate the contribution percentage of each of the three factors in soil resistivity, factorial analysis was conducted using SPSS software and the results showed in table 3.

The obtained factorial analysis showed that soil moisture (SM) had the highest contribution percent on soil resistivity reaching 54.99% followed by electrical conductivity by 25.92% and the least factor affecting ER was bulk density as its contribution was 18.06%. However, it could be concluded that soil moisture and EC are the most significant factors that controlling soil electrical resistivity of the investigated surface layer (0-30 cm). For the subsurface layer (30-60), the obtained linear multiple regression model was insignificant ($R^2$=0.540).

In conclusion, mapping of soil electrical resistivity could be used efficiently to express spatial variability of soil properties especially moisture- salinity content and to some extent bulk density. The produced soil maps could be used to better soil management.

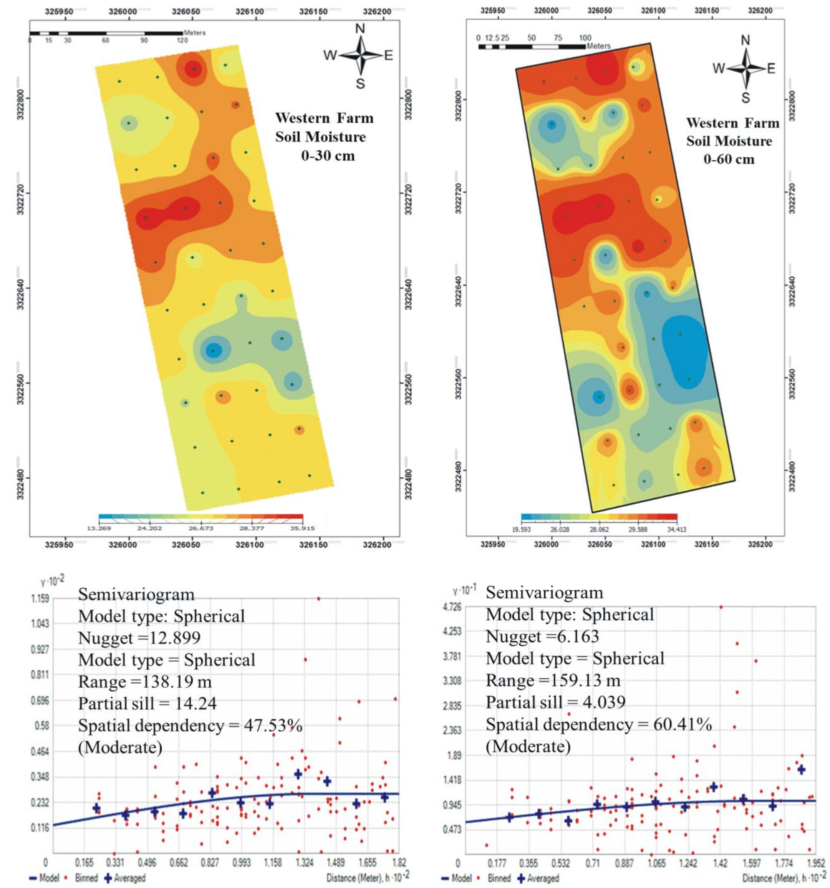



**Fig. 6 :** Soil moisture map of top- and subsoil as conjugated from their relevant soil resistivity maps.

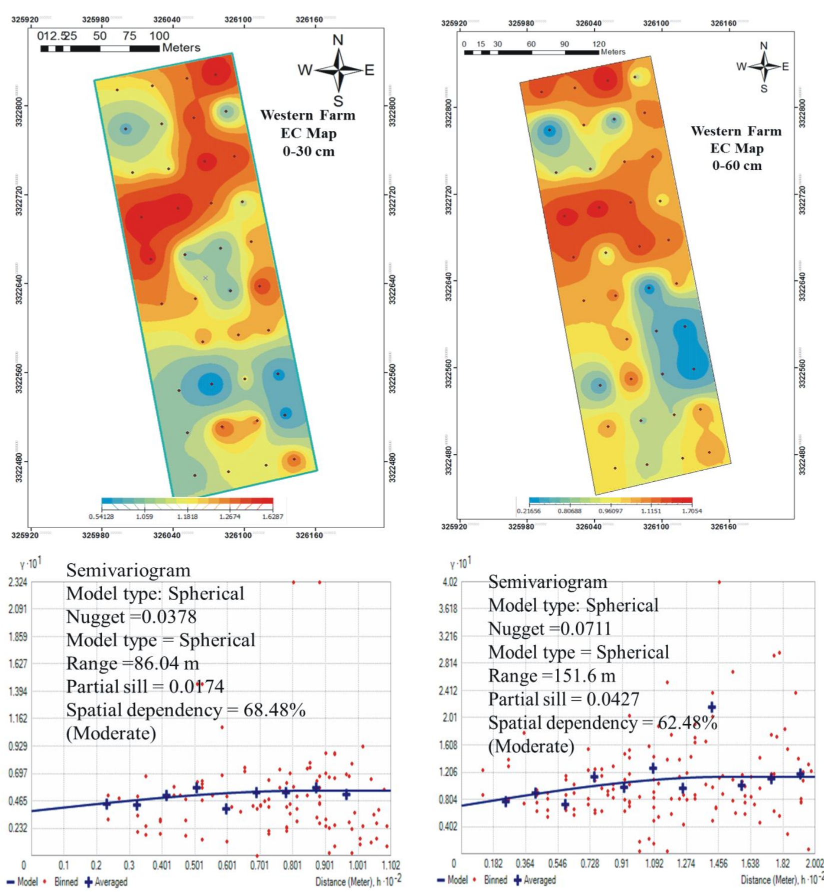



**Fig. 7 :** Soil salinity map of top- and subsoil as conjugated from their relevant soil resistivity maps.

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