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Modern Techniquesfor Mapping Soil Salinity and the Hard Pan Layer at the Agricultural and Research Station of KFU, Al Hassa, KSA

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Abstract: The agricultural and research station of King Faisal University, KSA is a key field of scientific studies conducted by faculty members and graduatesof King Faisal University. The soil and water are of the most important factors that determine the success of agricultural activity in any location and based on their characteristics, the type of plants, as well as their productivity are determined. Soil salinity and existing of the hardpan layer are consider to be of dominant problems which affecting the agricultural activities in this agricultural research station. To contribute to these problems, electromagnetic induction and electrical resistivity tomography implemented in this study. EM38-MK2 conductivity meter,as a cheap, rapid and effectivefor mapping of soil salinity, used in vertical mode to measure the electrical conductivity (EC) at depths of 75 and 150 cm at about 700 sites along the study area. Moreover, about 157 soil samples using the hand auger collected at depth intervals of 10-20 cm and 30-40 cm for the same site. The electrical conductivity for the collected soil samples measured at the lab to correlate with the EM38-Mk2 data. In addition, 2-D electrical tomography using SuperSting R8/IP 8 channel multi-electrode resistivity and IP imaging system with 112 electrodes at 3 meter spacing implemented along selected profiles to map the hardpan layer. Some soil pits has been excavated and to help in the interpretation of the resistivity tomograms and to know the nature of such layer. The collected EC using the data of the EM38-MK2 processed & analyzed and two salinity maps constructed at 75 & 15cm. In addition, two salinity maps constructed from the EC data of the collected soil samples at depth intervals of 10-20 cm and 30-40 cm. Both of salinity maps of EM38 are in good match with the salinity maps of lab measurements. The salinity variation found to be change laterally and vertically due to change in soil type/texture and soil moisture. Analysis and interpretation of the 2-D resistively data along with soil pits provides information on the geometry of the hardpan at the area of study. This hardpan layer is a shale layer with low resistivity zone on 2-D tomograms.

Key words: Soil Salinity · Hardpan · Soil water · Electromagnetic induction · Electrical resistivity tomography · Al Hassa Oasis · KSA

INTRODUCTION

The agricultural & research station of King Faisal University (KFU) located of about 15 Km from the headquarters of the KFU campus at Al Hassa, eastern province of Saudi Arabia (Figure 1). This area is a field for the training of KFU students and key field of studies and scientific and applied research conducted by faculty members and graduate students at the KFU particularly in the area of agricultural and food sciences. The territory of the station is about of six km^2 and has been divided to serve several fields, of research and scientific and practical observations. There many fields of crops, citrus groves, various fruit fields and the production of fodder. Moreover, the station includes a variety of plant nurseries and protected houses for executing research and experiments.

Al Hassa soils, where the area of study is located, is underlain by an impermeable marl layer (mixtures of clay and calcium carbonate) at depths ranging from zero to 2 m below the ground surface. Excesses irrigation water accumulates on top of this layer, forming a shallow water table beneath the soils of the Al Hassa Oasis. The depth to the water table affected by varying depth to the marl layer, the soil texture and the depths and spacing between field drainage canals [1]. The irrigated arid zone

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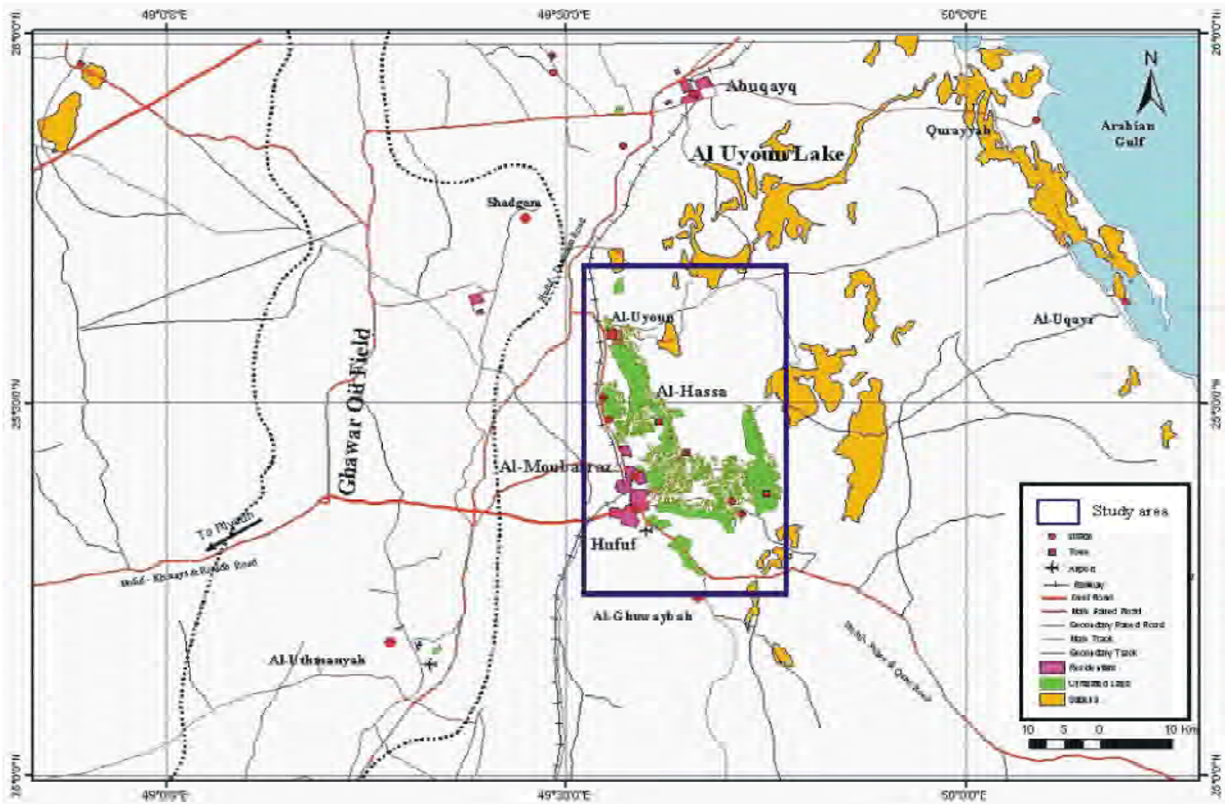

Fig. 1:Base map showing the area of study, Al Hassa, Eastern Province, KSA

of Al Hassa oasis faces twin problems of water scarcity and water logging accompanied by salinity. For more details about the studies related to the soil of Al Hassa [2, 3, 4]. [5] investigate the extent of soil salinity and the quality of irrigation water and the relationship with vegetation growth, employing NDVI derived from Landsat satellite imagery. [6] reported that salt affected soils in Al-Hassa region represent as much as 20% of the total area.

The soil and water are of the most important factors that determine the success of agricultural activity in any location and based on their characteristics, the type of plants, as well as their productivity are determined. Soil salinity and the existence of the hardpan layer are considered to be dominant problems which affect the agricultural activities in this agricultural research station.

In soil science, agriculture and gardening, hardpan is a general term for a dense layer of soil, residing usually below the uppermost topsoil layer. There are different types of hardpan, all sharing the general characteristic of being a distinct soil layer that is largely impervious to water. Some hardpans are formed by deposits in the soil that fuse and bind the soil particles. Hard pans restrict root growth and make it difficult for water, air, other gases plus soil organisms to move through the soil. They are often caused by tilling or ploughing to a particular depth. The hardpan is more likely to cause severe problems if it is closer to the surface, thicker and/or harder and particularly if it is present during a dry time or present during any other period that stresses plants.

Another major determinant is the soil particle size. Clay particles are some of the smallest particles commonly found in soils. Due to their structure the spaces between individual clay particles is quite small and already restricts the passage of water, negatively affecting drainage. Soils with high clay content are also easily compacted and affected by man-made discharges. Clay particles have a strong negative electrostatic charge and will readily bond to positively charged ions dissolved in the soil-water matrix. Common salts such as sodium molecules contained in wastewater can fulfil this role and lead to a localized hardpan in some soil types. This is a common cause of septic system failure due to the prevention of proper drainage in field. Hardpan can be a problem in farming and gardening by impeding drainage of water and restricting the growth of plant roots. Hard pans restrict root growth and make it difficult for water, air, other gases plus soil organisms to move through the soil.

Surface-geophysics methods offer quick and inexpensive means to characterize subsurface hydrogeology [7] and [8]. They provide information on subsurface properties, such as thickness of layers and saturation zones, depth to bedrock, location and orientation of bedrock fractures, fracture zones and faults. Electromagnetic (EM) induction & electrical resistivity tomography implemented in this study to contribute to these problems. The EM38-MK2 conductivity meter, is an inexpensive, rapid and effective means for mapping the soil salinity. In addition, 2-D electrical tomography using SuperSting R8/IP 8 channel multi-electrode resistivity and IP imaging system with 112 electrodes at 3 meter spacing implemented along selected profiles were used to map the hardpan layer.

EM instruments have been used extensively to determine the spatial distribution of soil attributes including clay content [9, 10] moisture [11, 12] and soil salinity [13, 14, 15, 16, 17, 18]. In other studies EM instruments have been used to determine; the nutrient status of soil [19]; depth to a clay layer [20], for identification of high SAR [21] and ESP [22]soil types and determination of organic carbon fraction [23].

Moreover, one of the new developments in recent years is the use of 2-D electrical imaging/tomography surveys to map areas with moderately complex geology [24].

Therefore, the main purpose of this paper is to map both the salinity and the hardpan layer at the area of study using these modern geophysical techniques. Such contribution will provide the technical support for planners, decision makers and researchers in the field of agricultural sciences whom used the study area for their research experiments.

Geophysical and Field Investigations: Modern agricultural production practices are rapidly evolving all over the world. These new production practices present significant applications for non-intrusive agricultural geophysical techniques. Such modern geophysical techniques are being incorporated within site-specific agriculture in the detection of soil horizons, soil compaction, soil salinity, mapping of hardpan layer and soil texture, etc. For more details about Agricultural Geophysics and their applications [25].

Electromagnetic induction sensors, such as EM38, are becoming more widely used for mapping relative differences in soil characteristics in agricultural fields including soil salinity [18]. In this study, the EM38-MK2 was used in vertical mode (Fig. 2, a) to measure the

Fig. 2a: EM38-MK2 during the data acquisition at the study area

Fig. 2b: The SuperSting R8/IP 8 resistivity system and the electrode arrays, during the mapping of the hardpan layer at the study area.

electrical conductivity (EC) along the study area. While, the 2-D electrical resistivity measurements was carried out using SuperSting R8/IP 8 channel multi-electrode resistivity and IP imaging system with 112 electrodes at 3 meter spacing manufactured by Advanced Geosciences, Inc., (AGI), (Fig. 2b).

EM38-MK2 was used in vertical mode to measure the electrical conductivity (EC) at depths of 75 and 150 cm at about 700 sites along the study area (Fig. 3). Moreover, about 157 soil samples were taken using the hand auger at depth intervals of 10-20 cm and 30-40 cm for the same site. The electrical conductivity for the collected soil samples were measured at the lab to correlate with the EM38-Mk2 data. The acquired data using the EM38-MK2 conductivity meter was processed using DAT38MK2 Ver. 1.05 package and exported to XYZ format for contouring.

2-D electrical imaging/tomography survey was implemented in this study along some selected profiles to map the hardpan layer at the area of study. The 2-D electrical resistivity measurements was carried out using SuperSting R8/IP 8 channel multi-electrode resistivity and IP imaging system with 112 electrodes at 3 meter spacing

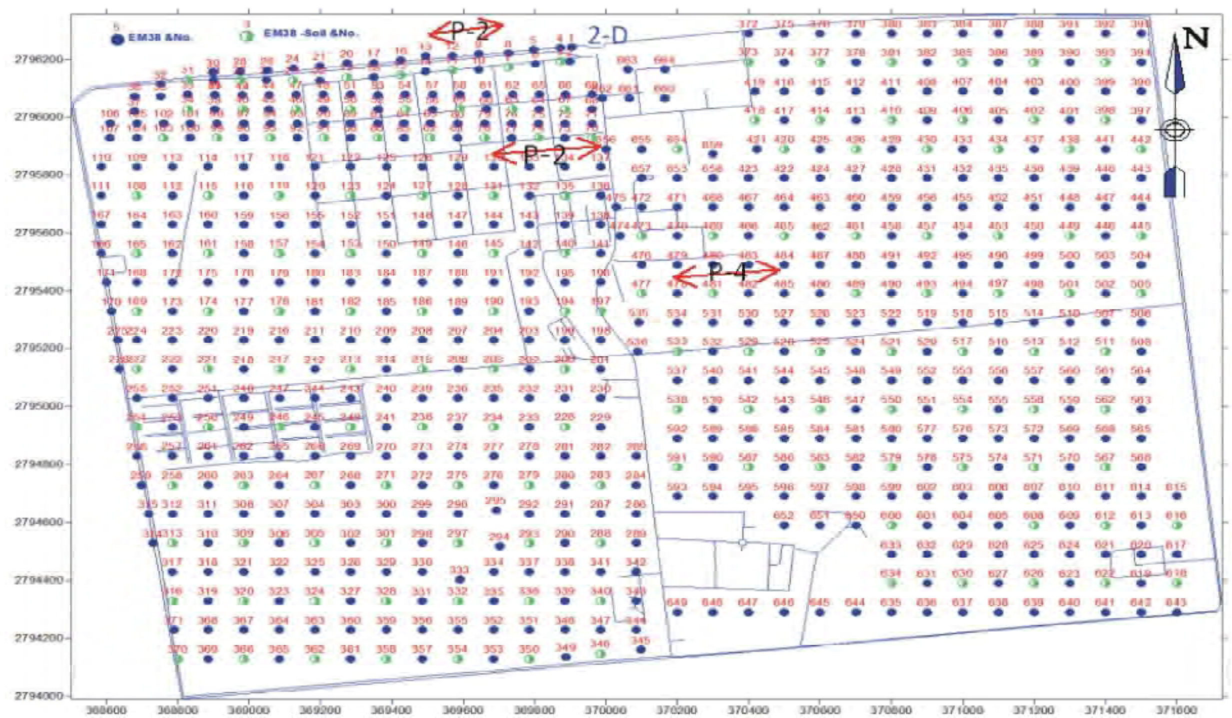

Fig. 3: Base map showing the locations of the EM38, soil samples sites, P-2& P-4 resistivity tomography profiles at study area

manufactured by Advanced Geosciences, Inc., (AGI). At each transect, Dipole-Dipole, Wenner-Schlumberger and Pole-Dipole configurations were implemented and merged during the processing and the interpretation of resistivity data. The locations of Profile 2(P-2) & Profile 4(P-4) are shown in Figure 3. Moreover, one hundred soil pits were excavated at the study area to investigate the physical & chemical characterization of such layer and to help with the interpretation of the resistivity tomograms.

The apparent resistivity data was inverted to create a model of the resistivity of the subsurface using Earthimager 2D Resistivity & IP inversion software by AGI.

RESULTS AND DISCUSSION

Two conductivity/salinity maps were constructed from the lab measurements of EC for the collected 157 soil samples at depth intervals of 10-20 cm and 30-40 cm (Figures 4a & 4b) respectively. Moreover, the processed EC data of the EM38-MK2 conductivity/salinity maps were also constructed at 75 & 150 cm at about 700 sites along the study area (Fig. 5a and b). It is worthy to mention that, both of salinity maps of EM38 are in good match with the salinity maps of lab measurements. The salinity variation found to be change laterally and vertically due to change in soil type/texture and soil moisture. It was found that the areas of high conductivity values of both maps shown in Figures 4a &4b and Figures 5aand b are attributed to existence of sabkha soil at some parts of the study area like the northeastern part of the study area. These sabkha found to be existing at the area of shallow hardpan layer mapped from 2-D resistively data along with soil pits (Fig. 7).

Investigations of the constructed 2-D resistivity tomograms along with the data from the excavated soil pits leads the mapping of the hardpan layer along the study area. Along these resistivity tomograms (Figures 6a and b), vertical variation of different lithological units are recognized.

The main three identified geoelectric-lithologic units along these tomograms (Figures 6a & 6b) are:

Layer-1 is a topsoil zone of loose to weakly consolidated sand. This zone corresponds to the upper part of the very resistive (> 50 ohm-m) layer. The resistive nature of this layer is indicative of dry conditions in the upper part of the measured sections.

Layer-2 this layer has a resistivity range of less than 10 Ohm-m. This low resistivity layer is composed of marl, clay, mudstone, or shale. This layer is existing at different

Fig. 4a: Spatial distribution of measured electrical conductivity for the collected soil samples at interval of 10-20 cm, Al Hassa area, KSA

Fig. 4b: Spatial distribution of measured electrical conductivity for the collected soil samples at interval of 30-40 cm Al Hassa area, KSA

Fig. 5a: Spatial distribution of measured electrical conductivity measured by EM38-Mk2 in vertical mode for 0.5m coil separation, Al Hassa area, KSA

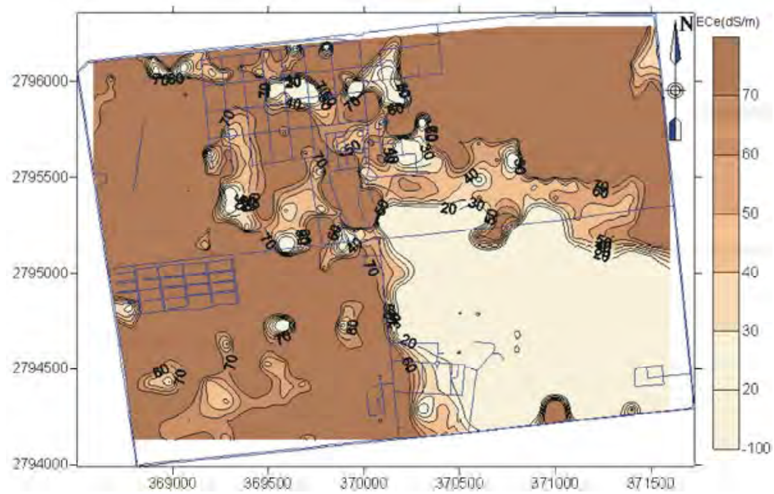

Fig. 5b: Spatial distribution of measured electrical conductivity measured by EM38-Mk2 in vertical mode for 1m coil separation, Al Hassa area, KSA.

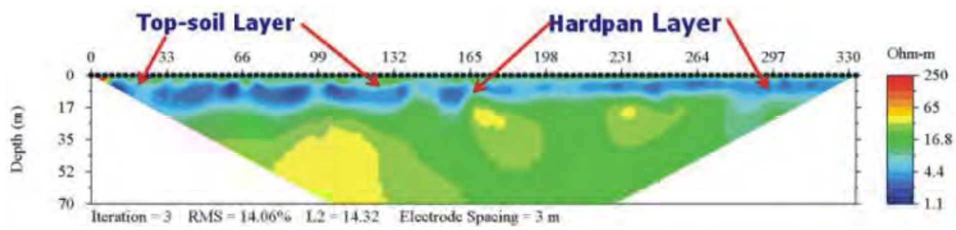

Fig. 6a: Two-D Resistivity profile P-2 (Fig. 3 for location)

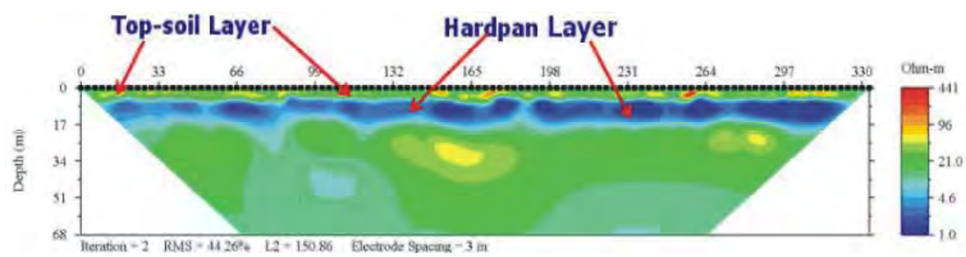

Fig. 6b: Two-D Resistivity profile P-4 (Fig. 3 for location)

depth intervals (Fig. 6, a & 6b). This layer directly affects the level of ground water and thus the accumulation of salt in some locations within the territory of the station, resulting in the presence of some of the sites affected by the salt composed sabkha, especially if it is very shallow. Moreover, it increases the electrical conductivity measured by EM38-Mk2 at these depth intervals.

Layer-3 is a thick zone of sand below the hardpan layer (Layer-2). The moderate to relatively small resistivity in this middle interval suggests partial saturation and/or the presence of a clay-rich matrix.

Figure 7 represents spatial distribution map for the depth of the hardpan Layer based on soil pits and 2-D inverted resistivity tomograms results. The hardpan layer at the most of the territory of the study area is at more depth of 80 cm, the dark green colour of Figure 7. According to these results and based on the criteria of [26]; most of the area is suitable for cultivation except at some locations, which are the north eastern, western and the southern parts (Figure 7). It is worthy to mention that the areas of high conductivity shown in Figures 4a & 4b and Figures 5a & 5b correlated with areas of shallow hardpan layer (Fig. 7). Existing of such hardpan layer at shallow depths is the reason of the sabkha soils of high conductivity. In addition, the existing of the hardpan layer affects the level of ground water and thus the accumulation of salt in some locations within the territory of the station, resulting in the presence of some of the sites affected by the salt composed sabkha.

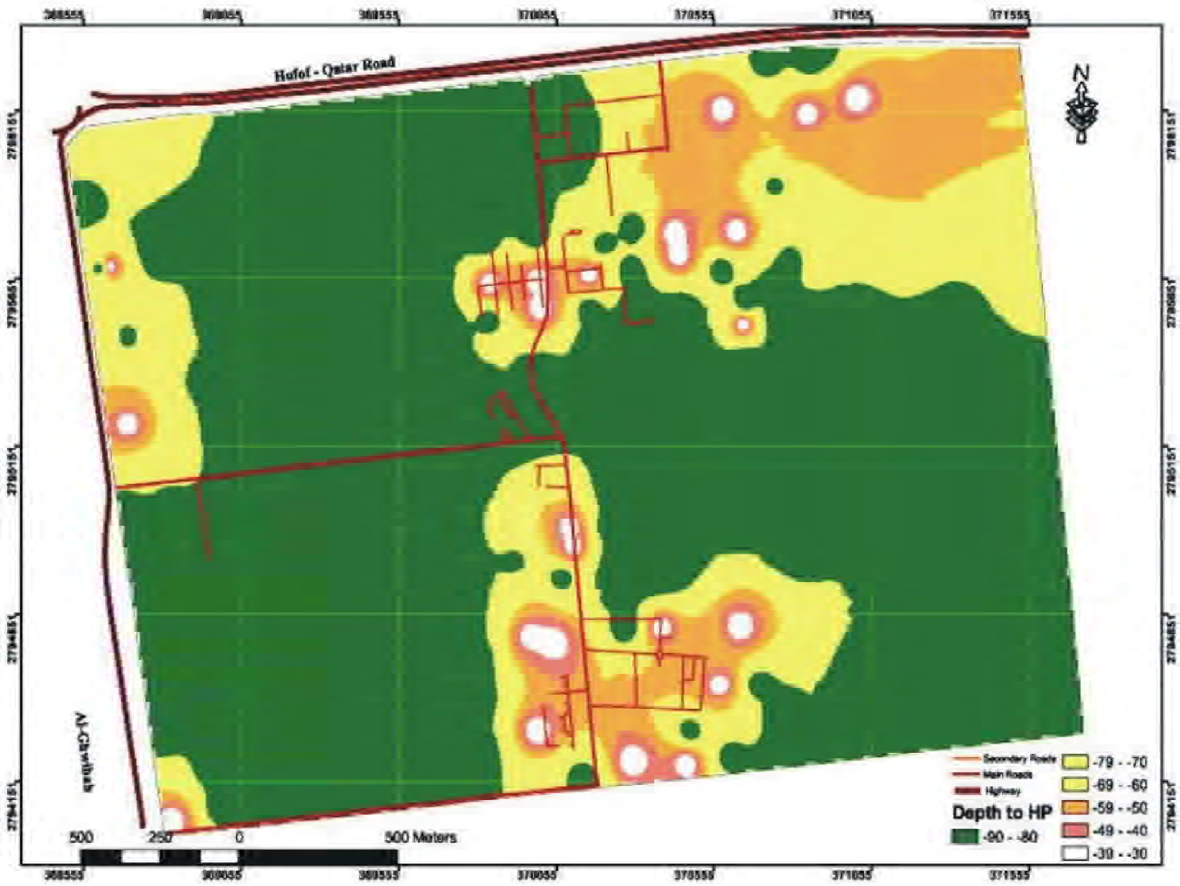

Fig. 7: Spatial Distribution map for the Depth of the Hardpan Layer, the categories of depth interval according to[26]

Shallow water table, which results from existence of hardpan, may have negative or positive effects on grown crops depending on its mineral type, permeability, depth and slope. Depending on nature of the hardpan, shallow groundwater may be either unavailable, a valuable water source for irrigation, or a stress factor due to water logging or salinity. During high atmospheric evaporative demand of the summer season, groundwater through capillary movement from the saturated zone up to the root absorption zone [27]. It reported that in arid and semi-arid dry climates, consumption of groundwater by crops might significantly reduce irrigation requirements [28]. In fact, when water table depth becomes very shallow, the positive influence of groundwater on yield changes to the negative effects due to water logging [29]. This found to develop anoxic conditions case, which reduced root activity, nutrient availability and plant germination and establishment[30]. Water tables near the surface can results into salty spots (sabkha) and reduce crop production because of water logging and high salinity.

CONCLUSIONS

Results of implementing electromagnetic induction & electrical resistivity tomography modern techniques contributed to salinity and hardpan layer problems in this study. Four salinity maps were constructed from lab results & EM38-MK2 conductivity meter measurements data. Both salinity maps of EM38 correlate well with the salinity maps of lab measurements. The tomograms of the acquired 2-D resistivity profiles and data of the excavated soil pits indicate remarkably the hardpan layer at the study area. Information about the depth, thickness of the hardpan layer & the thickness of the topmost soil are given. According to these results, a depth map for the hardpan layer was constructed. Based on criteria of [26]; most of the area is suitable for cultivation except at some locations. The existence of the hardpan layer at shallow depths is found to be the reason for the areas of high salinity at the study area.

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