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# Integration between Surface Geoelectrical and Geotechnical Datasets in Salah Al-DinArea, Central Iraq

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## ABSTRACT

This research aims to assess some geotechnical properties and aquifer parameters and consequently the applicability of predicting its properties from surface electrical resistivity. The main output is to get several geotechnical properties particularly those concerned with groundwater studies (such as porosity, and permeability) and aquifer properties (such as resistivity, hydraulic conductivity and transmissivity). To achieve this goal, interpretations of 50 Schlumberger VES points distributed along 5 profiles, located in Salah Al-Din Governorate in central Iraq, have been carried out. Sounding curve types obtained in the area are mostly QQ and HK types. The application of VES technique has provided detailed information on the thickness and hydrogeoelectrical characteristics of the aquifers in the study area. Based on VES interpretation and their correlation with available geotechnical data, four geoelectric layers were identified; these are topsoil, unsaturated zone, saturated zone and the conductive layer. In addition, two aquifers have been identified in the area under study. The upper is unconfined appeared mainly in eastern side of Tigris River, whereas the lower is semiconfined-confined appeared mainly in the western side of the River. Different target zones for groundwater potential have been recognized on the basis of geoelectric parameters that range between poor-good groundwater potential. Generally, the quality of ground water is considered to be brackish with respect to their total dissolved solids (TDS). Several discontinuities (probably faults) have been delineated according to the form of resistivity curves and geoelectrical sections. The study states that the resistivity values increase with increasing gypsum content in dry condition. But for saturated soil with high water content, the conductivity increases and hence the resistivity decreases. Besides, the increase in gypsum content leads to increase the porosity, then the resistivity increases too. A remarkable correlation is found among topsoil gypsum content, surface resistivity and porosity with Landsat image.

**Keywords:** Hydrogeophysical Electrical Resistivity; Vertical Electrical Sounding

(VES); Geoelectrical Section; (VES); Geoeletrical and Geotechnical parameters; Aquifer Parameters.

# التكامل بين بيانات الجيوكهربائية السطحية والجيوتكنيكية في منطقة صلاح الدين- وسط العراق

## الخلاصة

يهدف هذا البحث إلى تقييم الخواص الجيوتكنيكية ومعاملات طبقة المياه الجوفية وإمكانية التنبؤ بخواصها إعتمادا على القياسات الكهربائية السطحية. تتمثل المخرجات الرئيسة في الحصول على عدة خواص جيوتكنيكية خاصة بدراسات المياه الجوفية (مثل المسامية والنفاذية) وخواص طبقة المياه الجوفية (مثل المقاومة النوعية الكهربائية والتوصيلية الهيدروليكية والانتاجية). لتحقيق هذا الهدف، تم تفسير 50 نقطة جس كهربائية VES بترتيب شلمبرجر موزعة على 5 مسارات تقع في محافظة صلاح الدين في وسط العراق. تم الحصول على منحنيات الجس في المنطقة وهي في معظمها من نوع QQ و HK. وقد وفر تطبيق تقنية VES معلومات مفصلة عن السمك والخصائص الهيدروجيوكهربائية لطبقات المياه الجوفية في منطقة الدراسة . استنادا إلى تفسير نقط الجس VES وعلاقتها مع البيانات الجيوتكنيكية المتاحة ، تم تحديد أربع طبقات جيوكهربائية، وهذه هي التربة السطحية، المنطقة غير المشبعة، المنطقة المشبعة والطبقة الموصلة .وبالإضافة إلى ذلك، تم التعرف على اثنين من طبقات المياه الجوفية في المنطقة قيد الدراسة .الطبقة العليا غير المحصورة ظهرت أساسا في الجانب الشرقي من نهر دجلة، بينما تقتصر الطبقة السفلى شبه المحصورة أساسا في الجانب الغربي من النهر. تم التعرف على المناطق المستهدفة ذات الإمكانات المختلفة المتعلقة بالمياه الجوفية على أساس المعاملات الجيوكهربائية والتي تتراوح ما بين مناطق مياه جوفية محتملة فقيرة- جيدة .عموما، تعتبر نوعية المياه الجوفية قليلة الملوحة على أساس المواد الصلبة الكلية الذائبة فيها. وقد جرى تحديد عدة انقطاعات (ربما صدوع) وفقا لشكل منحنيات المقاومة النوعية والمقاطع الجيوكهربائية. بينت الدراسة أن قيم المقاومة النوعية تزداد مع زيادة المحتوى الجبسي في حالة الجفاف .ولكن بالنسبة للتربة المشبعة ذات المحتوى العالي للماء, ستزداد االتوصيلية وبالتالي تقل المقاومة النوعية. الى جانب ذلك، تؤدي الزيادة في المحتوى الجبسي إلى زيادة المسامية، ثم زيادة المقاومة النوعية أيضا. وجدت علاقة ملحوظة بين المحتوى الجبسي للتربة السطحية والمقاومة النوعية السطحية و المسامية مع مخيلة لاندسات.

## INTRODUCTION

Geophysical methods are nondestructive techniques that use the physical properties of earth materials to infer subsurface structure. Changes in stratigraphy and lithology are mapped through measurements from the surface. Not only can geophysical methods reduce the number of expensive boreholes required for site investigations, but they can provide detailed information of the subsurface between boreholes [1].

Geoelectrical resistivity techniques are increasingly used for a wide range of engineering geophysics, geotechnical and environmental problems. Because of simplicity in field implementation, resistivity surveys are still used in most investigations, however, they can lead to distort and misleading results in heterogeneous areas. Subsurface resistivities may be estimated from surface resistivity measurements. Also, it has been discovered that resistivity method is cost effective, efficient and less time consuming in geotechnical investigation than most geotechnical tests [2]. Another important advantage of electrical resistivity is that it produces continuous information of the subsurface and probes into several meters below the surface.

Electrical methods measure the bulk resistivity of the subsurface to determine geologic structure and /or physical properties of the geological materials. Resistivities of soils/rocks generally depend on the water content (porosity), the resistivity of the water, the clay content and the content of metallic minerals [3].

Interpretation of electrical measurement can give an understanding of the subsurface composition (geology), depth to competent layer (soil). Some considerations help in the determination of the resistivity of soils/rocks. As clean sands and gravels, which have high porosities, make good aquifers when saturated with water they can easily differentiated from low resistivity impermeable clays and marls, and also from bedrock [4]. Besides, a hard rock without pores or fractures is very resistive to the flow of electric current; dry sand without water is very resistive; porous or fractured rock bearing free water has resistivity, which depends on the resistivity of the water and on the porosity of the rock; impermeable clay layer, which is wet, has low resistivity but may not contain enough yields for successful groundwater exploitation [5]; mineral ore bodies (iron, sulphides) have very low resistivity due to their electronic conduction, usually lower or much lower than 1ohm.m [3].

The present paper reports recent electrical resistivity surveys in a popular area within Salah Al-Din Governorate in central Iraq. The main objective of the present study is to evaluate and integrate some geotechnical, hydrogeological properties and the hydraulic parameters of the penetrated aquifers extracted from surface resistivity parameters and boreholes drilling in estimating aquifer properties.

## BASIC THEORY

The theory of electrical resistivity suggests that electric the current flows in the subsurface soil by electrolytic rather than electronic processes (Kearey et al., 2002)[6]. Hence, porosity is the major control of resistivity of rocks, and that resistivity generally increases as porosity decreases. Porosity and cementation, on the other hand, are related.

Electrical resistivity studies in geophysics may be understood in the context of current flow through a subsurface medium consisting of layers of materials with different individual resistivities. For simplicity, all layers are assumed to be horizontal. The resistivity $\rho$ of a material is a measure of how well the material retards the flow of electrical current.

The resistivity method depends on the property of resistivity, which is the electrical resistance between opposite faces of a unit cube of a given soil or rock. The resistivity method is based on the fact that any subsurface variation in conductivity alters the pattern of current flow in the ground and therefore changes the distribution of electric potential at the surface. Since the electrical resistivity of such factors as superficial deposits and bedrock differ from each other, the resistivity method may be used in their detection and to give their approximate thicknesses, relative positions and depths.

The resistivity measurements are normally made by injecting current into the ground through two current electrodes (C1 and C2), and measuring the resulting voltage difference at two potential electrodes (P1 and P2) over a distance $a$. The current and potential electrodes are generally arranged in a linear pattern. The electrodes are arranged either in standard configuration (Wenner Array) or by using an expanding electrodes array centered on a reference point (Sclumberger array). The depth of penetration increases with increasing electrode distance ($a$). Resistivity meters normally give a resistance value:

$$R = \frac{V}{I} \quad \dots (1)$$

So in practice the apparent resistivity value is calculated by

$$\rho_a = kR \quad \dots (2)$$

From the current ($I$) and voltage ($V$) values, an apparent resistivity ($\rho_a$) value is calculated from dividing the measured potential difference by the applied current times the geometric factor ($k$),

$$\rho_a = k(\frac{V}{I}) \quad \dots (3)$$

Where $k$ is the geometric factor which depends on the arrangement of the four electrodes. Figure 1 shows the common arrays used in resistivity surveys together with their geometric factors. The calculated resistivity value is not the true resistivity of the subsurface, but an apparent resistivity value. To determine the true subsurface resistivity, an inversion of the measured apparent resistivity values using a computer program must be carried out.

The apparent resistivity is the bulk average resistivity of all soils and rocks influencing the flow of current. Substantial quantitative modeling is possible using either modeling or master curves. When the ground consists of a number of more or less horizontal layers, knowledge of the vertical variation in resistivity is required [7, 8].

Vertical electrical sounding (VES) is based on the fact that the current penetrates continuously deeper with increasing separation of the current electrodes and thereby reflects information about the resistivity variation with depth. The Schlumberger method although not as widely as used by engineers, is more suitable for quantitative interpretation [9]. Geophysical prospecting by means of VES is currently applied in the hydrogeological and geotechnical problems. It then means that electrical resistivity could be used to determine the degree of cementation to better characterize the subsurface soil for engineering foundation. Another important factor in knowing soil strength is the amount of fine (clay) present. Clay content in soil affects both soil strength as well as its resistivity [2]. Clay has very low electrical resistivity, therefore its contents in the soil may change the relationship between electrical parameter and soil strength [2]. Thus, the total resistivity of any medium is a function of some variables:

$$\rho = F(C, n, \Phi, \rho_w, T, \rho_m, S_w) \quad \dots (4)$$

Where $C$ = clay content, $n$ = ionic exchange capacity of clay mineral, $\rho_w$= resistivity of pore water, $T$ =temperature, $\rho_m$= matrix resistivity, $S_w$= degree of saturation [10].

The VES interpretation results (layer resistivities and thicknesses) were later used to derive the geoelectric parameters (the so-called Dar Zarrouk parameters) as a basis for the evaluation of aquifer properties such as aquifer transmissivity [11, 12, 13]. In hydrogeology, the geometry of the aquifer systems may be defined with respect to these geoelectrical parameters namely [14] sees Figure (1):

### Longitudinal conductance (ohm)$^{-1}$:

It is the total conductance along the direction of the bedding planes of ($n$) layers which is equal to total thickness of layers ($H$) divided by the total resistivities of layers, when the formation is with high conductivity (low resistivity) between two media of high resistivity. The total longitudinal unit conductance ($S_L$) is defined as:

$$S_L = \sum_{i=1}^{n} \frac{h_i}{\rho_i} \quad \ldots (5)$$

While the average longitudinal resistivity ($\rho_L$) is defined as the average resistivity along the bedding planes or equal to the total thickness ($H$) divided by the longitudinal conductance ($S_L$):

$$\rho_L = \frac{1}{\sigma_L} = \frac{H}{S_L} = \frac{\sum_{i=1}^{n} h_i}{\sum_{i=1}^{n} \frac{h_i}{\rho_i}} \quad \ldots (6)$$

### Transverse resistance (ohm.m$^2$):

It is the total transverse unit resistance ($R_T$) through a (1m$^2$) column cut perpendicular to the bedding planes of sequence of layers ($n$) with resistivities ($\rho_n$) and thicknesses ($h_n$), it is given by:

The total transverse unit resistance ($R_T$) is defined as:

$$R_T = \sum_{i=1}^{n} \rho_i h_i \quad \ldots (7)$$

Whereas, the transverse resistivity ($\rho_T$) is the average resistivity normal to the bedding planes of ($n$) layers with total thickness ($H$), or is the transverse resistance divided by the total thickness of layers, as follow:

$$\rho_T = \frac{R_T}{H} = \frac{\sum_{i=1}^{n} h_i \rho_i}{\sum_{i=1}^{n} h_i} \quad \ldots (8)$$

Always $\rho_T > \rho_L$ where the current exceeds the $\rho_L$ if the layers are horizontal.

### Anisotropy ($\lambda$):

The coefficient of anisotropy ($\lambda$) is defined as:

$$\lambda = \sqrt{\frac{\rho_T}{\rho_L}} = \frac{\sqrt{R_T S_L}}{H} \quad \ldots (9)$$

Higher values of anisotropy indicate sediments inhomogeneity.

An analytical relationship between transmissivity and the Dar Zarrouk parameters has been established:

$$T = \frac{K}{\rho}(R_T)\ ;\ \text{or} \qquad \ldots (10)$$

$$T = K\sigma(R_T) \qquad \ldots (11)$$

$$T = K\rho S_L \qquad \ldots\ (12)$$

Where $T$ is the transmissivity ($m^2/d$) defined as the product of aquifer hydraulic conductivity ($K$) and thickness ($h$), i.e.

$$T = Kh \qquad \ldots (13)$$

Besides, a correlation between hydraulic and electrical properties is possible as both properties are related to the pore space structure and heterogeneity. Thus, estimating aquifer properties and more specifically relating experimental expressions between electrical resistivity of an aquifer and its hydraulic parameters (such as hydraulic conductivity, apparent formation factor), or between transverse resistance and its transmissivity have been found by many researchers such as Niwas and Singhal, 1981, 1985 [12, 15]; Kelly and Reiter, 1984 [16]; Kelly and Frohlich, 1985 [17] and recently by Okiongbo and Akpofure (2012) [18] and Okiongbo and Odubo (2012) [19].

## GEOLOGY OF THE AREA

The area under study is located in central Iraq. Topographically, it is flat to gently undulating with some local elevated features represented by river terraces and several depressions. The whole area is bounded from the west by the eastern escarpment of the Wadi Al-Tharthar, on the NE by Jabal Hamrin and Jabal Makhul, and from the south by Adhaim River. Tigris River transverses the area longitudinally from NW to SE. Geologically, the area is built up by two types of sediments, sand, gravel, clay which belong to recent sediments (Quaternary-Pleistocene) and Mukdadia Formation (Pliocene), whereas the other type is sandstone, siltstone and claystone of Injana Formation (U. Miocene). Tectonically, the area belongs to the Stable and Unstable Shelf geotectonic units; its eastern part is situated in the most Tigris Subzone within the Mesopotamian zone [20] as in Figure (2).

## RESULTS AND INTERPRETATION

### Interpretation of Sounding Curves

One dimensional electrical resistivity survey using Schlumberger Vertical Electrical Sounding (VES) was carried out for 50 VES points distributed along 5 NE-SW profiles. This survey was achieved by FCSDIP (1989) [21] as a part of hydrogeological exploration work in Salah Al-Din Governorate in central Iraq. The approximate distance between profiles is 10 km with VES spacing of 2.5-5 km.

The preliminary interpretation of the measured VES points was made using the partial curve matching with the assistance of auxiliary graphs. ABEM VES software was used to determine the thicknesses and depths of different geoelectrical layers and their resistivities.

The VES curves show a range of 3-geoelectric layers (K), 4-geoelectric layers (QQ, HK, KQ) and to complex 5-geoelectric layers (HKQ). Table 1 shows the type and number of the interpreted geoelectrical curves which indicates clearly that the QQ, HK and HKQ are the common curves with 4-5 geoelectrical layers. The interpreted VES points may be subdivided into three main groups corresponding to distinctly different electrical and geologic sections Figure (3).

**Group I:** This group of sounding curves represents the predominant type which is QQ ($\rho_1>\rho_2>\rho_3>\rho_4$).

**Group II:** This group is of HK ($\rho_1>\rho_2<\rho_3>\rho_4$) and HKQ ($\rho_1>\rho_2>\rho_3<\rho_4>\rho_5$) types.

**Group III:** This group represents the KQ ($\rho_1<\rho_2>\rho_3>\rho_4$) and K ($\rho_1<\rho_2>\rho_3$) types.

The general shape of sounding curves refers to the descending terminal branch and in turn refers to the decreasing resistivity with depth. In addition, the area is characterized by its wide range of resistivities of unconsolidated sediments reflecting its alluvial nature.

**Geoelectrical Sections**

To obtain valuable information concerning the lithological and hydrogeological information about the investigated area, data of electrical resistivities and thicknesses obtained from VES curves were represented in geoelectrical sections along each profile. To overcome the problems of non-uniqueness which are well known in 1-D sounding [22], borehole and other available geological information are involved in such sections (as an example, see Figure (4).

The interpretation of VES curves and examining the geoelectrical section, the general description and information indicate the presence of 4 main geoelectrical layers:

**Geoelectrical Layer (1):** represents the thin topsoil above watertable with high resistivities (20-2815 ohm.m), 1-10 m thick representing the recent deposits (sand, gravel, clay, and secondary gypsum).

**Geoelectrical Layer (2):** represents the unsaturated zone with medium-high resistivities (11-740 ohm.m) and variable thickness ranges between 2-40 m representing sand and gravel sediments.

**Geoelectrical Layer (3):** represents the saturated zone with medium-low resistivities which could be subdivided into two sublayers according to the presence or absence of each one.

**Upper Saturated Zone (S.Z.1) ($3^-$):** characterizes by its medium resistivities (10-74 ohm.m) and thickness 6 - 100 m which may represent sand, gravel and clay with fresh-brackish water.

**Lower Saturated Zone (S.Z.2) ($3^=$):** characterizes by its low resistivities (4.8-16 ohm.m) and thickness 12-214 m. representing the sand and clay with increasing salinity.

**Geoelectrical Layer (4):** represents the very low resistivity layer (1-5.5 ohm.m) which may represent the clay layer with saline water type.

It appears from the geoelectrical sections that there are two main aquifers, both are of stratified type. The first aquifer which is considered as unconfined-semiconfined, is appeared mainly in the eastern side of Tigris River with maximum thickness 100 m and decreases toward the outcrop of the second aquifer. Whereas, the second confined-semiconfined aquifer is mainly appeared in the western side of Tigris River with thickness exceeds 200 m, besides small regions of the first unconfined layer (with maximum thickness 55 m) which decreases toward the outcrop of the second aquifer. Moreover, several discontinuities have been identified with general trend N-S.

## Aquifer Properties Maps with Determination of Yield Potential

Other geoelectrical parameters that have been determined from the resistivity and thickness of geoelectrical layers are the transverse resistance ($R_T$), longitudinal conductance ($S_L$) and anisotropy ($l$). If the aquifer is sandwiched between the resistive unsaturated zone and resistive bedrock, so the unique electrical parameter for aquifer is its longitudinal conductance ($S_L$). The longitudinal conductance cannot be used directly in correlation with transmissivity since it is the ratio of the thickness to resistivity rather than the product. To determine the average longitudinal conductance with good degree of confidence requires an independent measure of the saturated zone thickness. Low values of this parameter indicate thin aquifer. On the contrary, high values represent maximum thickness and indicate a good groundwater potential.

For aquifer located between resistive unsaturated zone and low permeability material as aquifer base situated on the top of fine sand and silt, such as most of the area under study, here the unique parameter defined for the aquifer is its transverse resistance $T_R$ (the product of thickness and average resistivity) which can be correlated with transmissivity. In such case, it is possible to do a complete curve interpretation and average aquifer transverse resistivity is obtained and also can be used in correlations. Dar Zarrouk parameters can be determined approximately from the sounding curves following the graphical method that explained by Kunetz (1966) [23] and Zohdy et al. (1980)[9].

Four contour maps were constructed from VES data representing the transverse resistance and longitudinal conductance of both aquifers. Figures see (5 to 8). By examining the transverse resistance maps Figures (5 and 6), one can locate the promising area of water bearing zone. For the first aquifer as in Figure (5), the maximum transverse resistance value is around 4000 ohm.m$^2$ in eastern Tigris River near Hamrin mountain, its value decreases gradually toward the river reaching less than 500 ohm.m$^2$. Whereas, lower values (< 200-2500 ohm.m$^2$) have been obtained in the western side. For the second aquifer, the transverse resistance value as in Figure (6) increases toward the river with a maximum value around 3300 ohm.m$^2$ in eastern side near Hamrin mountain and decreases gradually toward Tigris river. In the western side, its values are ranging between 250 to >1000 ohm.m$^2$.

From transverse resistance contour maps, one may conclude that as $T_R$ values increase from one sounding point to the next, this generally means that the thickness of the resistive deposits (gravels) in the section also increases. However the increase in $T_R$ might be called also by increase the resistivity values.

Examining the longitudinal conductance maps for the first aquifer asin Figure (7), the maximum and minimum values are around 11 and 0.2 mhos respectively.

While for the second aquifer as in Figure (8), the maximum and minimum value of longitudinal conductance are around 36 and 2 mhos respectively. Thus, low values of this parameter indicates a thin aquifer, and obviously these areas may be considered as the lowest priority as regards groundwater exploration. On the contrary, high values represent the maximum thickness and indicating a good groundwater potential.

Therefore, the use of Dar Zarrouk parameters is considered to be the basis for defining target areas of good groundwater potential and accordingly, the following zones may be recognized:

**Zone(1):** $T_R > 3000$ ohm.m$^2$ considered as good groundwater potential with fresh water is expected.

**Zone (2):** $T_R$ value is ranging between 2000-3000 ohm.m$^2$ with increasing salinity.

**Zone (3):** $T_R$ value is ranging between 1500-2000 ohm.m$^2$ with decreasing aquifer potential and increasing salinity.

**Zone (4):** $T_R$ value is ranging between 1000-1500 ohm.m$^2$, the aquifer is expected to be of poor yield.

**Zone (5):** $T_R < 1000$ ohm.m$^2$ poor yield aquifer, with saline water type is expected.

Comparing the transverse resistance and longitudinal conductance maps for both aquifers with their resistivity maps Figures (9 and 10), it is clear that the increase in $T_R$ might be called also by increase the resistivity values as shown in Figures (5 and 9) for the first aquifer and Figures (6 and 10) for the second one. While, for longitudinal conductance, it decreases when resistivity value increases Figures (7 and 9) for the 1st aquifer and Figures (8 and 10) for the 2nd).

Considering conductivity maps for the first aquifer Figure (11) the maximum and minimum values are 0.143 and 0.01 mhos/m respectively. While for the second aquifer Figure (12), the maximum and minimum values are 0.227 and 0.038 mho/m respectively. Thus, conductivity values decrease when resistivity values increase.

By comparing formation factor maps Figures (13and 14), porosity maps Figures (15 and 16) and permeability maps Figures (17 and 18) for the first and second aquifer respectively with their resistivity maps Figures (9 and 10), it is clear that the formation factor, porosity and permeability values increase when the aquifer resistivity value increases.

## Hydraulic and Physical Parameters

Determination of aquifer parameters and consequently that applicability of predicating aquifer properties are based on the results from surface electrical resistivity and any available pumping test. Table (2) summarized the results of VES interpretation and the obtained aquifer parameters that are presented in detail for 10 sites to illustrate the interpretation procedure used.

For estimating aquifer parameters, hydraulic conductivity ($K$) and transmissivity ($T$), it is necessary to determine the average aquifer resistivity ($\rho_f$), water resistivity ($r_w$), saturated thickness and formation factor (F.F). The use of formation factor, or normalized aquifer resistivity ($r^-_f = r_f * r^-_w / r_w$ where $r^-_w$ is the average water resistivity) is essential in any hydrogeological investigation. Besides, the transverse resistance can be used directly in correlations with aquifer transmissivity. Consequently, good correlations may be possible between aquifer hydraulic conductivity and transmissivity. Porosities have been estimated by using the formation factor that is related to porosity by Archie formula (1942) [24]. Hydraulic conductivity was obtained by dividing the field transmissivity by the electrical aquifer thickness. Also the hydraulic conductivity and transmissivity may be calculated by knowing the values of the constant ($Ks$) if the transverse resistance and conductivity of the aquifer are obtained by resistivity measurements.

## Gypsum Content Distribution

To show the relation between surface electrical resistivity and gypsum contents in the topsoils, the distribution of gypsum will be studied. The data used for this purpose obtained from the gypseous soil database project of SCGSM (2003) [25]. The constructed gypsum content distribution map Figure (19 a) for the study area, shows that the maximum and minimum values of gypsum content are 70% to about 12% respectively. The relation between gypsum content distribution in the topsoils and surface electrical resistivity shows that the resistivity values increase with the presence of dry gypsum.

## Gypsum Content, Porosity, Surface Resistivity and Landsat Image

Gypseous soils cover 31.7% of the surface area of Iraq with gypsum content ranges between 10-70% [26]. Great developments in gypseous soils have been taken place in the last two decades. In the area of study, its range is between 11.6-70 %, so their study is important due to the need of construction of major projects such as hydraulic structures, industrials and buildings.

In this study, it is obvious from Figures (19 a and b) that the increase in gypsum content in soils and surface resistivity values depends mainly on water content in soils. The resistivity values increase with the presence of dry gypsum (anhydrite $CaSO_4$). So the increase in salt proportion, in general, and especially gypsum will decrease soil conductivity and increase its resistivity. But for saturated soil, i.e. with high water content, in this case the conductivity increases with the presence of dissolved salts and hence the resistivity decrease.

Considering the relation between surface resistivity maps with the satellite image Figures (19 b and d) of the study area, it is clear that there is concordance between them. In the image, Tigris River course, appeared as dark green color, is associated with low resistivity values. Moreover, dark grey color which is usually reflected by wet regions (such as temporary channels and lakes; water covered areas, flood areas and sabkha areas) are associated with low surface resistivity values. While, light grey color reflected by dry regions (such as those non covered areas).

The increase of gypsum content leads to increase the porosity, then the resistivity increases too as the resistivity has an inverse relation with electric conductivity which is shown clearly in Figures (19 a and c). So the results obtained from electrical resistivity method give a preliminary indication about gypsum content distribution.

Moreover, a remarkable correlation between the gypsum content and porosity of the topsoil with Landsat image is noticed. Where the dark brown color represents the saturated soil with high porosity and low gypsum content, while the fade brown represents the dry soil with low porosity and high gypsum content.

## CONCLUSIONS

The results of this study have led to the following conclusions:

1. Sounding curve types obtained in the area are mostly QQ and HK types.
2. The application of VES technique has provided detailed information on the thickness and hydrogeoelectrical characteristics of the aquifers in the study area. Four geoelectric layers were identified; these are topsoil, unsaturated zone, saturated zone and the conductive layer.
3. Two aquifers have been identified in the area under study. The upper is unconfined appeared mainly in eastern side of Tigris River, whereas the lower is semiconfined-confined appeared mainly in the western side of the River.
4. Different target zones for groundwater potential have been recognized on the basis of geoelectric parameters (mainly transverse resistance $T_R$) that range between poor-good groundwater potential. Generally the quality of ground water is considered to be brackish with respect to their total dissolved solids (TDS).
5. Several discontinuities (probably faults) have been delineated according to the form of resistivity curves and geoelectrical sections.
6. The hydraulic parameters of the first aquifer are as follows: porosity 6–49 %, hydraulic conductivity 0.2 - 47 m / day, tranmissivity 10-1300 $m^2$/day, whereas for the second aquifer are: porosity 14-80 %, hydraulic conductivity 0.1-7.8 m/day and transmissivity 11-185 $m^2$/day.
7. A remarkable correlation is found among topsoil gypsum content, surface resistivity and porosity with Landsat image.

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## Table (1) Types and numbers of the interpreted VES curves.

| Type of curve | No. of interpreted curves |
|---|---|
| QQ | 26 |
| HK-HKQ | 16 |
| KQ | 5 |
| K | 3 |
| **Total** | 50 VES points |

## Table (2) Results of VES points and pumping Tests.

### a. First Aquifer

| VES No. | Water Resistivity $\rho_w$ (ohm.m) | Aquifer Resistivity $\rho_f$ (ohm.m) | Aquifer Thickness $H$ (m) | Transverse Resistance $(T$ (ohm.m$^2$) | Longitudinal Conductance ($S_L$) (mhos) | Water Conductivity ($Ec$) (µmhos) | Total Dissolved Solids ($TDS$) (ppm) | Formation Factor ($F.F$) $\rho_f/\rho_w$ | Porosity ($n$ %) | Hydraulic Conductivity $K=T$(field)$/h$ (m/day) | Normalized Aquifer Resistivity (ohm.m) $\rho'=\rho_f\rho'_w/\rho_w$ $\rho'_w=3.3146$ | $T_R/\rho_w=F.F\times H$ | NormalisedTransverse Resistance $T_R'=T_R\,\rho'_w/\rho_w$ (ohm.m$^2$) | Aquifer Transmissivity (m$^2$/day) $T=(K\sigma)T_R'$ Av.$K\sigma=0.2176$ (1$^{st}$ Aquifer) Av.$K\sigma=0.103$ (2$^{nd}$ Aquifer) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P1/1 | 3.6 | 46 | 7 | 322 | 0.15 | 2780 | 2014 | 12.8 | 14 | 4.26 | 42.4 | 89.4 | 296.5 | 64.5 |
| P1/5 | 3.22 | 18 | 9 | 162 | 0.5 | 3120 | 2426 | 5.6 | 27 | 3.44 | 18.5 | 50.31 | 166.8 | 36.3 |
| P2/1 | 3.6 | 37 | 7.4 | 274 | 0.2 | 2780 | 2014 | 10.3 | 17 | 4.1 | 34.1 | 76.1 | 252.3 | 54.9 |
| P2/8 | 2.8 | 27.6 | 63 | 1739 | 2.3 | 3864 | 2777 | 9.9 | 17 | - | 32.7 | 621.1 | 2058.6 | 448 |
| P3/1 | 3.6 | 10.2 | 83 | 847 | 8.1 | 2780 | 2014 | 2.8 | 44.8 | 0.36 | 9.4 | 235.3 | 779.9 | 169.7 |
| P3/10 | 2.6 | 35 | 105.3 | 3686 | 3 | 3790 | 3216 | 13.5 | 14 | - | 44.6 | 1417.7 | 4699.1 | 1022.5 |
| P4/9 | 2 | 46 | 12 | 552 | 0.26 | 6000 | 4341 | 23 | 9 | 11.36 | 76.2 | 276 | 914.8 | 199.1 |
| P4/10 | 2 | 48.3 | 5.7 | 275 | 0.12 | 3540 | 2597 | 24.2 | 9 | 47.1 | 80 | 137.5 | 455.8 | 99.2 |
| P5/2 | 2.5 | 50.6 | 31.5 | 1594 | 0.62 | 4030 | 3426 | 20.2 | 10 | 6.1 | 67.1 | 637.6 | 2013.4 | 438.1 |
| P5/5 | 2.5 | 17 | 11 | 187 | 0.7 | 4030 | 3426 | 6.8 | 23 | 17.3 | 22.5 | 74.8 | 247.9 | 53.9 |

### b. Second Aquifer

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P1/1 | 3.6 | 5 | 125 | 625 | 25 | 2780 | 2014 | 1.38 | 78 | 0.24 | 4.6 | 173.6 | 575.5 | 59.3 |
| P1/5 | 3.22 | 8.5 | 12 | 102 | 1.4 | 3120 | 2426 | 2.64 | 47 | 2.6 | 18.45 | 31.7 | 105 | 10.8 |
| P2/1 | 3.6 | 6.8 | 159 | 1081 | 23.4 | 2780 | 2014 | 1.89 | 61 | 0.19 | 33.9 | 300.3 | 995.3 | 102.5 |
| P2/8 | 2.8 | - | - | - | - | - | - | - | - | - | - | - | - | - |
| P3/1 | 3.6 | - | - | - | - | - | - | - | - | - | - | - | - | - |
| P3/10 | 2.6 | - | - | - | - | - | - | - | - | - | - | - | - | - |
| P4/9 | 2 | 7.6 | 115.5 | 878 | 15.2 | 6000 | 4341 | 3.8 | 36 | 1.18 | 75.9 | 439 | 1455.2 | 149.9 |
| P4/10 | 2 | 4.8 | 86 | 413 | 17.9 | 3540 | 2597 | 2.4 | 51 | 3.12 | 79.7 | 206.5 | 684.5 | 70.5 |
| P5/2 | 2.5 | 13 | 24.6 | 320 | 1.9 | 4030 | 3426 | 5.2 | 28 | 7.75 | 17.2 | 128 | 424.3 | 43.7 |
| P5/5 | 2.5 | 11 | 125 | 1375 | 10.9 | 4030 | 3426 | 4.4 | 32 | 1.53 | 22.4 | 550 | 1823 | 187.8 |

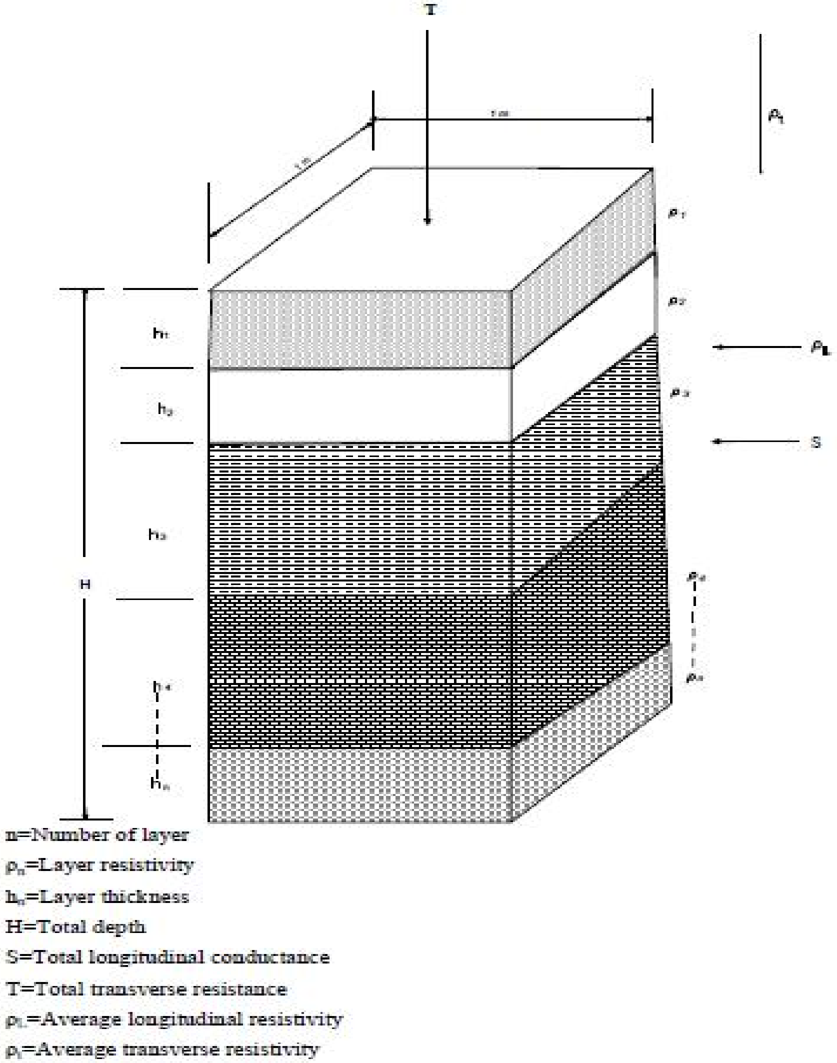


**Figure (1) a typical geoelectrical section [14].**

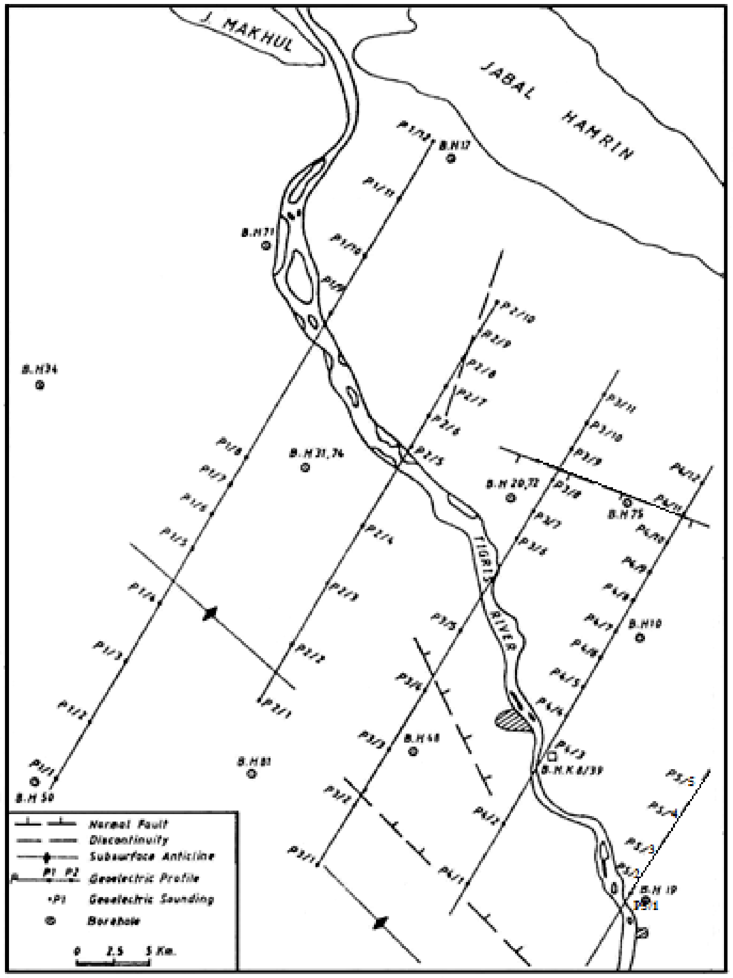


**Figure (2) Structural map with the location of VES points, Traverses and drilled boreholes [21].**

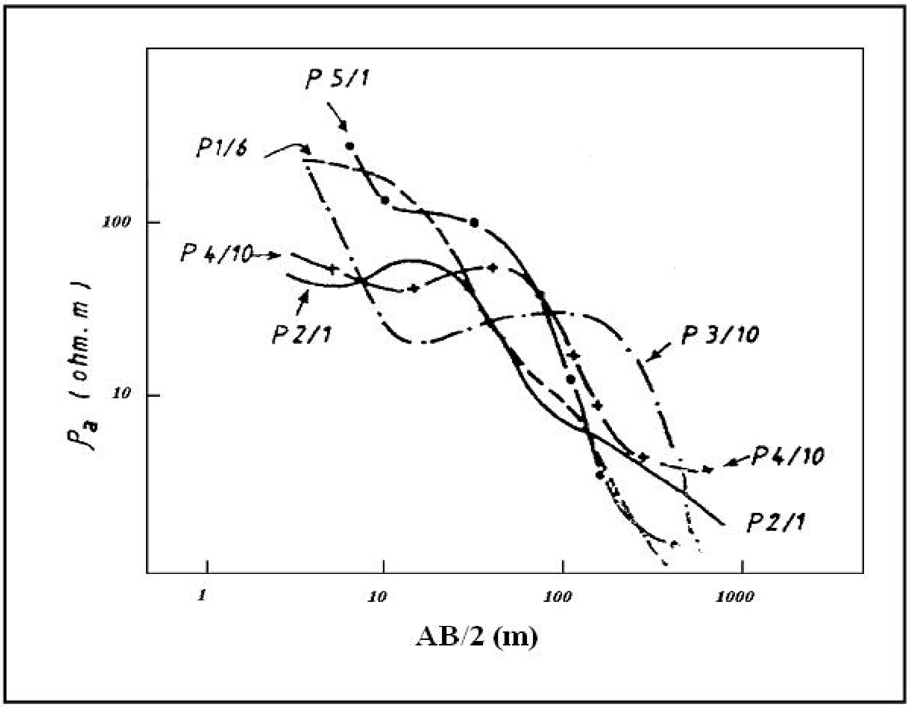


**Figure (3) some representative VES curves.**

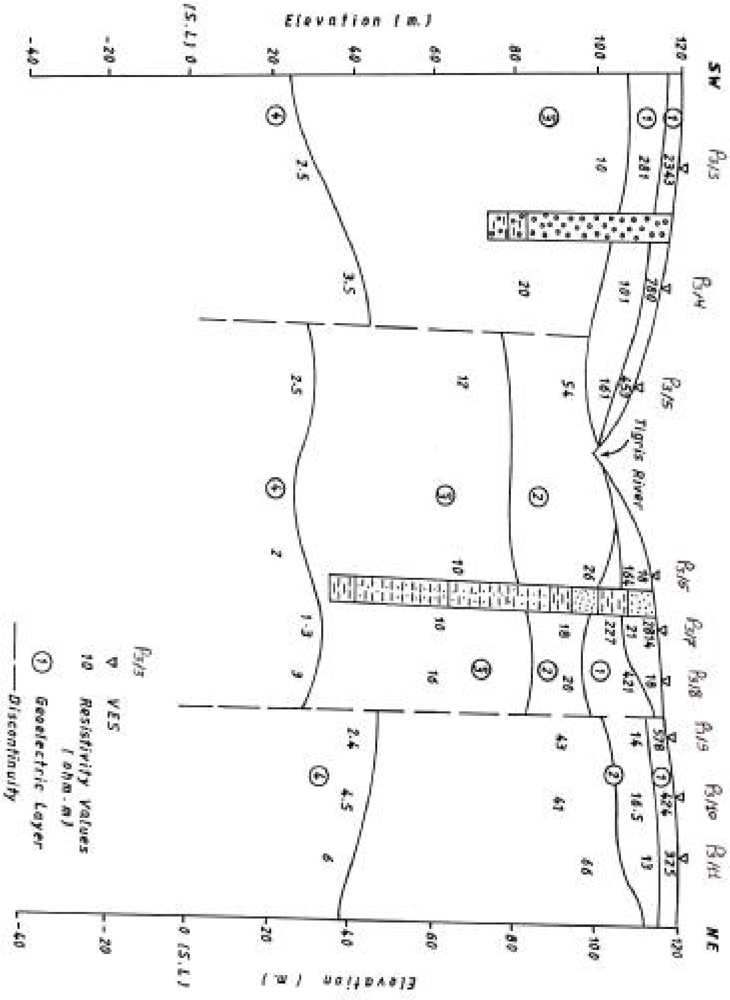


**Figure (4) Geoelectric Section for Traverse No.3.**

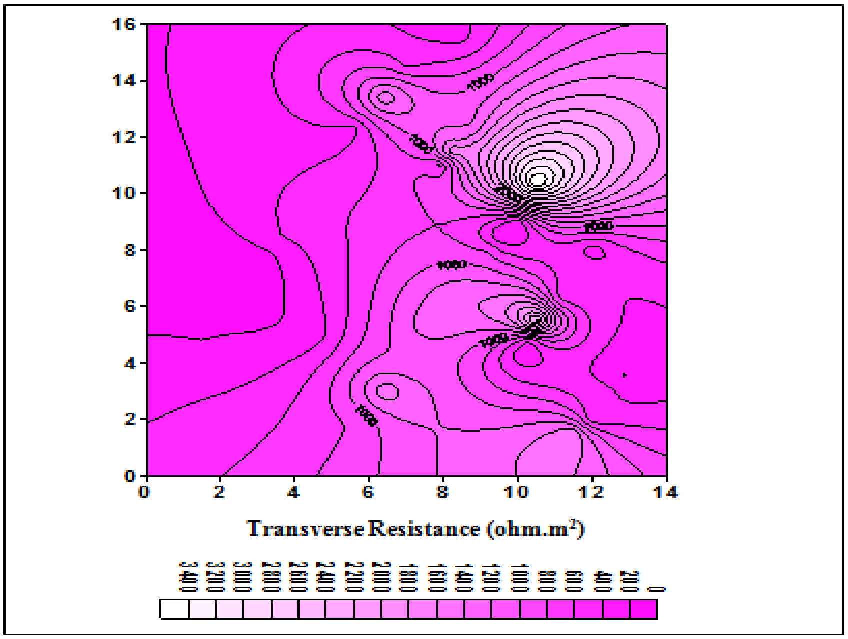


Figure (5) Transverse resistance for the first aquifer.

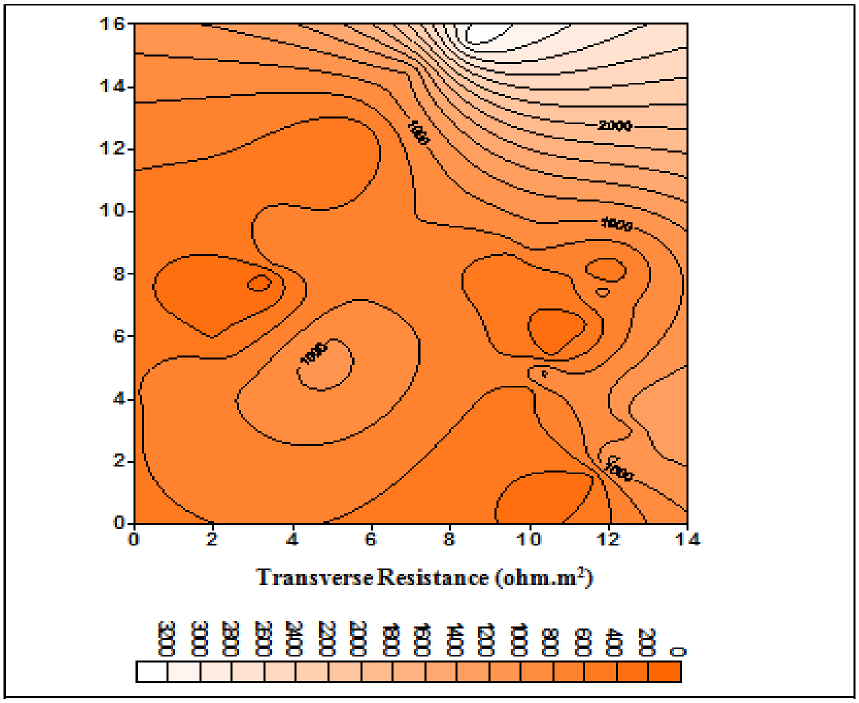


Figure (6) Transverse resistance for the second aquifer.

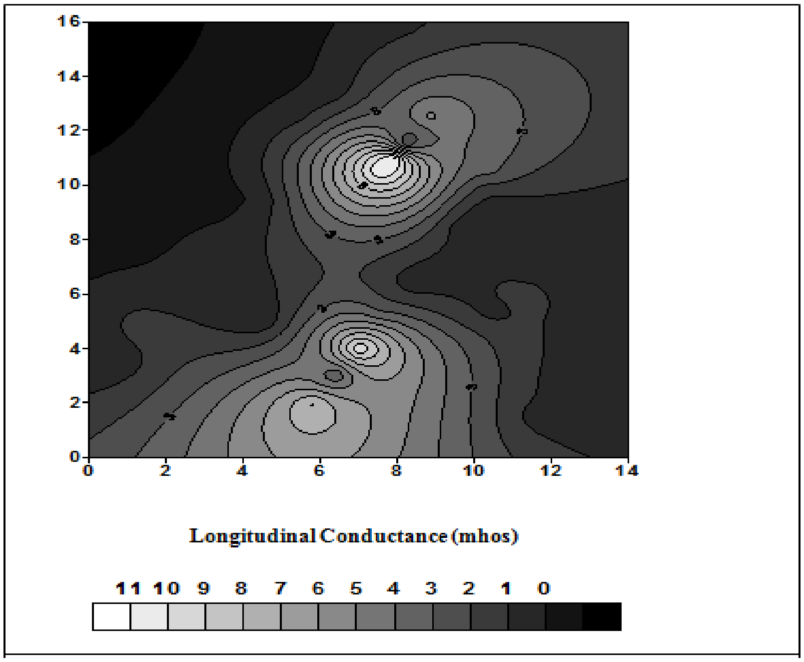


Figure (7) longitudinal conductance for the first aquifer.

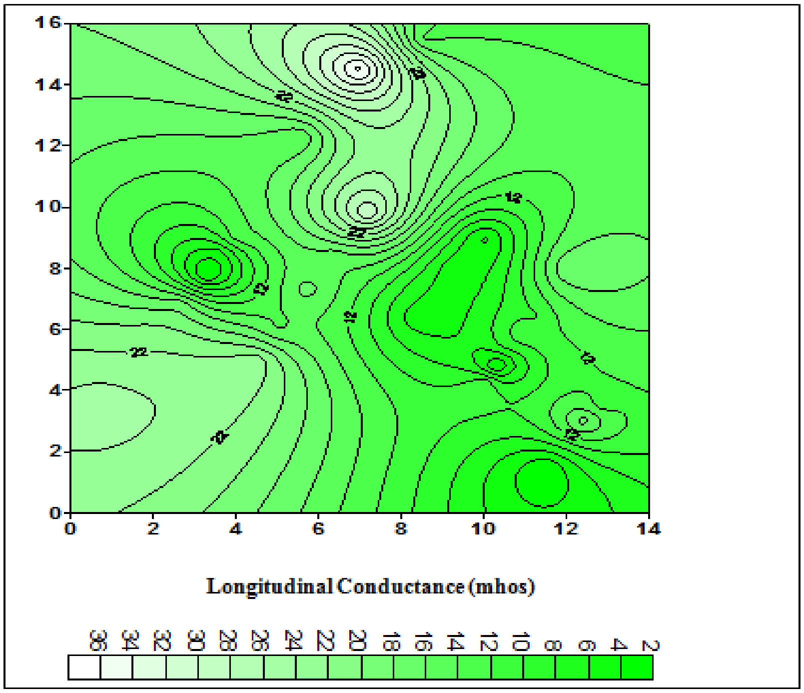


Figure (8) longitudinal conductance for the second aquifer.

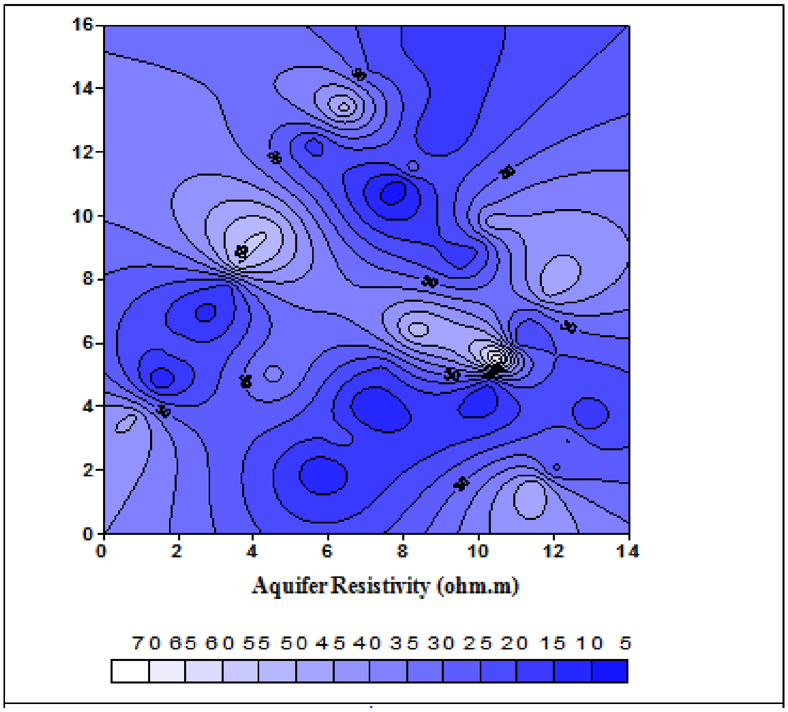


Figure (9) Aquifer resistivity for the first aquifer.

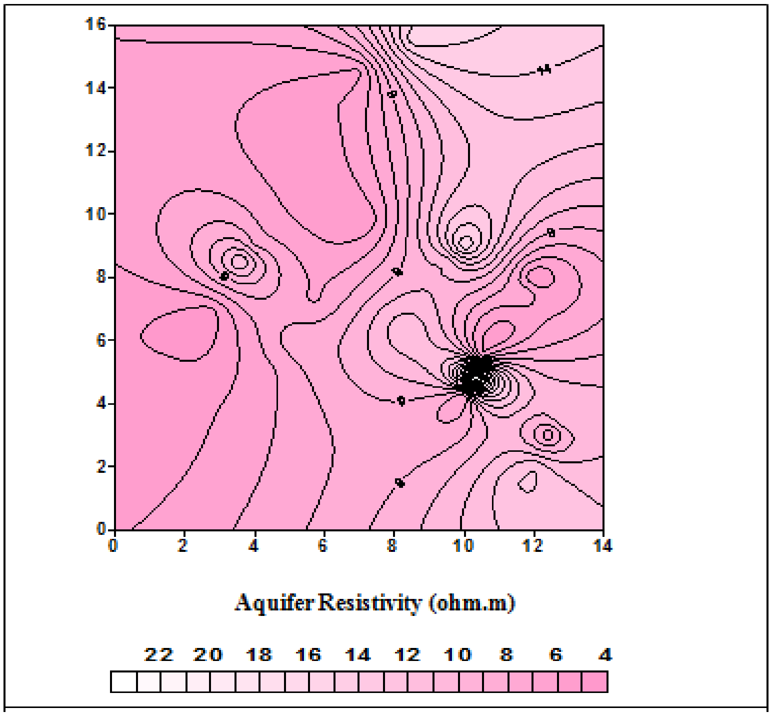


Figure (10) Aquifer resistivity for the second aquifer.

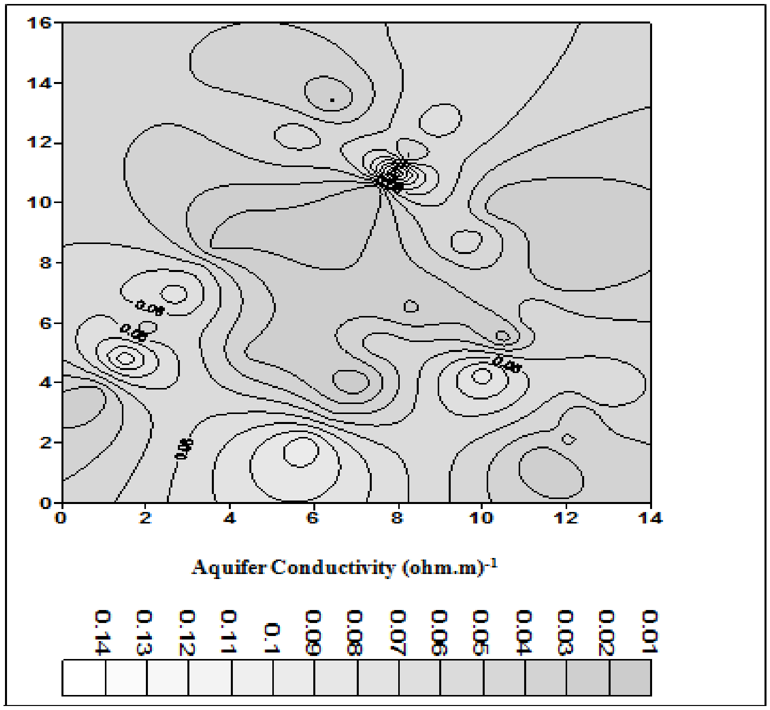


**Figure (11) Conductivity for the first aquifer.**

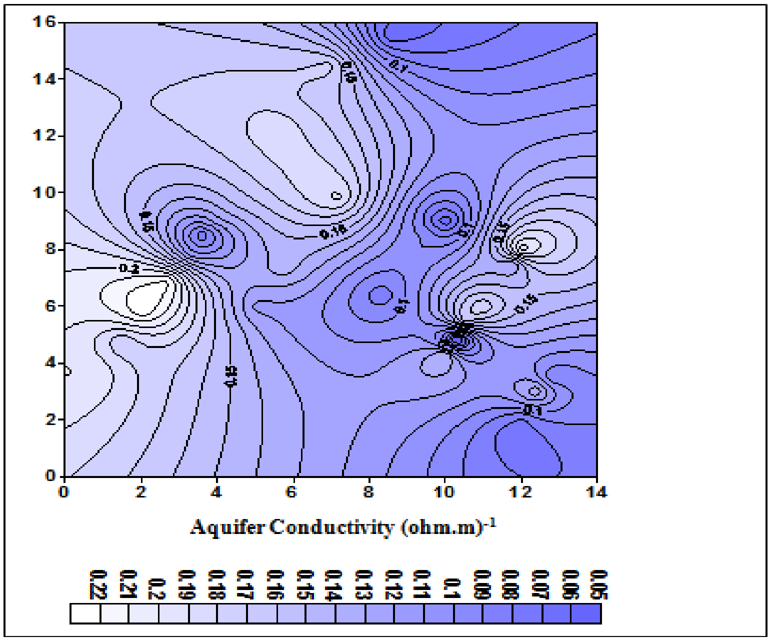


**Figure (12) Conductivity for the second aquifer.**

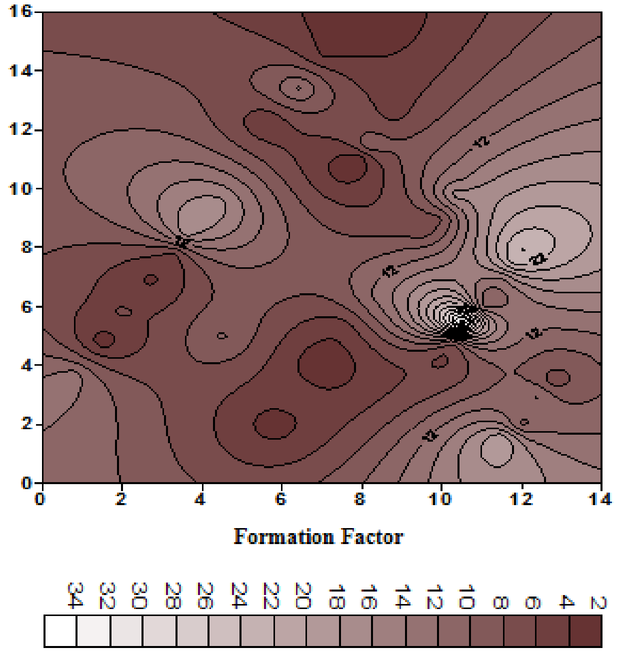


Figure (13) Formation factor for the first aquifer.

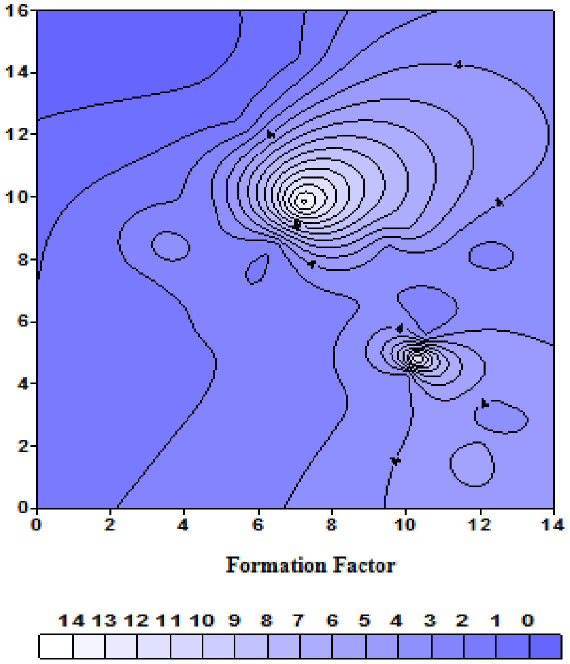


Figure (14) Formation factor for the second aquifer.

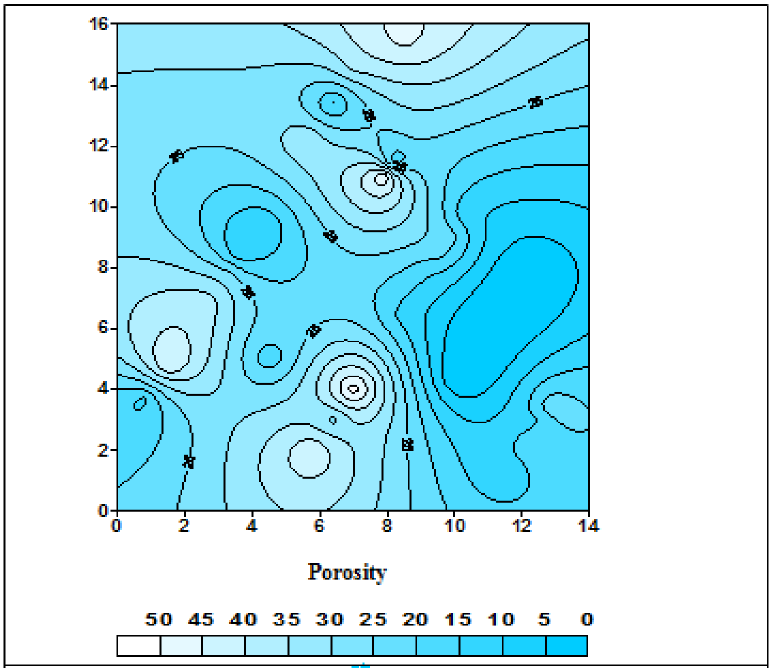


Figure (15) Porosity for the first aquifer.

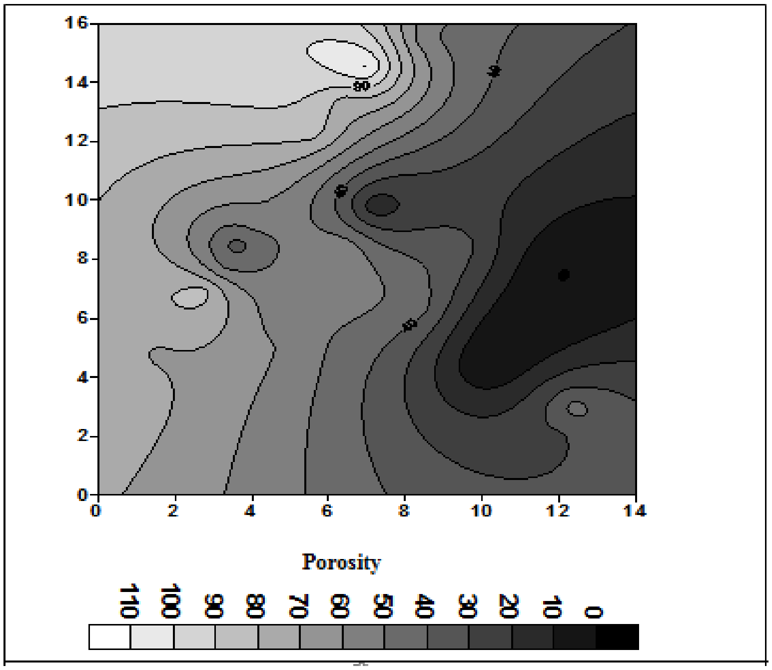


Figure (16) Porosity for the second aquifer.

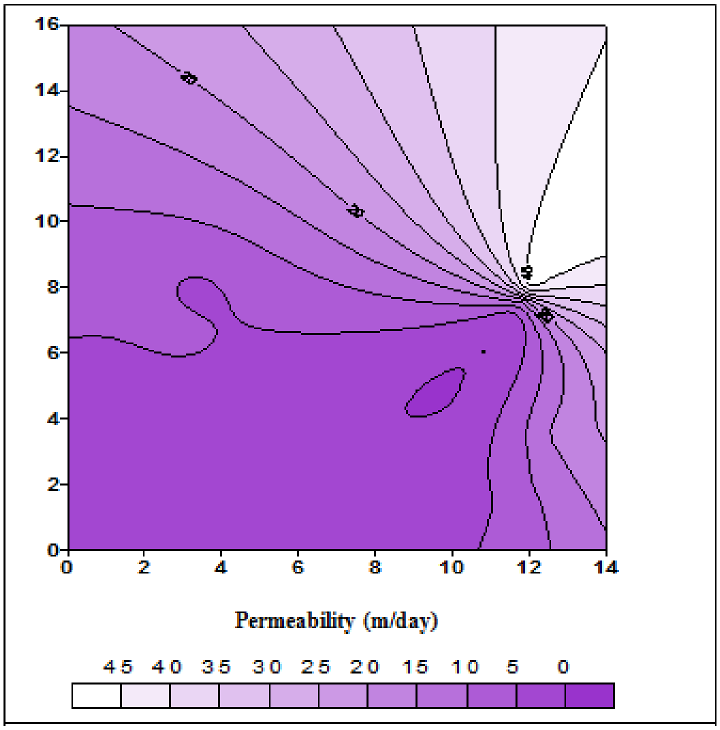


Figure (17) Permeability for the first aquifer.

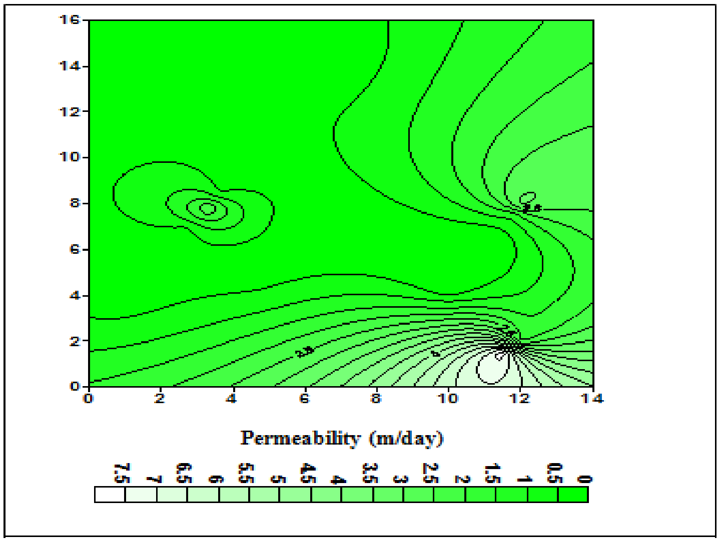
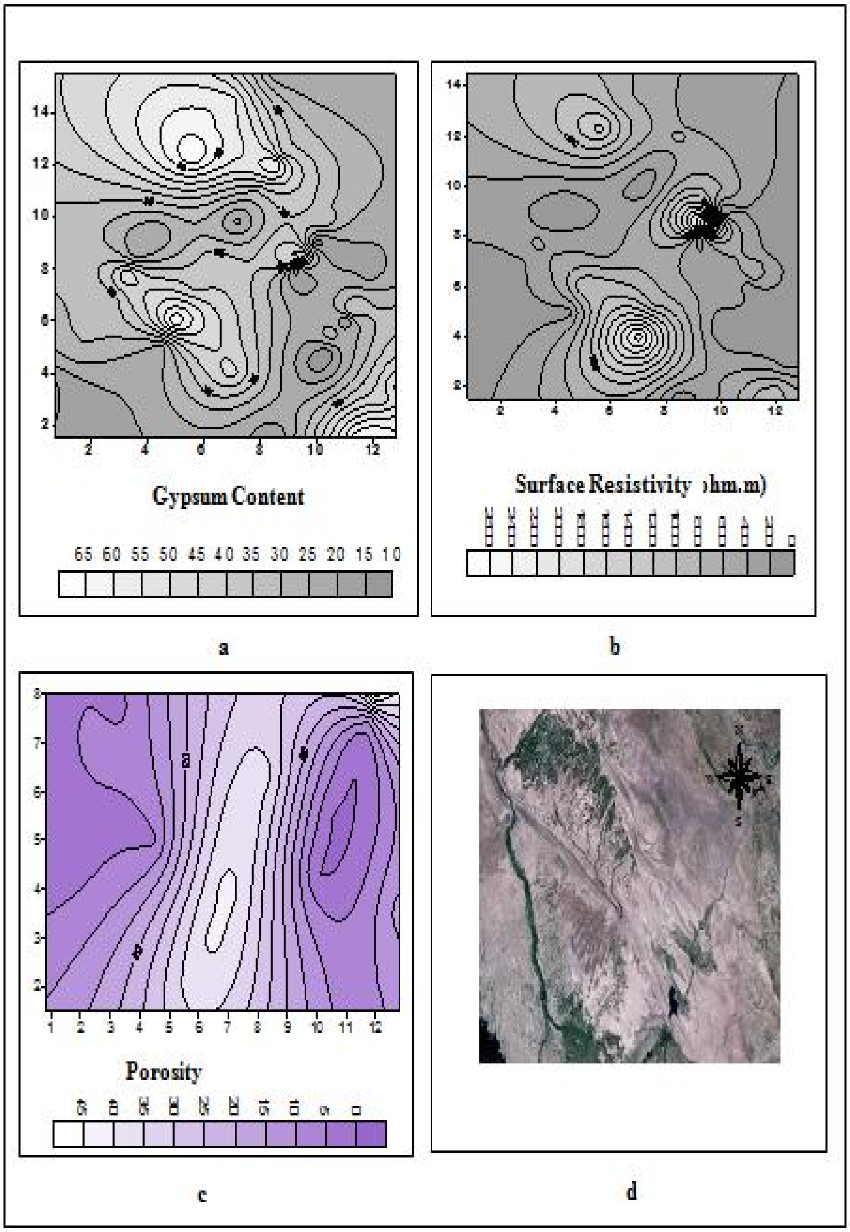


Figure (18) Permeability for the second aquifer.



a

b

c

d

**Figuer (19) Correlation among topsoil gypsum content, Surface resistivity and porosity contour maps With Landsat image.**