The Role of (Geoelectric and Hydrogeologic) Parameters in the Evaluation of Groundwater reservoir at South of Jabal Sinjar area.

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Abstract

In this study the (geoelectric – hydrogeologic) parameters which are obtained by the quantitative interpretation of (80) Schlumberger Vertical Electrical Sounding (VES) points distributed in six linear profiles within the study area are used in addition to (6) pumping test locations for the groundwater reservoir located to the south of Jabal Sinjar (Sinjar anticline). The studied area covers about 7920Km^2. The (VES) field readings were interpreted manually by using the auxiliary point method-partial resistivity curve matching,then the interpreted results enhanced by using computer software specialized for the 1D- (VES) resistivity curves interpretation. The (VES) results analyzed by using modern techniques in order to construct a new predicted hydrogeologic maps through the application of an empirical statistical relations between geoelectric and the Hydraulic parameters. The results of empirical relations represent the predicted hydraulic parameters for the points where no pumping tests achieved. The results represents the predicted hydraulic conductivity (K), Transmissivity(Tr), Specific capacity(Sc) and Total Dissolved Solids (TDS). A computer software used to display the results as maps to display the calculated hydrogeologic parameters variation across the studied area. This result helps to delineate the most productive and good quality groundwater within the study area.

Keyword: geoelectrical-Hydrogeologic relations, Groundwater reservoir evaluation.

دور المعاملات (الجيوكهربائية والهيدروجيولوجية) في تقييم خزان المياه الجوفية لمنطقة جنوب جبل سنجار

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الخلاصة

تستخدم هذه الدراسة المعاملات (الجيوكهربائية و الهيدروجيولوجية) المستحصلة من تفسير ٨٠ نقطة جس كهربائي عمودي (VES) موزعة على ستة مسارات خطية في منطقة الدراسة فضلا" عن معلومات الضخ الاختباري لستة آبار محفورة ضمن خزان المياه الجوفية الممتد ضمن مساحه تقدر بحوالي ٧٩٢٠ كم^{٢} واقعة الى جنوب جبل سنجار (طية سنجار المحدبة). تم معالجة القراءات الحقلية يدويا" بأستخدام التطابق الجزئي وبطريقة النقطة المساعدة لتفسير منحنيات المقاومة الكهربائية ثم تم تحسين نتائج التفسير بواسطة استخدام برنامج خاص بمعالجة و تفسير منحنيات المقاومة الكهربائية للجس الكهربائي العمودي الاحادي البعد . اجريت عملية تحليل

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النتائج للجس العمودي باستخدام طريقة حديثة لغرض استنباط خرائط هيدروجيولوجية تخمينية جديدة و ذلك من خلال تطبيق علاقات تجريبية بين المعاملات الهيدروجيولوجية و الجيوكهربائية خاصة بمنطقة الدراسة، كما تم استخدام برامج حاسوب اخرى لعرض النتائج على شكل خرائط للمعاملات الهيدروجيولوجية المخمنة و المتمثلة بالتوصيلية الهيدروليكية(K) Hydraulic Conductivity، المرورية (Tr) Transmissivity، السعة الانتاجية Specific Capacity(Sc) و كمية الاملاح المذابة (TDS) Total Dissolved Solids وتوضيح التغيرات الحاصلة في تلك المعاملات ا ضمن منطقة الدراسة. لقد ساعدت النتائج على تحديد مناطق تواجد المياه الجوفية الاكثر انتاجية و الافضل نوعية" ضمن منطقة الدراسة.

Introduction:

The field estimations of hydraulic parameters are not always available; as a result, many investigation techniques were commonly employed with the objective of the estimation of the spatial distribution for the hydraulic parameters. The hydraulic conductivity (K) is the most problematic to obtain because of its great range of observed values or the unsatisfactory laboratory measurements. The application of field hydrogeological methods is a standard technique for evaluating aquifer properties. The estimation of hydraulic conductivity (K) and Transmissivity (Tr) values from field pumping tests and down-hole well logging data, can however be very expensive and time consuming. In this context, surface geophysical (Resistivity Method) may provide rapid and effective techniques for groundwater exploration and aquifer evaluation [1].

The pumping tests which produce hydraulic conductivity results are often limited in number or, sometimes not well distributed over the whole study area. The obtaining of reliable values for the hydraulic conductivity of an aquifer is difficult due to lateral and vertical heterogeneities which are usually present in water-bearing geologic strata [2].

The complicated factors effect on the resistivity values, the lithology and water quality effects cannot be differentiated by the geoelectric resistivity survey alone. Therefore, for an effective use of geoelectric resistivity data to the hydrogeologic study, the correlation between real wells lithology data and the electrical field data is strongly recommended [3].

The (VES) field data in this study was provided by the Iraqi general commission of groundwater which performed this survey in the middle of eighties. The aim was to update the data for this survey in order to save costs and efforts. Therefore, two additional Schlumberger (VES) checking points resurveyed at field on their same locations at the middle northern part of the study area on June-2012. A comparison made between old and new resistivity sounding curves in order to check out the differences that took place in the groundwater table levels.

Geo-statistical empirical relations have been established later between the hydrogeologic and geoelectric parameters. These relations built between (geoelectrical parameters), which are: {Aquifers bulk resistivity, Formation factor (FF),Longitudinal unit conductance (S), Longitudinal resistivity (ρ_l), Transverse resistance (T) and Transverse Resistivity (ρ_t) } ; and the (Hydrogeological parameters), which are: {hydraulic conductivity (K), Transmissivity (Tr) and Specific capacity (Sp)}. The information obtained by pumping tests performed on boreholes located near (VES) points for six well distributed locations within the study area, as it appears in figure(1). The relations yielded equations applied later on other (VES) geoelectrical columns within the study area where no pumping tests are achieved in order to calculate the predicted values of the hydraulic parameters geo-statistically. The results presented as equi-hydraulic parameters contour maps, 3D-representations that shows these parameter variations within the study area.

Location and geology of the Study Area:

The groundwater reservoir for the studied area represents a region with an area of about 7920 Km^2 located southward to Sinjar anticline in the NW part of Iraq. The area bounded by the coordinates which appears in figure (1), it shows the location and (VES) points/profiles distribution for the studied area.

The study area ground surface covered with the Quarternary deposits of Pliestocene and Holocene periods, while Tertiary and cretaceous deposits are buried beneath and doesn't expose to surface only far toward north outside the study area limits [4]. The Sinjar plain area shows the following geology [5 and 6]:

- Topsoil layer : composed of Quaternary deposits of sand and loamy soil with scattered gypsum content. Around Sinjar anticline the soil shows slightly cemented rock fragments, Silt and Sand, these deposits called (slope deposits).
- Terrace deposits: represents the Pliestocene or lower Quarternary deposits which exposed in some small spots and consist of conglomerates with lenses of sand, silt and less amount of clay.
- Miqdadiyah or (lower Bakhtiari) formation deposits: It represents the Pliocene and a small part of early Miocene and consists of gravely sandstone, claystones and siltstones.

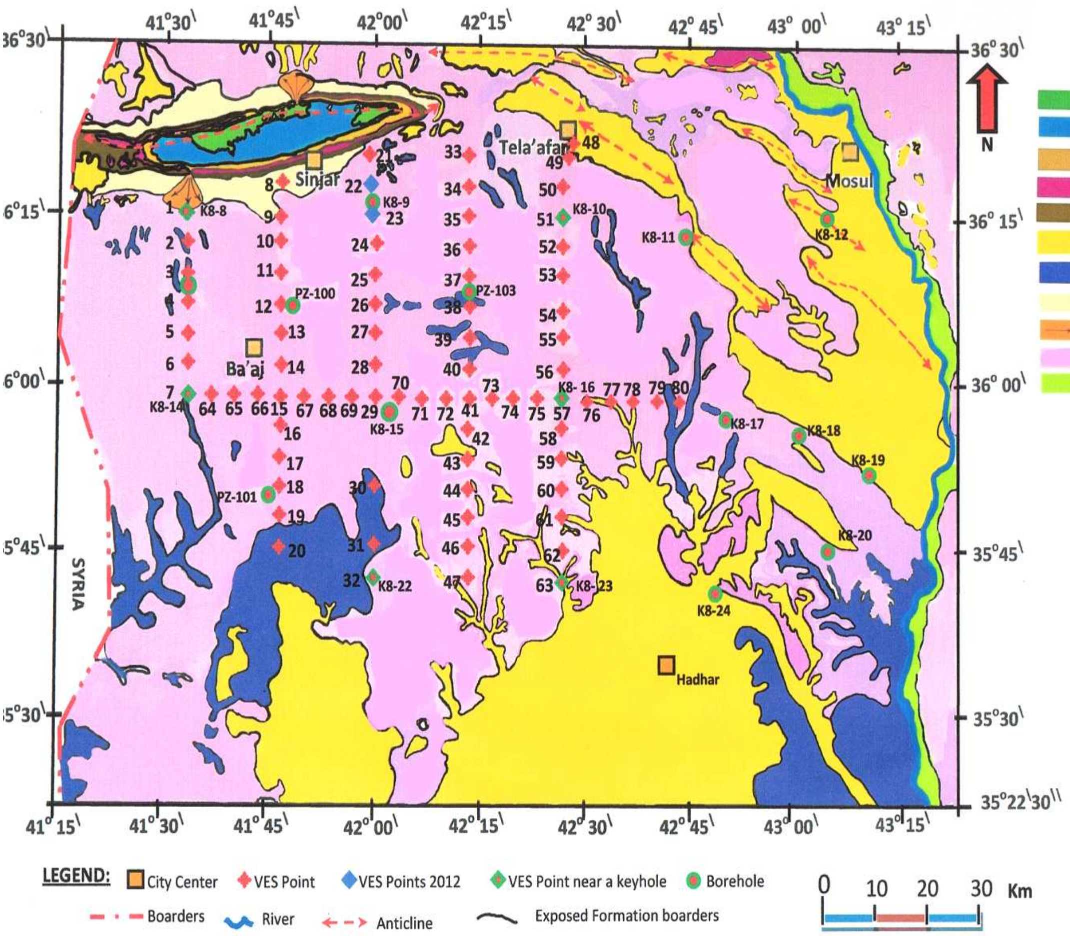


Figure1- Maps showing the study area location and the (VES) profiles distribution.

- Injana or (upper Fars) formation deposits: It belongs to the middle Miocene and consists mainly of coarse grained sandstone and claystone which may exposed to surface in a relatively small spots.
- Fatha or (lower Fars) formation deposits: It belongs to lower middle Miocene and consists of green marlstone, Anhydrite, thinly bedded limestone and gypsum. The upper member for this formation consists of green marlstones and red claystones.

Materials and Method:

Its common in the geoelectrical – hydrogeological studies to use the Ohm resistivitymeter as a field instrument and Schlumberger configuration as a ground electrodes array, figure (2).

In the generalized Schlumberger array the distance between the potential electrodes (MN) is small compared to the distance between current electrodes (AB) and AB ≥ 5MN, (8).

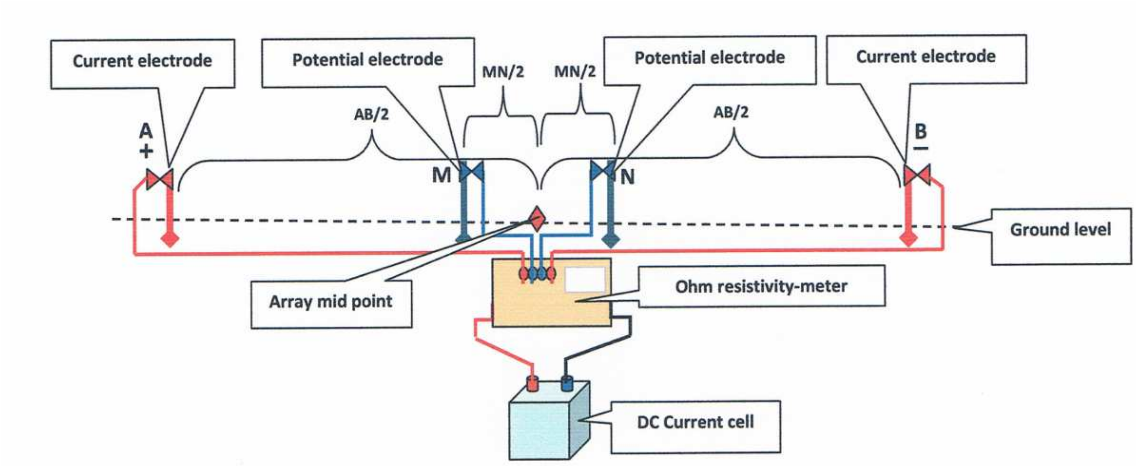


Figure 2- The electrode array for Schlumberger configuration at field resistivity survey.

The (VES) points apparent resistivity (ρ_a) field readings in this study were obtained as the half current electrodes separation (AB/2) which was usually increased in steps starting from 3.2 to 1250 m, while the half distance between potential electrodes MN/2 was gradually increased in steps starting from 1 m to a 50 m, according to the geometrical factor (K) for Schlumberger configuration in order to obtain a measurable potential difference. The current gain (output current) of the resistivitymeter increased gradually from 1 to 1000 mAmp. To yield a current penetration to the required depths.

The Schlumberger array (Fig 2) was used by keeping the potential electrodes at a closer distance. The apparent resistivity (ρ_a) was determined using Equation below (7):

$$\rho = \pi \left\{ \frac{\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{MN} \right\} \Delta \frac{V}{I}$$

Where AB = distance between the current electrodes in meters, MN = distance between potential electrodes in meters, ΔV= potential difference measured between the potential electrodes (volts), and I = the applied current strength.

The (VES) points distributed on six profiles with a midpoint interspacing of (2.5 to 5 Km). Two additional checking (VES) points were performed using Schlumberger array also with (AB) spread range of (1-500 m) and (MN) range of (0.5-80m), on 30/June/2012, at the same locations of the two (VES No. 22 &23], their locations assigned precisely at field by using the Global Positioning System GPS device. The idea was to check out the difference took place on the groundwater table level from the middle of eighties until nowadays. The previously two mentioned (VES) points were located in the middle northern part of the study area, figure (1), and performed at field by using the ABEM SAS-300 resistivitymeter. Later, a comparison made between the old and new (VES) curves in order to detect the low resistivity zone upper level difference between the two periods of time. See figures (3 and 4).

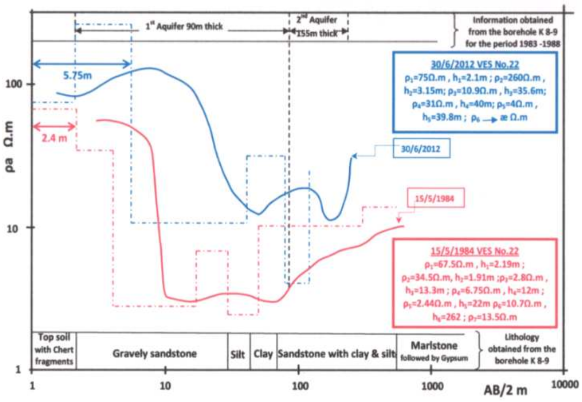


Figure 3- The (VES No.22) difference in ground water table level from the middle of eighties until June/30/2012 is about (3.35 meter only).

The comparison between the field resistivity (VES) curves that appears on the figures (3 and 4) shows a slight difference between the old and new low resistivity zone upper limit depth at the same locations.

The drawdown amount in the low resistivity zone upper limit depth which represents the groundwater table depth from ground surface was approximately (3.35 m) for the VES No.22, and (1m) for the VES No.23. Such results referred to a slight difference in the ground water table depth between the old survey which assisted by boreholes information, and the new survey where no need for drilling any further new boreholes. This encouraged the researchers to continue with using the available eighty (VES) points data to achieve advanced interpretational techniques through the estimation of the geoelectrical parameters then studying its statistical relations with the hydrogeologic parameters which obtained by the six pumping tests near (VES) points locations within the study area.

The resistivity curves were interpreted by attending the manual Auxiliary Point Method of partial matching using (Orellana and Mooney, 1966) two layers Schlumberger standard curves from the reference [9]. The field data (ρ_a), AB/2 and MN/2 input to a computer software for 1D-(VES) processing and interpretation. The software uses the common forward and inversion technique [10] .

Both manual and computer processing and interpretation have been applied for all of the (VES) points. It's important to mention that the enhancement of (VES) results by using computer software should be attended very carefully without affecting certain thickness values of layers, especially, those which are supported by the boreholes thickness information.

The (VES) resistivity curves interpretation results represent layers thickness(h) in meter and true resistivity(ρ) in ohm.m for each electrical zone within each of the (80) geoelectrical columns located under the midpoints of the (VES) points.

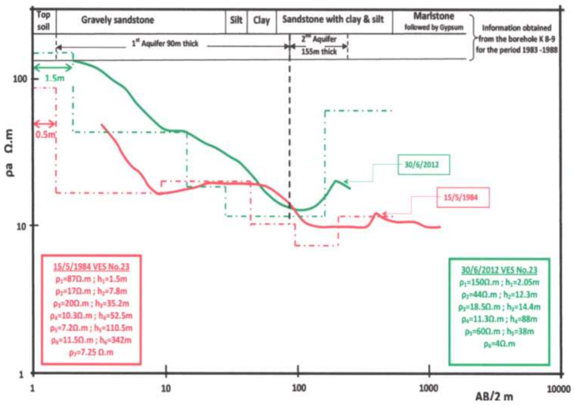


Figure 4- The (VES No.23) difference in groundwater table level from the middle of eighties until June/30/2012 is about (1 meter only).

The Hydraulic parameters which are (Transmissivity (Tr), Specific capacity(Sp), Discharge (Q), saturation zone thickness(H) and brine Electrical Conductivity (E.C.)), were obtained from the pumping tests at six distributed locations next to, or between six (VES)points. Table (1) describes these parameters .

The Dar-Zarrouk (D-Z) parameters which discussed by the reference [11], and have been calculated for each of the 80 geoelectrical columns. Information from the table (1) used to calculate the hydrogeologic parameters and displayed beside the calculated geoelectrical parameters in table (2). Archie in 1942 introduced the concept of Formation Factor (F_F) in his work on the Petrophysics of brine-filled rocks. Formation Factor (F) is given by:

$$F_F = \rho / \rho_w$$

Where: ρ= resistivity of the brine-saturated rock, and ρ_w = resistivity of the brine.

According to Archie the formation factor (F_F), is related to porosity (ϕ), by:

$$F_F = a\,\phi^{-m}$$

Where a and m = constants related to the rock type.

Table1- the geoelectric and hydrogeologic parameters obtained by VES and pumping tests on six well distributed locations in the study area.

Borehole No.	VES points next or between boreholes	Transmissivity (Tr) (m^3 per day/m)	Discharge Q (L/Sec)	Thickness of saturated column,H (m)	Specific Capacity = Q/S (L/Sec./m)	E.C. (µmho/cm)
K8-9	**22 - 23**	**56.12**	**5**	**24.5**	**0.2**	**2000**
K8-14	**7**	**4.6**	**3.8**	**62.86**	**0.06**	**6000**
PZ-100	**12**	**39.2**	**5.7**	**18.29**	**0.31**	**3150**
K8-15	**29 -70**	**60.42**	**5.625**	**11.85**	**0.47**	**8300**
PZ-103	**37- 38**	**37**	**11**	**45.04**	**0.24**	**5820**
K8-17	**80**	**0.594**	**11**	**43.35**	**0.253748558**	**5455**

Table 2-The calculated geoelectric parameters for the six pumping tests near (VES) locations within Sinjar plain area. These parameters used later to establish the (Hydrogeologic-Geoelectric) empirical relationships.

Borehole No.	VES point near /at bore-hole	Bulk Aquifer resistivity (ρ) µohm.Cm	Calculated Brine Resistivity (ρw)= 1/E.C. µohm.cm	FnFactor FF=$\rho/\rho w$ unit less	Calculated Hydraulic Conduct. (K)=Tr/H M^3per day/m^2	Longtudinal conduct. (S) Mho S=$\Sigma(hi/\rho i)$	Longtudinal Resistivity (ρ_l) ρ_l=H/S Ω.m	Transverse Resistance (T)(Ω.m^2) T= $\Sigma(hi*\rho i)$	Transverse Resistivity (ρ_t) ρ_t =T/H Ω.m
K8-9	**22 – 23**	**0.0020**	**0.0005**	**4.034**	**2.290**	**45.3592**	**9.326**	**4788.89**	**10.91**
K8-14	**7**	**0.00087**	**0.000166**	**5.227**	**0.0731**	**29.608**	**8.301095**	**2679.50**	**10.90**
PZ-100	**12**	**0.00207**	**0.000317**	**6.525**	**2.1432**	**28.86913**	**11.132**	**3930.8**	**12.23**
K8-15	**29 -70**	**0.0027**	**0.0001204**	**22.95**	**5.0987**	**115.808**	**5.37**	**4829.40**	**8.186**
PZ-103	**37- 38**	**0.00156**	**0.0001718**	**9.079**	**0.8214**	**41.649**	**7.6996**	**2035.55**	**9.204**
K8-17	**80**	**0.00312**	**0.0001833**	**17.02**	**0.0137**	**22.915**	**4.601658**	**715.39**	**6.784**

Jones and Buford 1951, extended the use of this equation, relating formation factor and porosity to fresh water saturated granular aquifers. For loosely –packed, granular materials, the constants a and m have commonly been assigned values of 1.0 and 1.3 respectively [(Wyllie and Gregory, 1953; Parkhomenko, 1969; and Frohlich, 1974) in reference [12]].

The empirical statistical relations between Geoelctrical and Hydrogeologic parameters:

The measurements of aquifers resistivity are intuitively attractive for estimating aquiferhydraulic conductivity (K) because of the fundamental relation between hydraulic conductivity and electrical conductivity through their common dependence on tortuosity and porosity [13]. Also the fact that surface electrical measurements are capable of sampling an appropriately large volume of an aquifer is significant. The transmissivity (Tr) is a hydraulic parameter proportional to the hydraulic conductivity (K) or permeability, and the thickness (H) of the aquifer. Also, the transverse resistivity (ρt) is a geophysical parameter proportional to the resistivity (ρ) and thickness (H) of the aquifer, according to the following formulas:

$$\mathbf{Tr = K * H \quad ; \quad \rho_t = \rho * h}$$

The two formulas' are of the same type, because they characterize an aquifer formation [14]. This type of relationships, together with aquifer thickness, can be used to determine the Transmissivity (Tr) of the aquifer. The (VES) and pumping tests data are used to build up the relationship between aquifer resistivity and hydraulic conductivity. If this kind of relations could be developed, then it could be used together with the aquifer thickness to evaluate the water –producing capability of the aquifer. [15]

The hydraulic conductivity (K) values for the study area groundwater reservoir calculated using the previous formula, see table (2), as the data of Transmissivity (Tr) and saturated zone thickness (H) are available from the pumping tests results for the six locations. A directly proportional empirical relation has been established between the calculated hydraulic conductivity (K), and the aquifer bulk resistivity (ρ) which obtained from the (VES) interpretation results for five of the pumping tests locations. The method of analysis used is the least square method and yielded the linear equation: (K = 0.262 ρ – 2.792), which has a correlation coefficient (R = 0.95603), as it seen in the figure (5).

This equation used to predict hydraulic conductivity (K) in every geoelectric column within the study area where mostly no pumping tests data available. The predicted (K) values are used to establish map and 3D-representation for the study area by attending the kriging interpolation method. Figure (6) displays the predicted hydraulic conductivity (K) map for the study area.

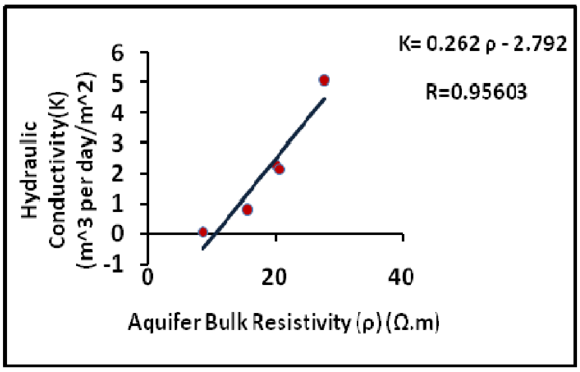


Figure 5- The empirical relation between (K) and aquifer bulk resistivity for five pumping tests near (VES) point's locations in the study area.

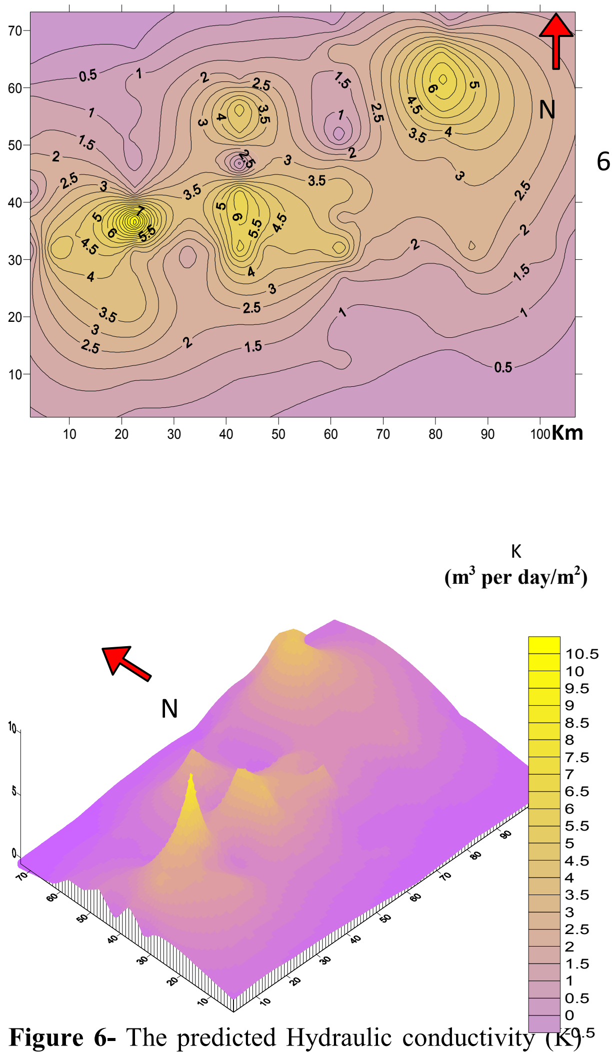


Figure 6- The predicted Hydraulic conductivity (K) C.I. = 0.5 (m^3 per day/m^2). (K) values obtained by applying the equation of figure(5).

The kriging geostatistical interpolation gridding method produces visually appealing maps from irregularly spaced data. Its a very flexible gridding method that uses a weighting, which assigns more influence to the nearest data points in the interpolation of values for unknown locations. Kriging depends on spatial and statistical relationships to calculate the surface [15].

The formation factor (F_F) calculated according to Archie's formula. See table (2). The empirical relation between the transverse resistance (T) and Transmissivity (Tr) for the six pumping tests near (VES) locations within the study area yielded the equation ($T=55.2\ Tr +1341$) with a correlation coefficient ($R=0.85$), see the figure (7). This equation used later to integrate (Tr) for the other (VES) points locations and used to draw up the predicted (Tr) contour map that appears in the figure (8).

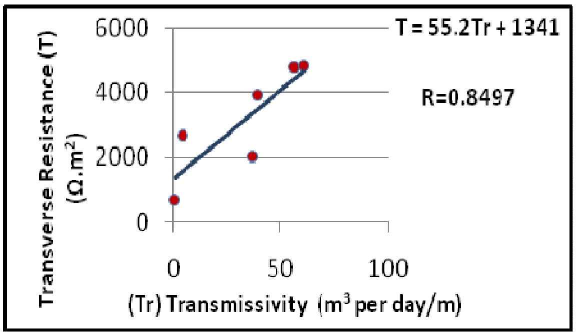


Figure 7- The empirical relation between (T) and (Tr) for six pumping tests near (VES) points locations.

Like Transmissivity (Tr) and hydraulic conductivity (K),the aquifer (Specific capacity) (Sc),table (2), is another important hydrogeologic parameter used in evaluating the productivity of the groundwater aquifer. Its measured in (liter per day/meter) and its value was obtained from pumping tests results. The relations between (Sc) and aquifer bulk resistivity for the six pumping tests near (VES) points locations yielded the equation ($Sc=0.011\ \rho +0.008$) with a correlation coefficient ($R=0.72$), as it appears in figure (9).

This equation used to estimate the aquifer predicted (Sc) values for the other (VES) locations and used to construct the predicted (Sc) map that displayed in figure (10).

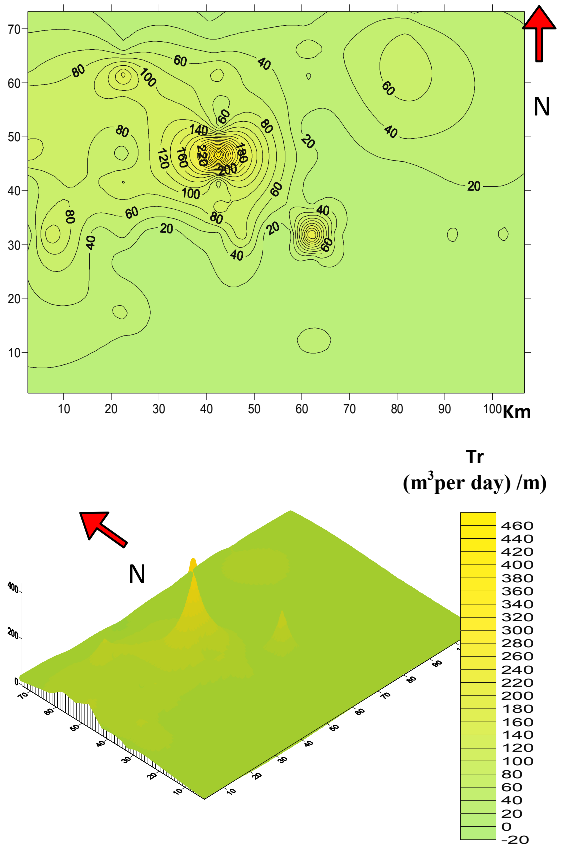


Figure 8- The predicted (Tr) map, Values obtained by using the equation of figure (7) relation, C.I.= 20 (m^3per day /m)

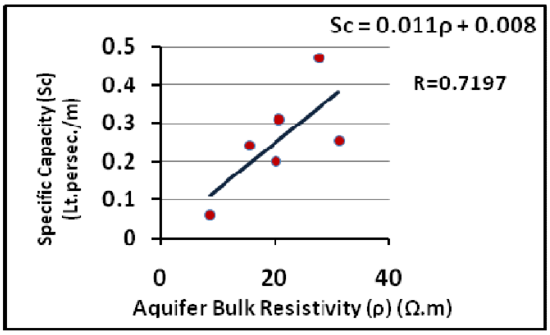
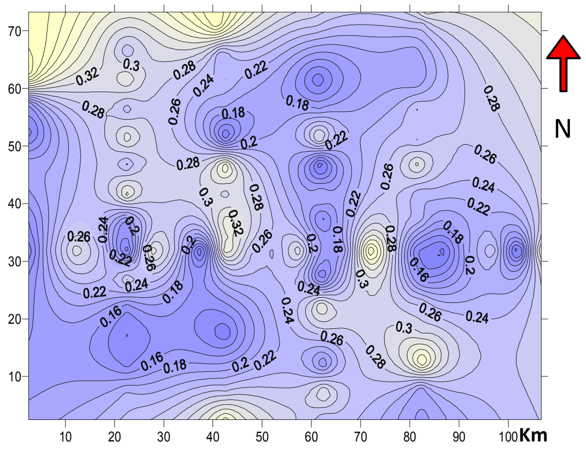


Figure 9- The empirical relation between (ρ) and (Sc) for six pumping tests near (VES) points locations.



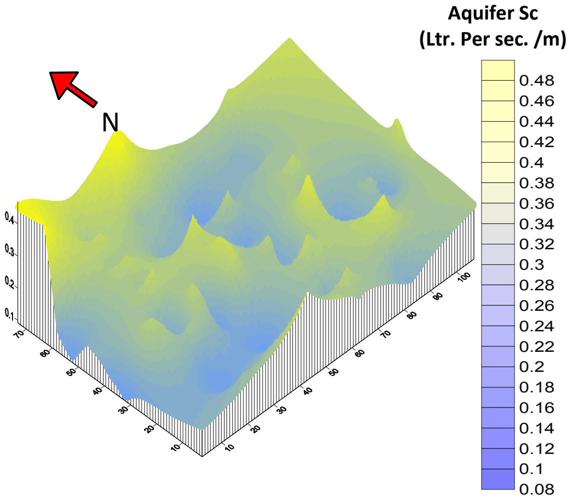


Figure 10- The predicted aquifer (Sc) map, C.I. = 0.02 (liter per second/m), its values integrated by applying the equation of figure (9).

It was proposed to establish a relation between geoelectrical parameters (ρ_l, ρ_t and ρ_m), and groundwater (TDS) for these six locations. The aim behind such relation is to assign the most affected geoelectric parameter by the (TDS) content in the groundwater aquifer. These relations appear in figures (11, 12 and 13). It was found that the highest correlation coefficient (R) value (R=0.72) belongs to the relation between (ρ_l) and (TDS) that appears in figure (11). In other words, (ρ_l) represent the most affected variable by the (TDS) content for the currently studied aquifer and this explains the highest (R) value. The (ρ_l – TDS) inversely proportional relation yielded the equation (TDS = -530.3 ρ_l + 8041) with the highest (R=0.72) value which has been chosen to integrate (TDS) values for the studied groundwater reservoir and presented as a map in figure (14).

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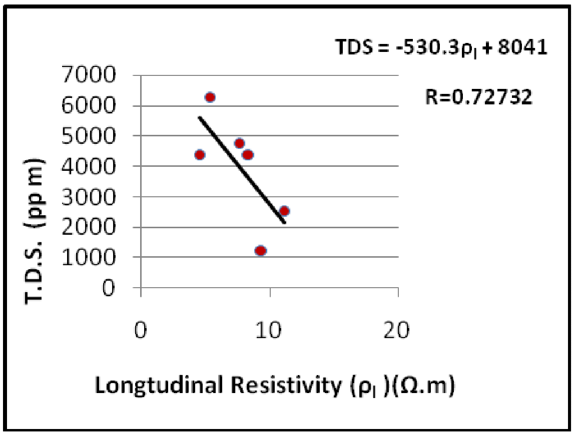

Figure 11- The empirical relation between (ρ_l) and (TDS) for the six pumping tests near (VES) locations.

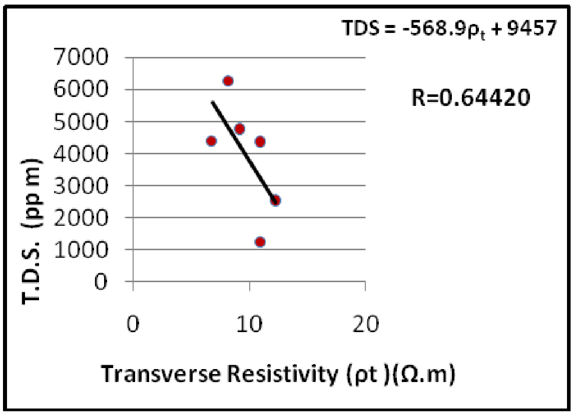

Figure 12-The empirical relation between (ρ_t) and (TDS) for the six pumping tests near (VES) locations.

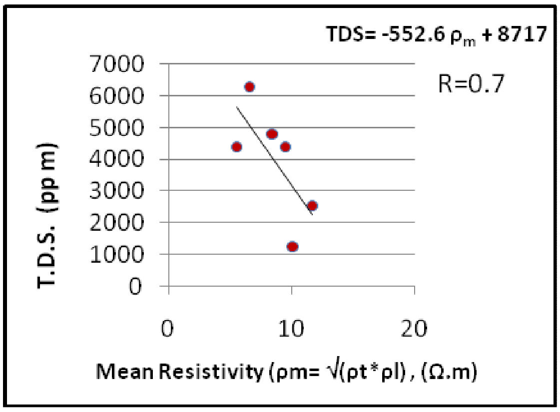

Figure 13-The empirical relation between (ρ_m) and (TDS) for the six pumping tests near (VES) locations.

Conclusions:

The comparison between the old and new (VES) surveys referred to a slight drawdown with the groundwater table in the studied area groundwater reservoir. The difference in water table was estimated by the interpretation for both old and new curves and gave a difference of (1 – 3.35 m) in groundwater table depth.

It was concluded that the most affected geoelectric parameter by the aquifer (TDS) content is the longitudinal resistivity (ρ_l). This has been proven by the (ρ_l _ TDS) relation that appears in figure (11), this relation produced the highest correlation coefficient (R=0.72) value among the other geoelectric parameters (ρ_t and ρ_m) relations with (TDS) in the studied groundwater reservoir. Therefore, the (ρ_l _ TDS) relationship chosen to construct the predicted (TDS) map that shown in figure (14).

The most northern and northwestern parts of the study area yielded (TDS) values ranging between (500 – 5000 ppm), it refers to a fresh to brackish groundwater aquifer area that is mostly adjacent to Sinjar anticline (less salinity ground water area). This fresh-brackish groundwater aquifer area has a (K) range of (0.5 – 6.5 m^3per day/m^2), (Tr) range of (18 – 220 m^3per day/m) and (Sc) range of (0.32 – 0.5 Liter persecond/m).

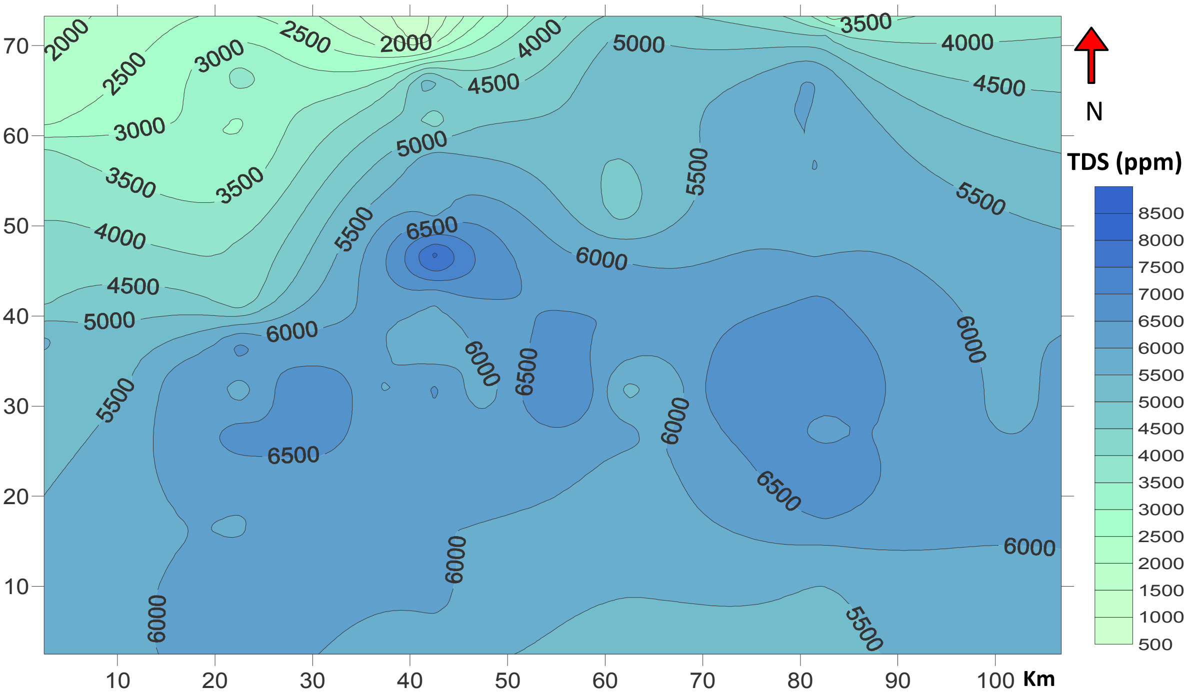

Figure 14- The predicted (TDS) contour map estimated by the empirical relation between (TDS)_ and the longitudinal resistivity (ρ_l) in figure (13) . C.I. =500 ppm .

The other parts of the study area that has predicted (TDS) values of higher than (5000 ppm) considered as a saline groundwater aquifer. Its (TDS) ranged between (5000 – 8500 ppm), figure (14), but it shows high (K) values in some parts that may reach to (10.5 m^3per day/m^2), (Tr) that may reach to (460 m^3per day/m) and aquifer (Sc) reaches to (0.5 Liter per second/m).

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