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Estimating Ground Water Aquifer Transmissivity Using well Specific Capacity Data For Tazerbo Wellfield, SE - Libya.

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الملخص:

أن من المفيد الاستعانة بالبيانات الخاصة بالسعة النوعية للآبار(S_C) لتقدير الناقلية لخزانات المياه الجوفية (T)، حيث استخدامها يزيد من طرق حسابها. في هذه الدراسة، تم اختبار مدى امكانية استخدام السعة النوعية للآبار بحساب الناقلية وذلك باستخدام بيانات اختبار الضخ المتغير الذي أجري لخزان المياه الجوفية بحقل تازربو بالجنوب الشرقي لليبيا. حيث ان الخطوات الرئيسية المتبعة بالبحث هي: أولاً، تطبيق المعادلة التحليلية Theis nonequilibrium وحلها بواسطة برنامج AQTESOLV. ثانياً، تقييم المعادلات التجريبية الخاصة بحساب الناقلية لخزانات المياه الجوفية المكونة من الحجر الرملي من السعة النوعية للآبار. وأخيراً اقتراح علاقة تجريبية بين الناقلية والسعة النوعية لطبقة المياه الجوفية لحقل آبار تازربو ومقارنتها بالعلاقات القائمة الأخرى. وتمت المقارنة بين القيم المحسوبة كما ذكر سابقاً , بحساب معامل الكفاءة (E%) و متوسط الخطأ النسبي المطلق (MAPE%).وأخيراً خلص البحث الي المعادلة ($T = 1.98 S_c^{0.91}$) بمعامل فاعلية عالي للعلاقة المستنتجة (E=0.92) و متوسط خطأ النسبي للنتائج منخفض (MAPE% = 5.01)، وبمتوسط للنتائج ضمن نطاق حدود الثقة 95 ٪. وعند تحليل النتائج المتحصل عليها من المعادلات التي لخصت من الدراسات السابقة لخزانات جوفية رملية أوضحت عدم كفائتها بحساب الناقلية، فيما عدا معادلة Sandra (2016) فهي تنتج قيم للناقلية قريبة إلى القيمة المحسوبة من اختبار الضخ المتغير.

Abstract:

Since the wells specific capacity data useful for estimating aquifers transmissivity, should be used to increase the number of ground water aquifer transmissivity estimations. In this study, an investigation of transmissivity (T) estimating using specific capacity (S_c) in the aquifer region of Tazerbo wellfield - SE Libya was established. The main procedure for transmissivity estimation in this study was: first, using analytical equation derived from Theis nonequilibrium formula solved by AQTESOLV software. Second, evaluation the existing empirical equations for sandstone aquifers transmissivity. Finally a new empirical relationship between transmissivity and specific capacity for Tazerbo wellfield aquifer was proposed and compared with other existing relationships. At this point the comparison between transmissivity values done by statistical analysis like efficiency coefficient (E) and mean absolute error (MAPE%).Moreover, this study shows that ($T = 1.98 S_c^{0.908}$) producing results close to the values obtained from step pumping test with (E=0.92) and (MAPE=5.01%), and provide an average value of transmissivity within the range of 95CI%.Transmissivity obtained from the selected relationships display that they are not effective for the study area aquifer, except Sandra (2016) equation provides a closed transmissivity values to the calculated one with (E=0.83) and (MAPE=7.05%).

Key words: Sandstone Aquifer; Transmissivity; Specific Capacity; Tazerbo wellfield, transmissivity and specific capacity empirical relationship.

1. Introduction :

Transmissivity, one of the most fundamental parameters of ground water aquifers. Many techniques are available to calculate transmissivity by using time drawdown aquifer tests. Since the high cost of performing an aquifer test and the expertise required to collect and analyze the data, most water supply wells, have not had the tests performed on them. As the well specific capacity is partly a function of the hydraulic properties of the aquifer, several investigators have tried to relate it to the transmissivity. Furthermore relating specific capacity to transmissivity can increase the number of aquifer ground water transmissivity estimation. There are several different approaches for estimating transmissivity from specific capacity such as analytical, semi-analytical, and empirical. The appropriate technique for relating specific capacity to transmissivity depends on well construction, pumping rates, and the accuracy of the applied technique. Empirical relationships between the transmissivity T and the specific capacity S_c measured in the same well have also been established by several authors, the studies were selected and listed below are related to our study for the same objective :

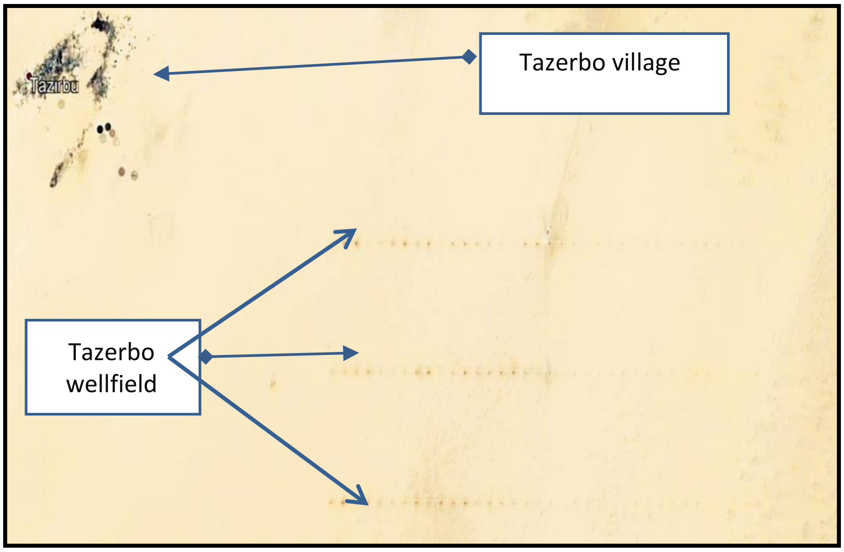
Sandra, et al, 2016 they investigated the possibility and reliability of estimating the transmissivity using numerous available specific capacity data in the Saguenay River watershed in the province of Quebec, Canada. In their research a relationship between 1415 transmissivity and specific capacity for granular aquifers is proposed and compared with other existing relationships. The resulting of their empirical equation have correlation coefficient of 0.66. **El Osta, 2012,** In his research, he attempted to made evaluation of factors causing excessive well losses in El Shab area - Egypt. They relating the 30 wells step pumping test and aquifer hydraulic characteristics to find out the relationship between these hydraulic parameters. The established relation- ships between well losses constant with transmissivity and specific capacity indicate, indefinite clear trend relation for transmissivity with very low coefficient of determination, R^2 (0.00059), and a negative linear relation for specific capacity with a low coefficient of determination (0.065) respectively. **Rotzoll, et al, 2007,** their study examined the relationship between specific capacity S_C and both T transmissivity , K permeability for the volcanic rock aquifers of Maui Hawaii, USA. The relationships provide estimation of aquifer parameters with correlation coefficients between 0.81 and 0.99. **Mace, et al, 2001**, The purpose of their report is to categorized and summarized the different techniques available for relating specific capacity to transmissivity. The report presented analytical, empirical, and geostatistical approaches for estimating transmissivity from specific capacity. In addition to a review of the literature, also presented new estimating transmissivity from specific capacity data for several sandstone aquifers in Texas. In their study in Texas have shown that estimating transmissivity from specific capacity (five empirical equations) provide estimation of aquifer parameters with determination coefficients from 0.45 to 0.82.

The purpose of this study is evaluating the different empirical equations available for relating well specific capacity to aquifer transmissivity of Tazerbo wellfield -SE Libya. Furthermore estimating transmissivity from specific capacity applying the analytical solution using a AQTESOLV software version 4.5. Finally a new empirical equation estimating transmissivity from 92 wells specific capacity data for Tazerbo wellfield. Transmissivity values are calculated from specific capacity data (Thies equation) compared with the results from the equations involves empirically relating transmissivity to specific capacity for sandstone aquifer. The comparison is done with statistical analysis like efficiency coefficient (E) and mean absolute error (MAPE%).

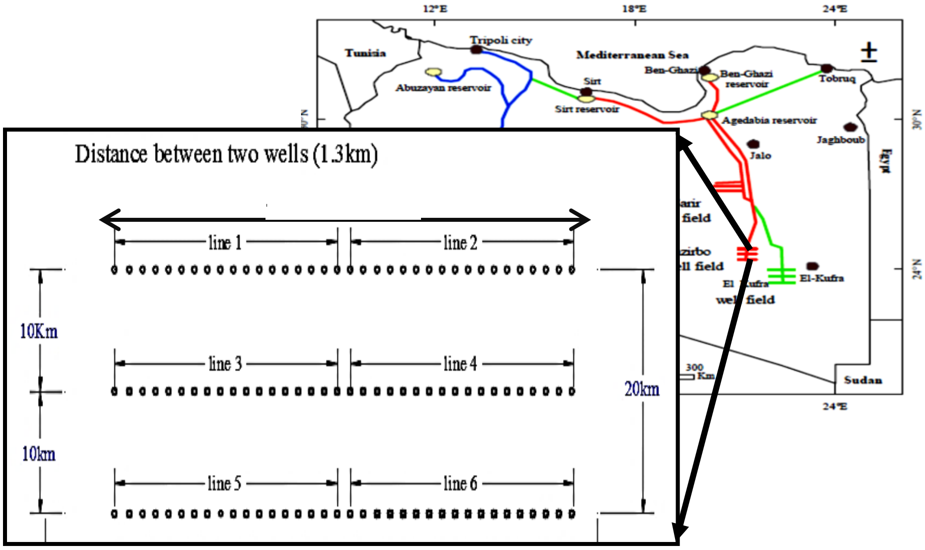
2. Methodology and Area of study

1.2 Area Of Study

Tazerbo wellfield is one of two well fields of Great Man Mead River project GMMRP Phase I. The Study area layout is illustrated in Figures (1 and 2). It is bounded by longitudes 21^0 and 22^0 E and by latitudes 25^0 and 26^0 N. The production Wells distributed in 6 lines, with a distance of 1.3 km between two wells. These wells are distributed into three parallel lines; each line is divided in two sections, and each line consists of 36 wells. The total depth of the production wells in Tazerbo wellfield ranges from 460 to 580 m. Analysis of core and cutting samples from the wellfield indicted the aquifer, consists mainly of silica. The water depth is variable from one site to another, from 260 m in the NE and NW to 400 m in the SE and SW. Transmissivity had been estimated based on the long-term pumping tests between 3.71×10^{-2} to 7.92×10^{-3} m^2/s (Al Faitouri, 2013).



Figure(1) Location Of The Tazerbo Wellfield (Google Earth-2018).



Figure(2) Location And Layout Of Tazerbo Wellfield .

2.2 Specific Capacity:

Step drawdown test developed to assess the well performance and to determine the optimum pumping rate. The borehole is pumped at a number of incremental rates, gradually increasing discharge, and the drawdown is measured during each of these steps of pumping see figure (3). It is usual to measure until drawdown begins to stabilize at each rate before proceeding to the next step. In addition at least 5 pumping steps are needed, each step lasting from 1 to 2 hours see Figure (3) (Kruseman, and Ridder, 2000).

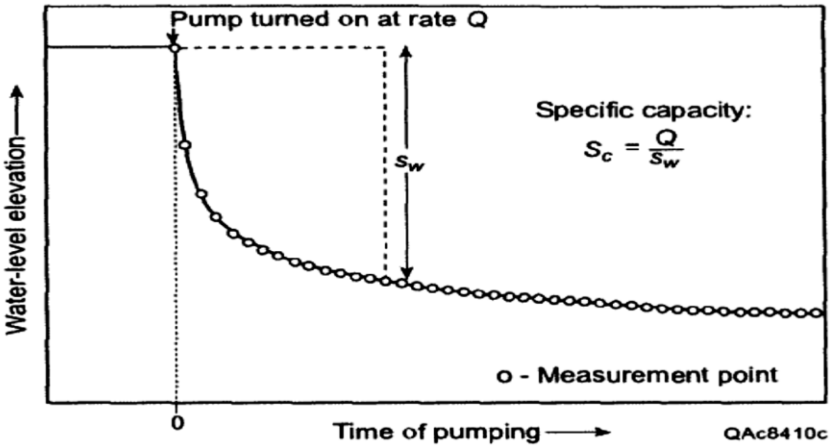


Figure (3) Data from a pumping test on a well completed in a confined aquifer. Specific capacity is determined from one point during the test.

The specific capacity Sc is the ratio of discharging (Q) to steady drawdown (Sw).

$$S_c = \frac{Q}{S_W} \qquad (1)$$

The specific capacity can be calculated for each step, and it should be roughly constant until a pumping rate beyond that sustainable by the borehole is attempted in a step. The specific capacity can also be used as resource of estimating transmissivity. Theis and others (1963) presented an equation to relate specific capacity to transmissivity as:

$$Sc = \frac{4\pi T}{\ln[2.25Ttp/r_w^2\,S]} \qquad (2)$$

Equation (2) which is based on the Theis nonequilibrium equation, where S is the storativity of the aquifer, r_w is the well radius, T is the transmissivity and tp is the pumping time. Furthermore this equation cannot be solved directly it must be solved graphically or iteratively.

3.2Empirical Methods

Empirical methods consist of the statistical relation of aquifer transmissivity to specific capacity measured in the same well. Several authors have developed empirical relationships between transmissivity and specific capacity summarized at table 1 (Mace, et al, 2001), (Rotzoll, et al, 2007). Razak and Huntly (1991), they found that at least 25 pairs would be needed. Huntley and others (1992) found that measured transmissivities for wells in fractured rocks were lower than transmissivities determined by using theoretical relationships. Mace (1997) developed an empirical relationship for a karstic aquifer and showed that data from karstic aquifers in Florida and Ohio overlaid the relationship, suggesting that the relationship may be applied to other karstic aquifers. Fabbri (1997) developed an empirical relationship for a limestone fractured aquifer in Italy. Fabbri thought that his equation differed from that of Huntley and others (1992) because of partial penetration of his wells (Mace, et al, 2001). In all the previous studies listed before, they found that correlation is better between log-transforms of aquifer transmissivity and well specific capacity, and the linear relationship can thus be expressed as:

$T = a(S_c)^b$

where a and b are regression coefficients of the power relationship.

Table 1 Summary Of Empirical Relationships Between well Specific Capacity And aquifer Transmissivity (Mace, et al,2001),(Rotzoll, et al, 2007)**.**

Author	Setting	Units	empirical relationships	Number of used data
Eagon and Johe (1972)	Fractured carbonate	m^2/day	$T = 3.24S_c^{0.81}$	not specified
Razak and Huntly (1991)	Heterogeneous alluvim	m^2/day	$T = 15.3S_c^{0.67}$	215
Huntly,et al (1992)	Fractured hard rock	m^2/day	$T = 0.12S_c^{1.18}$	not specified
El-Naqa (1994)	Fractured carbonate	m^2/day	$T = 1.81S_c^{0.917}$	237
Mace(1997)	Fractured , carbonate	m^2/day	$T = 0.76S_c^{1.08}$	71
Mace(1997)	Fractured , carbonate	m^2/day	$T = 1.23S_c^{1.05}$	14

Fabbri(1997)	Fractured carbonate	m^2/day	$T = 0.785S_c^{1.07}$	45
Mace(2001)	Sandstone	m^2/day	$T = 2.75S_c^{0.82}$	147
Mace(2001)	Sandstone	m^2/day	$T = 3.16S_c^{0.79}$	28
Mace(2001)	Sandstone	m^2/day	$T = 1.51S_c^{0.91}$	33
Mace(2001)	Fractured carbonate	m^2/day	$T = 0.78S_c^{0.98}$	46
Mace(2001)	Sandstone	m^2/day	$T = 1.07S_c^{1.01}$	21
Mace,et al (1999)	Sandstone	m^2/day	$T = 1.03S_c^{1.08}$	214
Logan (1964)	Sandstone	m^2/day	$T = 1.22S_c$	not specified
Snivastav, et al(2007)	Alluvial	m^2/sec	$T = 0.48S_c^{0.66}$	13
Fabbrib and piccinini (2013)	Homogeneous alluvial	m^2/sec	$T = 5S_c^{1.043}$	14
Al Farrah, et al.(2013)	Clayey sand and marl	m^2/sec	$T = 0.744S_c^{0.85}$	15
Sandra (2016)	sand and gravel	m^2/sec	$T = 4.48S_c^{1.15}$	58

4.2 Model Performance Verification :

In this study, several statistical parameters were used to evaluate the performance of estimated transmissivity equations , which were given by the following relations:

1- Mean absolute percentage error (MAPE%)

$$\mathrm{MAPE\%} = \frac{100}{n}\sum_{i=1}^{n}\left|\frac{\mathrm{Xobs.}_i - \mathrm{Xpre.}_i}{\mathrm{Xobs.}_i}\right| \qquad (3)$$

2- 95% confidence limit (95CI%):

The uncertainty of any estimation methods can be calculated using prediction intervals that define an envelope which established by obtained the standard error of the observed values mean as :

$$s_x = \frac{s}{\sqrt{n-1}} \qquad (4)$$

The quantity $\frac{(\mathrm{Xobs.} - \overline{\mathrm{X_{obs.}}})}{\mathrm{Sx}}$ has a t-distribution with n-1 degrees of freedom, And for 95% confidence limit

$$\mathrm{X_{obs.}} - 1.95\left(\frac{s}{\sqrt{n-1}}\right) < \overline{\mathrm{X_{pre.}}} < \mathrm{X_{obs.}} + 1.95\left(\frac{s}{\sqrt{n-1}}\right) \qquad (5)$$

The value on the left side of the inequality yields the lower limit, and on the right side yields the upper limit for the mean observed values. The uncertainty of the regression can be quantified by using prediction intervals that define an envelope around the line that in turn defines how certain an estimate of predicted is for a given specific capacity value which is ± (95% CI).

3- E Efficiency factor:

Efficiency factor (E = 0 to 1) is calculated on the relationship between the predicted and observed mean deviations and it can show the correlation between the predicted and observed data. E is better suited to evaluate model goodness-of-fit than the R^2 (the square root of the correlation coefficient between the predicted and observed value).

$$E = 1 - \frac{\sum_{i=1}^{n}(\mathrm{Xobs.}_i - \mathrm{Xpre.}_i)^2}{\sum_{i=1}^{n}(\mathrm{Xobs.}_i - \overline{\mathrm{Xobs.}_\imath})^2} \qquad (6)$$

Where:

n= number of data, $X_{obs.i}$= observed value, $X_{pre.i}$= predicted value, S = standard deviation of observed value, $\overline{\mathrm{Xobs.}}$ = the mean of observed data, $\overline{\mathrm{Xpre.}} =$ the mean of predicted data.

A better fit, with zero indicating (MAPE%) and high value of (E) and a perfect prediction. The probability of procedure produces an interval that contains the actual true parameter value is known as the confidence level and is generally chosen to be 95CI%. So the model if have a good performance well produce a results within the range of 95CI% of the mean observed data.

4.Estimation of Transmissivity Using Specific Capacity Data for Tazerbo WellField:

1.4 Transmissivity values from step drawdown test (Theis analytical approach).

The step drawdown dataset used at this study was composed of information obtained from 92 single pumping wells test. The step drawdown test involved pumping the well at four successively increasing pumping rates or steps each of 3-hour duration. The initial pumping rate was 40L/sec followed by 80L/se, 120L/sec, and 150L/sec. The minimum required data for each well to be included in this study is the well yield (Q), the pumping duration (t), the static water level (SWL) and all of that are presents at Table 2, also all the documented data are available from GMMRA. Because Theis equation, cannot be solved directly for transmissivity, it must be solved graphically or iteratively, which can be done manually or by using a calculator, can also solved easily by using computers such as a AQTESOLV software (Duffield, 2007). The results presents at Table 3 and Figures (4 and 5) showing that the estimation using the Thies iterative method yield a transmissivity with an average of 0.77m^2/min, and maximum and minimum values are respectively 1.24, 0.49 m^2/min. Moreover the results were obtained meet the observed values, thus indicates that specific capacity tests can be reliably used to estimate transmissivity.

Table 2 Statistical Analysis of Field Measurement, Tazerbo Wellfield .

	Z m Well elevation	**S m Final Drawdown**	**E % Well Efficiency**	**Hs m static water level**	**b m The aquifer thickness**	**Q m^3/min last step rat test**
Average value	270.61	18.00	85.02	5.00	151.52	9.24
Max. value	284.11	28.20	97.32	11.24	184.53	9.54
Min. value	167.60	10.59	70.46	-1.94	104.51	8.48

Table 3 Statistical Analysis of the step pumping test result, Tazerbo Wellfield

Variable	Mean	Minimum	Maximum
Sc m^2/min Specific capacity	0.35	0.22	0.59
T m^2/min Transmissivity obtained from Theis Eq.	0.77	0.49	1.24

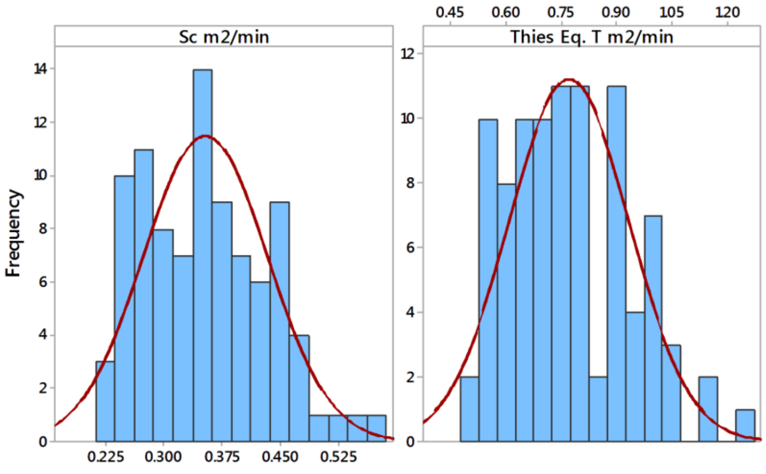


Figure (4) Transmissivity and Specific capacity m^2/min Histogram (Tazerbo Wellfield) .

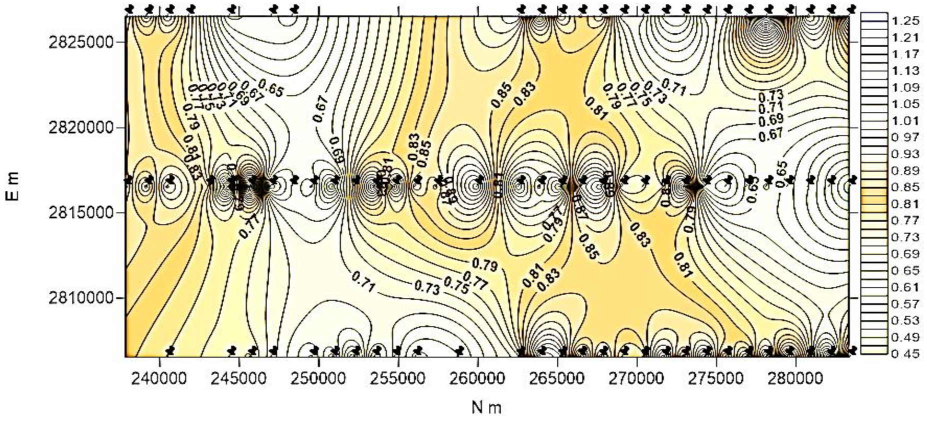


Figure (5) Transmissivity contour map of Tazerbo wellfield aquifer and the well location .

4.2 Transmissivity values from Empirical equations for Sandston aquifers:

Several researchers have developed empirical relationships between transmissivity and specific capacity for a range of hydrologic settings. The existing relationships which used in this study chosen the equations developed for sandstone aquifers, because the Tazerbo wellfield placed on the Sarir Sandstone aquifer. The investigators described empirical relationships between transmissivity and specific capacity for Sandstone aquifers based on the results of step pumping test are: Mace, et al (2000 and 1999), Al Farrah, et al(2013), and Sandra, (2016) see Table 1. Once the best-fit line is found, the coefficient of efficiency (E) describes how much of the observed variability of parameters can be explained by the regression model.

Table 4 and Figure (6) provide information about the results from empirical equation estimation of transmissivity of sandstone aquifers. The use of such a relationships are reliable with their use in previous studies. But when they applied in Tazerbo wellfield step tests data, lead a weak coefficient of determination (E) also large absolute percentage error (MAPE%).

Table 4 Summary of statistical results error of the empirical relationships between specific capacity and transmissivity

Equation for Transmissivity estimation m^2/min	MAP E%	E	The average Tm^2/min	Maximum value Tm^2/min	Minimum value Tm^2/min	95CI% m^2/min
Theis Eq. Step-drawdown test			0.77	1.24	0.49	0.74 — 0.81
Sandra (2016)	7.27	0.83	0.74	1.31	0.43	
Al Farrah et al (2013)	27.07	0.15	0.56	0.86	0.38	
Mace and other (2001)(1)	58.69	0	0.32	0.48	0.22	
Mace and other (2001)(2)	60.60	0	0.30	0.45	0.21	
Mace and other (2001)(3)	60.34	0	0.30	0.48	0.20	
Mace and other (2001)(5)	47.69	0	0.40	0.67	0.25	
Mace and other (99)	22.20	0.25	0.60	1.03	0.37	

The empirical equations Mace (2001, 99) and Al Farrah (2013) are not effective for the transmissivity estimation and cannot reliably applied to this study data. On the other hand Sandra (2016) equation provides a closed results to the calculated transmissivity of Tazerbo wellfield, with higher E=0.83 and lower MAPE=7.27%, than other equations were used in this study. In addition Sandra (2016) equation provides an average value of transmissivity within the range of (95CI%) for the calculated transmissivity.

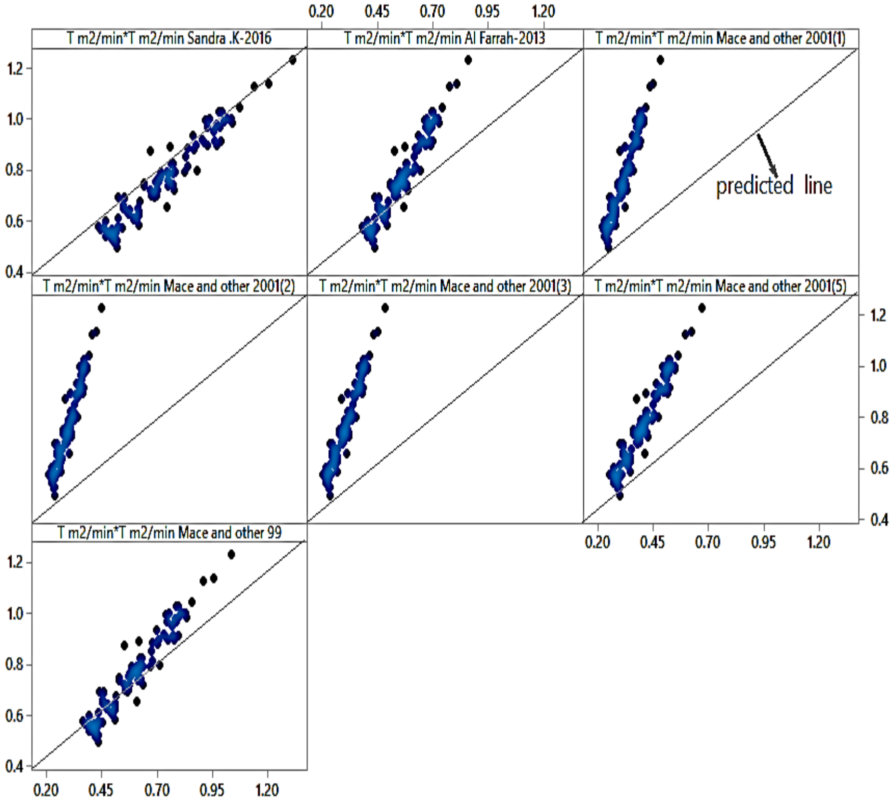


Figure (6) compression between the Empirical relationships results, Sandra(2016), Mace(2001)(1,2,3,5), Al Farrah (2013), Mace (1999) and the transmissivity obtained from Theis Eq. also showing the variation from the predicted line.

3.4 Transmissivity values from developing Empirical equation for Tazerbo Wellfield :

In this research, nonlinear regression analysis of step pumping test data was used as a method for estimating aquifer transmissivity. The nonlinear regression analysis can provide a means for analyzing step pumping tests which may not have been easily interpreted using traditional techniques, as the nonlinear regression analysis attempts to match all the test data at both large and small values of time. However, this analysis also illustrates that fitting methods cannot be totally automated, but rather must be interpreted in light of other hydrogeological data in order to arrive a reasonable model for the aquifer.

As mentioned before, an empirical relationships between the transmissivity and the specific capacity measured in the same well was established by several authors. For most of these studies, transmissivity was calculated with the Theis (1935) method and specific capacity was taken in step drawdown test. In the present study, 92 values of specific capacity obtained from the GMMRA for Tazerbo wellfield used to developed a new empirical relationship between transmissivity and specific capacity. The calculated values were compared with values of transmissivity from step pumping tests also the existing empirical equation for sand stone aquifers. This comparative study has never been conducted before in a study region. The results will add to the development of a cost effective tool for expert estimation the hydraulic properties of aquifers and their reliability at a regional scale. In the concerned aquifer, the relationship was derived from nonlinear regression method using the values of transmissivity (from step pumping test) and measured specific capacity both in m^2/min units. The best-fitting line between these parameters indicates encouraging relationship see Figures (7 and 8).

Moreover, this study shows that $T = 1.98(S_c)^{0.91}$ meeting the results which obtained from step pumping test value with high (E=0.91), and low (MAPE=5.01%), and provide an average value of transmissivity is (0.77 m^2/min) within the range of 95CI% see Table 5.

This established empirical equation can be used to predict the transmissivity of the study area aquifer in all new sites for well drilling at which the specific capacity measured which is expensive, but with low potential error of prediction.

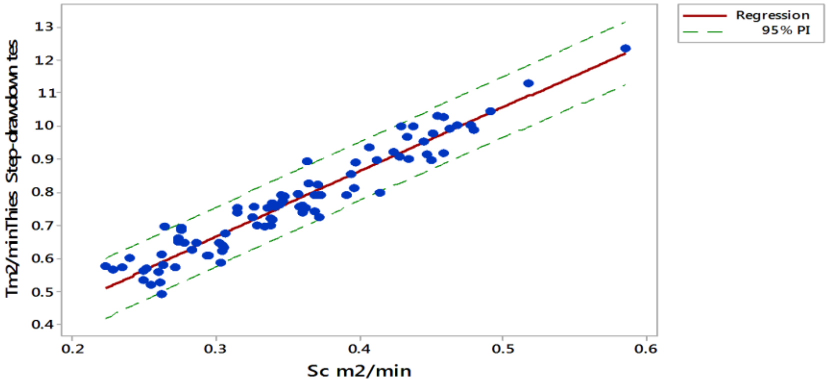


Figure (7) Empirical relationships between transmissivity and specific capacity by nonlinear regression technique for Tazerbo wellfields, showing the best-fit line and the 95-percent prediction intervals .

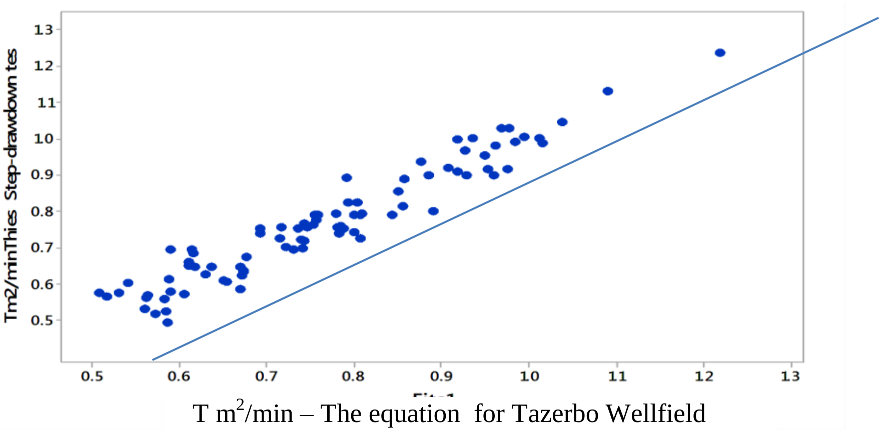


Figure (8) comparison between the new Empirical relationships between transmissivity and specific capacity and the observed transmissivity for Tazerbo wellfields, showing the predicted line .

Table 5 Summary of statistical error for the equation of Tazerbo Wellfield results.

Methods for Transmissivity estimation m^2/min	MAPE%	E	The average Tm^2/min	Maximum value Tm^2/min	Minimum value Tm^2/min	95CI%
Theis Eq. Step-drawdown test			0.77	1.24	0.49	0.74 — 0.81
Sandra (2016)	7.27	0.83	0.74	1.31	0.43	
The Equation Of Tazerbo Wellfield	5.01	0.91	0.77	1.22	0.51	

5- Discussion and conclusion

In existence of well complete pumping tests, a reliable statistical and spatial description of hydraulic properties has been achieved in such as the Tazerbo wellfield aquifer. The Tazerbo wellfield aquifer transmissivity calculated using Theis iterative equation solved by AQTESOLV software. Nearby the mean value of transmissivity is 0.77 m^2/min is similar to that obtained from GMMRA, For these reasons, transmissivity values obtained from step pumping test with the iterative method can be considered as reliable estimates. Empirical relationships between transmissivity and specific capacity obtained in different studies from different sandstone aquifers were presented and examined. Moreover uses of such a relationships are reliable with their use in previous studies. But when they applied in Tazerbo wellfield, lead a weak coefficient of determination and large absolute percentage error. Nonetheless Sandra (2016) equation provides a closed results with higher (E=0.83) and lower (MAPE=7.27%), than other equations were used. The values of transmissivity were calculated from step pumping tests over the study area (50 Km x 20Km) with long-duration pumping is significant as a larger number of data can lead to better regression analysis of the transmissivity values for the regional study, and improvement the accuracy of developing new empirical relation between transmissivity and specific capacity data. Using the previous information increases the number of hydraulic property values estimated in a region, and thus allows for a better regional characterization of aquifers at a low cost. Finally, the new empirical relationship between T and S_c has been established for Tazerbo wellfield aquifer. The best fit line equation is $T = 1.98(S_c)^{0.91}$ with (E=0.91), and (MAPE=5.01%). This relationship, permits for a fast and easy estimation of the transmissivity of the tested aquifer while conducting a specific capacity test, and can be useful for similar environments.

Acknowledgements

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