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# Assessment of Confined Aquifer Parameters of North Kabul Sub-Basin of Kabul Basin

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***Abstract*— Assessment of confined aquifer parameters, namely, transmissivity T, storage coefficient S and hydrological boundaries, from pump-test data has been a continual field of research. Several conventional and computer based methods are available for analyzing pump-test data. A simple method by Sushil K. Singh has been presented for precise determination of aquifer parameters using early drawdown data. The method does not require curve matching, initial guess of the parameters, or special care to check for u< 0.01, and the computations involved can be performed on a calculator. This paper shows that these early drawdown data, especially in the neighborhood of u= 0.43, can yield accurate values of aquifer parameters. The present method converges with the Cooper-Jacob method when the late drawdown data are considered.**

**The principle objective of this study is to estimate the confined aquifer parameters of the North Kabul sub-basin of Kabul city as accurate, reliable and economical as possible. Also to determine the parameters, hydrological boundaries and their respond to pumping with a method with site applicability and with short time of pump test, with a method applicable to time and resource constraints. The first study to estimate the aquifer parameters from pump test was analytically derived by Theis (1935), which is valid for groundwater radial unsteady flow based on the Darcy law. Later, a large number of graphical and analytical methods (Cooper and Jacob 1946, Chow 1952, Walton 1962, Papadopulos and Cooper 1967, Saleem 1970, Wikramaranta 1985, Yeh 1987b, Şen 1988) and numerical methods (Rai 1985, Yeh 1987a, Şen 1986, El-Khatib 1987, Bourdet et al 1989, Srivastava and Guzman-Guzman 1994, Singh 2001, Mesut Cimen 2008) based on the Theis equation are proposed by many scientists. Both graphical and analytical, and numerical methods have their own merits and demerits. Present method (Sushil K. Singh) for estimating confined aquifer parameters uses a few early drawdowns to yield accurate values. It enables estimation of aquifer parameters from short duration pump-test data or initial data recorded during an abandoned pump test, which might otherwise be considered inappropriate for reliable estimation of the aquifer parameters.**

**Using the present method the confined aquifer parameter of Kabul Basin is estimated in 14 points. The T and S values estimated by this method have a very little difference between each other. In general based on average we can say that the transmissivity of confined aquifer of North Kabul sub-basin is 94.76m^/day and the storage coefficient is 0.00241. The reliability of these values is judged by calculation of the Standard Error of Estimate (SEE) considering variartions of observed and computed drawdown for early as well as late drawdown data. The minimum value of SEE = 6.1 * 10^-4 and the maximum value is 1.46 * 10^-3. These values shows the reliability of this method compared to other existing methods in the literature while this method used early drawdown data and again reproduced the early and late time drawdown data using estimated aquifer parameters(T&S) with such a SEE values. None of the above mentioned methods bearing such a SEE values on published drawdown data. As the confined aquifer of North Kabul sub-basin is like fossil there is no leakage between confined and unconfined is reported and also there is no recharge boundary is available [JICA]. The hydrological impervious boundary of the aquifer is not determined because of the location of the observation and pumped wells far from the boundary and no well is located near to the boundary.**

***Keywords*—Confined Aquifer, Cooper Jacob Method, Transmissivity, Storage Coefficient, Standard Error of Estimate.**

## I. INTRODUCTION

Groundwater is water found beneath the surface of the earth and it is an important part of the water cycle. When it rains on land, some water evaporates, some flows into creeks and rivers and some soaks into the soil and is used by vegetation. Excess water may soak into the soil beyond the plant root zone until it reaches the saturation zone. At this point all spaces in the soil and rock are full of water. This water is called groundwater.

Groundwater development dates from ancient times. The old-testament contains numerous references to groundwater, springs, and wells. Other than dug wells, groundwater in ancient times was supplied from horizontal wells known as qanats. These persist to the present day and can be found in a band across the arid regions of Southwestern Asia and North Africa extending from Afghanistan to Morocco.

Groundwater is a precious and the most widely distributed resource of the earth and unlike any other mineral resource, it gets its annual replenishment from the atmospheric precipitation. Of these global water resources about 97.2% is salt water mainly in oceans, and only 2.8% is available as fresh water at any time on the planet earth. Out of this 2.8%, about 2.2% is available as surface water and 0.6% as groundwater. Even out of this 2.2% of surface water, 2.15% is fresh water in glaciers and icecaps and only of the order of 0.01% (1.36x10^8) million m^3 is available in lakes and reservoirs, and 0.0001% in streams; the remaining being in other forms as water vapor and soil moisture. Out of 0.6% of stored groundwater, only about 0.3% (41.1x10^8) million m^3 can be economically extracted with the present drilling technology, the remaining being unavailable as it is situated below a depth of 800 m. Thus the groundwater is the largest source of water in the world excluding water in glaciers and icecaps.

As our purpose is to evaluate the parameters of the aquifers, here we start from the formations which store water (referred as aquifers). Groundwater occurs in many types of geologic formations; those known as aquifers are of most importance. A geological formation that will yield significant quantities of water has been defined as an aquifer.

Most aquifers are of large areal extent and may be visualized as underground storage reservoirs. Water enters a reservoir from natural or artificial recharge; it primarily flows out under the action of gravity or is extracted by wells. Aquifer may be classified as unconfined or confined, depending on the presence or absence of a water table, while a leaky aquifer represents a combination of the two types.

An unconfined aquifer is one in which a water table varies in undulating form and in slope, depending on areas of recharge and discharge, pumpage from wells, and permeability.

Rises and falls in the water table correspond to changes in the volume of water in storage within an aquifer.

Confined aquifers, also known as artesian or pressure aquifers or deep aquifers, occur where groundwater is confined under pressure greater than atmospheric by overlying relatively impermeable strata. In a well penetrating such an aquifer, the water level will rise above the bottom of the confining bed. Water enters a confined aquifer in an area where the confining bed rises to the surface where the confining bed ends underground, the aquifer becomes unconfined.

For mathematical calculations of the storage and flow of groundwater, aquifers are frequently assumed to be homogeneous and isotropic. A homogeneous aquifer possesses hydrologic properties that are everywhere identical. An isotropic aquifer's properties are independent of direction. Such idealized aquifers do not exist; however, good quantitative approximations can be obtained by these assumptions, particularly where average aquifer conditions are employed on a large scale.

As our objective is to determine the aquifer parameters, here we are going to define some properties of the aquifer. A storage coefficient or storativity is defined as the volume of water that an aquifer releases from or takes into storage per unit surface area of aquifer per unit change in the component of head normal to that surface. The coefficient is a dimensionless quantity involving a volume of water per volume of aquifer. In most confined aquifers, values fall in the range $0.00005 < S < 0.005$, indicating that large pressure changes over extensive areas are required to produce substantial water yields. Storage coefficients can best be determined from pumping tests of wells.

For practical work in groundwater hydrology, where water is the prevailing fluid, hydraulic conductivity K is employed. A medium has a unit hydraulic conductivity if it will transmit in unit time a unit volume of groundwater at the prevailing kinematic viscosity (equals dynamic viscosity divided by fluid density) through a cross section of unit area, measured at right angles to the direction of flow, under a unit hydraulic gradient. The units are m/day indicating that hydraulic conductivity has units of velocity and the term transmissivity T is widely employed in groundwater hydraulics. The most reliable method for estimating aquifer Transmissivity is by pumping tests of wells based on observations of water levels near pumping wells.

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The principle objective of the groundwater studies is to determine how much groundwater can be safely withdrawn perennially from the aquifers in the area under study. This determination involves the transmissibility and storage coefficient, lateral extend of aquifer and its hydraulic boundaries, leakage if any, and the effect of proposed developments on recharge and discharge conditions. In all these studies two different flow conditions are assumed; steady state condition, i.e., when the flow is steady and the water levels have stopped to decline and non-steady state condition, i.e., when the rate of flow through aquifer is changing and the water levels are declining. As in reality all the time the unsteady flow occurs, so we start from unsteady flow.

When a well penetrating an extensive confined aquifer, is pumped at a constant rate, the influence of the discharge extends outward with time. The rate of decline of head times the storage coefficient summed over the area of influence equals the discharge. Because the water must come from a reduction of storage within the aquifer, the head will continue to decline as long as the aquifer is effectively infinite; therefore, unsteady flow or transient, flow exists. The rate of decline, however, decreases continuously as the area of influence expands.

The applicable partial differential equation in polar coordinate is

$$\frac{\partial^2 h}{\partial r^2} + \frac{1}{r}\frac{\partial h}{\partial r} = \frac{S}{T}\frac{\partial h}{\partial t} \qquad \text{……..…….. (1)}$$

where in this partial differential equation h = head (m), r = radial distance from the well that was pumped (m), S = storage coefficient (dimension less), T= transmissivity (m^2/min, and t = time since the beginning of pumping (min).

This obtained solution for the Eq.1 based on the analogy between groundwater flow and heat conduction. By assuming the well is replaced by a mathematical sink of constant strength and imposing the boundary conditions $h=h_0$ for t=0, and $h \rightarrow h_0$ as $r \rightarrow \infty$ for t>=0, the solution is obtained as;

……...

$$s = \frac{Q}{4\pi T}\int_u^{\infty}\frac{e^{-u}du}{u} = \frac{Q}{4\pi T}W(u) \qquad (2)$$

$$= \frac{Q}{4\pi T}\left[-0.5772 - \ln u + u - \frac{u^2}{2\cdot 2!} + \frac{u^3}{3\cdot 3!} - \frac{u^4}{4\cdot 4!} + \cdots\right]$$

where s is drawdown, Q is the constant well discharge and argument u as;

$$u = \frac{Sr^2}{4Tt} \qquad \text{……… (3)}$$

The Eq.2 is known as the non-equilibrium or Theis equation. The integral is function of the lower limit u and is known as an exponential integral. It can be expanded as a convergent series as shown in second part of Eq.2 and is termed the well function W (u).

The non-equilibrium equation permits determination of the aquifer parameters S and T by means of pumping tests of wells. The equation is widely applied in practice and is preferred over the equilibrium equation because (1) a value for S can be determined, (2) only one observation well is required, (3) a shorter period of pumping is generally necessary, and (4) no assumption of steady-state flow conditions is required.
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## II. Study Area

The groundwater resource is one the precious resources of the earth, and one fifth of all the water used in the world is obtained from ground water resources. So, Kabul city as a capital, and the most populated city in Afghanistan, with around 4.5 million populations, is among those cities which obtains its required water for social and economical purposes from groundwater resources. So, it is needed to determine the aquifer parameters and boundaries and leakage if any, for safely and perennial withdrawal of water for specified needs.

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The main objective of the study has been chosen is to estimate the parameters and boundaries of North Kabul sub-basin aquifer as accurate, reliable and economical as possible.

The Study Area covers the North Kabul Sub-Basin of Kabul Basin where a part of Kabul City exists with current population of 4.5 million in (2010). The Kabul Basin is located between longitude 68°59’30.9” and 69°22’27.4” E and from latitude 34°24’18.0” to 34°36’33.1” N (from 500500 to 534200 E and from 3807750 to 3830300 N in UTM zone 41N), with an area of around 480 km2. The basin is enclosed by low but quite steep mountain ranges, and divided into two sub-basins by also low but steep mountain range with NW-SE direction (this range is called as “Barrier mountain range”, hereafter). Its western sub-basin is called the Darlaman sub-basin, and in its eastern side the North Kabul, Pol-e-Charkhy, and Logar sub-basins are located. These sub-basins are separated by low, gentle and flat-topped hills. Our interest is North Kabul Sub-Basin.

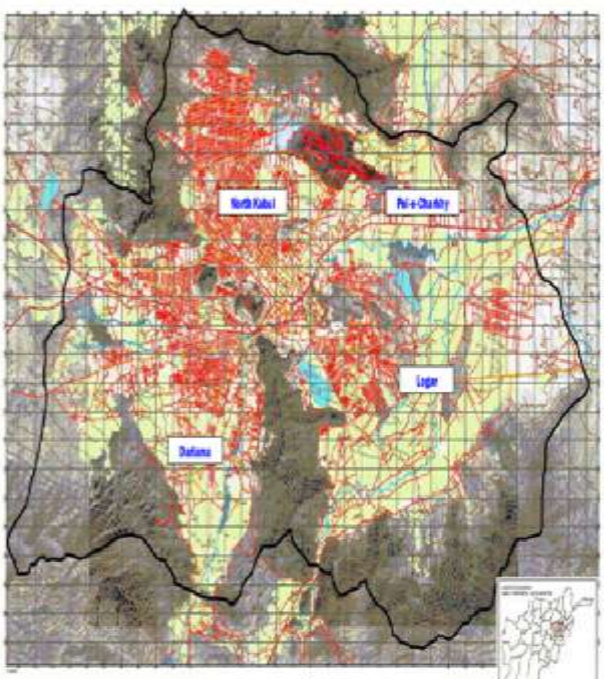

**Fig.1 Sub-Basins in the central Kabul Basin**

Aquifer in the Kabul Basin so-called fossil water is outside of the natural water cycle. Due to the limited, or no, recharge to the aquifer, fossil water is not usually developed as a water source.

However, other water sources in Kabul basin are quite limited to the ever increasing population, and thus there is a high risk of water shortage crisis anytime when drought or any technical problem happens. Thus, deep aquifer is

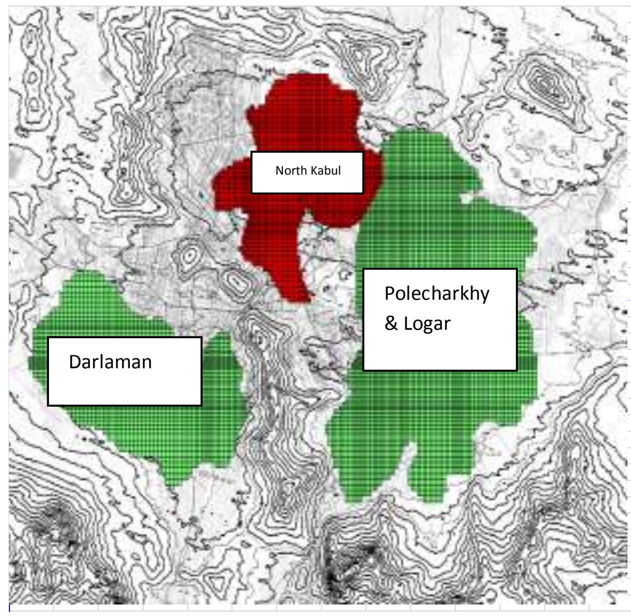


**Fig.2 Sub-Basins in the central Kabul Basin**

analyzed mainly to examine the development potential for emergency purpose. That is to study how much of water can be discharged for how long time based on groundwater simulation.

Nevertheless the depths of Neogene Aquifer is very deep, as lower than around 300m below ground surface, the water heads of the aquifer were very shallow as less than 3m to around 12m from the surface in the maximum[JICA]. The well names and the depths are given in the following table.

The following are the aim and objectives of the paper:

- Estimation of aquifer parameters of Kabul basin aquifers as accurate, reliable and economical as possible.
- Estimation of parameters by a simple method with on-site compatibility.
- Locating the aquifer boundaries, for assessing extend of a bounded aquifer to predict its response to pumping.
- Estimation of parameters by analyzing the early drawdown data which are not sufficient for analyzing by other methods.

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- Estimation of parameters by using short pumping periods.
- Estimation of parameters by using of the abandoned pump test data.
- Estimation of parameters by more compatibility to time and resource constraints.

| Name of Well | Depth (m) Below GL | Location |
|---|---|---|
| OW-1 | 450m | North Kabul |
| TW-1 | 580 | North Kabul |
| TW-2 | 640 | North Kabul |
| MW-1 | 385 | North Kabul |
| AF 10 | 540 | North Kabul |
| AF 09 | 475 | North Kabul |
| AF 08 | 560 | North Kabul |
| AF 06B | 430 | North Kabul |
| AF 06A | 390 | North Kabul |
| AF 05 | 545 | North Kabul |
| AF 04 | 386 | North Kabul |
| KM 01 | 520 | North Kabul |
| KM 02 | 430 | North Kabul |
| UN 01 | 540 | North Kabul |

**TABLE I**
**NAMES OF WELLS WITH THEIR DEPTH IN DEEP AQUIFER**

## III. METHODOLOGY AND EXPERIMENTATION

The Method we have chosen for determination of confined aquifer parameters of North Kabul sub-basin is Sushil K. Singh's Method [2001]. Sushil K. Singh [2001] developed a simple method uses few early drawdown to estimate confined aquifer parameters very accurately. This method has the same assumptions as Theis, Cooper-Jacob, and so on… that the aquifer should be assumed homogenous, isotropic and infinite areal extend. The drawdown s at an observation well resulting from pumping well with negligible storage drilled through full thickness of the aquifer, is given by equation 4 as follows;

$$s = \frac{Q}{4\pi T}\int_u^\infty \frac{e^{-x}}{x}\,dx = \frac{Q}{4\pi T}W(u) \qquad \text{…... (4)}$$

where

u= [S/(4Tα)] …. (5)

and α =t/r^2. Divide Equation 4 by α

$$S^1 = (s/\alpha) = \{[Q/(4\pi T\alpha)]*[W(u)]\} \text{ …….. (6)}$$

where Q= constant rate of pumping (m^3/min); W (u) =well function in groundwater literature (Bear 1972); α =t/r^2; t= time since pumping is started (min); r=distance of the observation of from the pumping well(m).

When $s'$ is plotted against α, a bell shaped curve is obtained for early drawdown data as shown in figure 1. Let the peak of the curve be $s'_*(s_*/\alpha_*)$ and $\alpha_*$ be the time at which the peak occurs. Differentiating Equation 6 with respect to α and equating to zero, the following characteristics of the peak are obtained.

$$u_* = 0.4348182 \qquad \text{……... (7)}$$

$$W(u_*) = 0.6473823 \qquad \text{……... (8)}$$

Substituting (7) and (8) in (4) and (5), respectively, the following expressions for the aquifer parameters are obtained:

$$T = \frac{Q}{4\pi s_*}W(u_*) = 5.152\times 10^{-2}\frac{Q}{s_*} \qquad \text{……. (9)}$$

$$S = \frac{4Tu_*}{r^2} = 1.7393T\alpha_* \qquad \text{……. (10)}$$

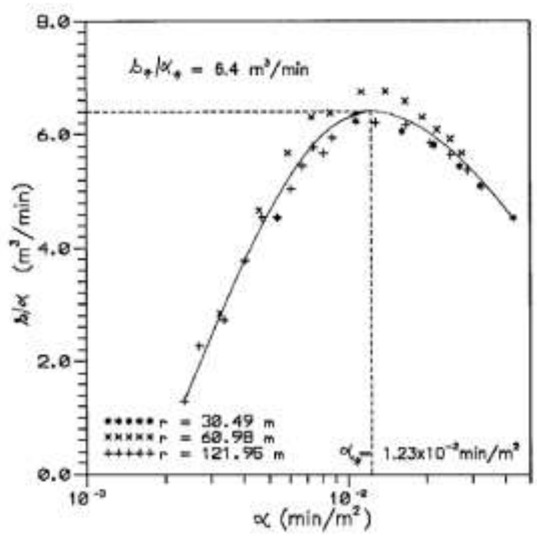


**Fig.3 An example of smooth curve of $s'$ against α**

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There is one condition for identifying the peak from $s'$ versus α curve, that is, at least there will be one point having u>0.4348. For the early drawdowns recorded at a shorter time interval, the peak can be accurately located by drawing a smooth curve through a few points near the peak. By knowing $s'_*$ and $\alpha_*$, we can calculate $s_* = s'_* * \alpha_*$. Once $s_*$ and $\alpha_*$ values are known, T and S can be calculated from (8) and (9). This method needs a few early drawdowns and requires less subjectivity for locating the peak point compared to curve matching. Accuracy of the T and S values depend on accuracy of the locating peak point on $s'$ versus α graph.

For single observation well, s/t is plotted against t and the peak ($t_*$, $s_*/t_*$) are specified by drawing a smooth curve through the points. $s_*$ can be calculated by product of the coordinate points at the peak. $\alpha_*$ can be obtained by relation of $t_*/r^2$. From (9) and (10) easily can be understood that, the $s_*$ and $\alpha_*$ are inverse measure of the T and T/S (aquifer diffusivity), respectively. This shows that $s_*/\alpha_*$ is an inverse measure of storage coefficient. Hence, (4) can be rewritten in terms of $s_*$ and $\alpha_*$ as follows:

$$\frac{s}{s_*} = 1.5446W\left(\frac{0.4348\alpha_*}{\alpha}\right) \quad \text{.... (11)}$$

If the peak could not be located on either an s/ α versus α or s/t versus t curve, the parameters $s_*$ and $\alpha_*$ can be obtained from the late drawdowns for which u<0.01. For this case (11) may be written

$$\frac{s}{s_*} = 3.5566 \log\left(\frac{1.2913\alpha}{\alpha_*}\right) \quad \text{..... (12)}$$

It shows that when s is plotted against t or α, a straight line is obtained on a semi log graph with t or α on the log axis. Therefore, the present method converges to Cooper-Jacob method for u<0.01. The parameters $s_*$ and $t_*$ or $\alpha_*$ are given as follows:

$$s_* = 0.2812\Delta s \quad \text{............ (13)}$$

$$t_* = 1.2913t_0; \quad \alpha_* = 1.2913\alpha_0 \quad \text{......(14 a,b)}$$

Where $\alpha_0$ = intersection of line on the x-axis giving s=0. In fitting the straight line, data for which u<0.01 should not be considered.

Using of equation (11) for predicting leaky aquifer drawdown data shows a large deviation from the observed ones. The hydrologic boundary conditions' (e.g., a recharge boundary or an impervious boundary) effect can also be identified by this method from late drawdown data in same manner similar to the Cooper-Jacob method. Therefore, this method is able to recognize the non-ideal aquifer conditions.

This method can give reliable estimates of the parameters from early drawdowns observed during an abandoned pump test, which may be inappropriate for reliable estimates of aquifer parameters by other methods. This method does not require curve matching or initial guess for parameters. Using of this method needs much shorter duration of pump test, thus, saves time and money. It is able to identify leaky aquifer condition from late drawdown data and also it can determine the hydraulic boundaries of an aquifer. Its applicability needs at least one point having u value >0.44. Application of this method on published data shows that the aquifer parameters can be estimated more accurately even when only a few early drawdown data are used with more reliability.

The reliability of the estimated parameters may be judged by the following criterion

$$\text{SEE}=\left(\frac{1}{n-p}\sum_{i=1}^{n} e_i^2\right)^{0.5} \quad \text{......... (15)}$$

where SEE=standard error of estimate; (s-s')i=ei=residual error for the ith observed drawdown; n=number of observed drawdown; and p=number of parameters estimated. If a high value of SEE is observed and the predicted drawdown data differ substantially from those observed, a non-ideal aquifer condition other than that assumed is confirmed. In that case, the estimates of the parameters are not valid.

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## IV. Analysis of Pump Test Data

The method (Sushil K. Singh) described in earlier has been applied on 14 sets of pump test data collected from different parts of Kabul Basin. The first 4 sets of data are taken from "The Study on Groundwater Resources Potential in Kabul Basin in The Islamic Republic of Afghanistan [2011]" report. The second remaining 10 sets of data are taken from "Well Rehabilitation Report 2011 prepared by Central Authority for Water Supply and Sanitation (CAWSS)".

For each set of data; values of drawdown/time (s/t) are plotted against time (t), and the peak (s/t)* and t* are located by drawing a smooth best-fit curve through the plotted points for each selected case by using SigmaPlot software. By using peak values α, transmissivity (T) and Storage Coefficient (S) are calculated one by one using Equations 9 and 10. At this point, it is worth mentioning that s* and t* can be obtained with the same accuracy using even fewer data points than actually given in the data set tables.

The reliability of the method is based upon Standard Error of the Estimate (SEE) between the observed and computed drawdown data using Equation 15 given for SEE. The lower the value of SEE, the more reliable is the estimate. This is because a low value of SEE denotes a low value of integral squared error. A reliable estimate of parameters would yield the drawdown with less error.

In the following part only Well OW-1 data set is given and analyzed. The aquifer parameters with their reliabilities are discussed in details but the other data sets are not show and discussed but, only the value of T, S and SSE are calculated and given in the table 3.

This well is located in North Kabul sub-basin. The table 2 shows the Pump Test data collected in an observation well located in a radial distance of 25.1m from pumped well. The value of the constant discharge is (Q)=0.178m^3/min.

The first column in the table 2 gives the time interval of the pump test, the observed drawdowns associated with time intervals are given in second column and the drawdown/time values which are calculated by Excel is give in third column. In the fourth column the computed drawdown data using estimated parameters (T&S) are given. About 47 drawdown data or in other word 150min of the pump test duration is chosen from actual data sheet of this pump test but only 17min is shown here.

The values of s/t versus t values based on the table 2 are plotted and a smooth best-fit curve is drawn through the values and is shown in Figure 4.

**TABLE III**
**PUMP TEST DATA OF WELL OW-I**

| | | | | |
|---|---|---|---|---|
| Constant Discharge (Q) (m^3/min) = | | 0.178 | Transmissivity (m^2/day)= | 96.09722319 |
| Observation Well Distance (m) = | | 25.1 | Storage Coefficient= | 0.002553516 |
| Peak Details of the Curve | t* (min)= | 13.86 | (s/t)* (m/min)= | 0.009946 |
| s*=t* x (s/t)* (m)= | 0.13785156 | a=t*/r^2 (min/m^2)= | 0.021999651 | SEE=0.00061137 4 |
| t (min) | s (m) | s/t (m/min) | Computed drawdowns (s') | 47 drawdowns |
| 0 | 0.000 | 0.00000 | 0 | |
| 1 | 0.005 | 0.00500 | 0.004 | |
| 2 | 0.015 | 0.00750 | 0.014 | |
| 3 | 0.025 | 0.00833 | 0.024 | |
| 4 | 0.035 | 0.00875 | 0.034 | |
| 5 | 0.045 | 0.00900 | 0.044 | |
| 6 | 0.055 | 0.00917 | 0.054 | |
| 7 | 0.065 | 0.00929 | 0.065 | |
| 8 | 0.075 | 0.00938 | 0.075 | |
| 9 | 0.088 | 0.00978 | 0.089 | |
| 10 | 0.098 | 0.00980 | 0.099 | |
| 11 | 0.108 | 0.00982 | 0.109 | |
| 12 | 0.118 | 0.00983 | 0.119 | |
| 13 | 0.128 | 0.00985 | 0.129 | |
| 14 | 0.138 | 0.00986 | 0.139 | |
| 15 | 0.148 | 0.00987 | 0.148 | |
| 16 | 0.158 | 0.00988 | 0.158 | |
| 17 | 0.168 | 0.00988 | 0.168 | |

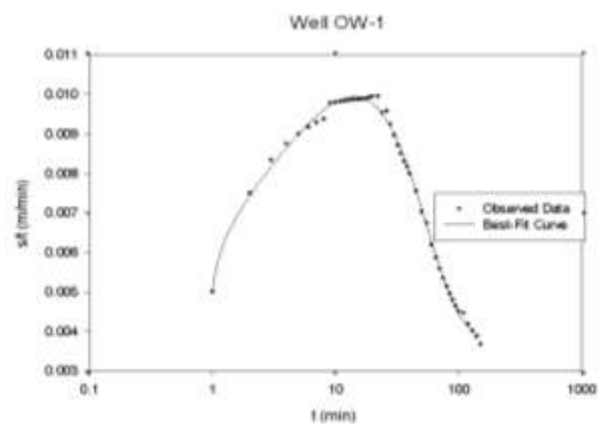


**Fig.4 Variation of s/t with t (Data of well OW-1)**

The Figure 4 shows the variation of drawdown/time with time and a smooth curve is drawn through these points. As it is obvious from the plot, this curve can be developed with same accuracy with less number of early drawdown data. But, we have chosen this much drawdown data to show the reliability of this method for estimation of late drawdown. Here about 30 drawdown or about 40min of the pump test duration are also sufficient for the peak to be accurately developed.

This plot is drawn in the SigmaPlot software based on table 4. The peaks of the curve is situated on t*=13.86min and (s/t)*= 0.009946m/min.

By using these values the α is calculated using given formulas and then the values of T and S are calculated using Equations 9 and 10 respectively. The values of T=96.09722319m^2 and the S= 0.00255. As it is mentioned in details of the study area in the last part based on the geological investigations on Kabul Basin Aquifers, there is no leakage in the aquifer and also there is no recharge boundary to effect the T and S values and also this well is situated in a place far from the impervious boundaries of the aquifer, to be effected by presence of the boundary. The SEE value is calculated as 0.000611374 which show the better reliability of this method. The following table gives the all values of parameters calculated by this method for each data set.

**TABLE IIIII**
**AQUIFER PARAMETERS ESTIMATED WITH PRESENT METHOD SEE VALUES**

| Name of Well | Location | Estimated parameters | | Considered Drawdowns No. | Actually Required Drawdowns | SEE |
|---|---|---|---|---|---|---|
| | | Transmissivity (m^2/day) | Storage Coefficient | | | |
| OW-1 | North Kabul | 96.10 | 0.00255 | 47 | 30 | 0.00061 |
| TW-1 | North Kabul | 94.36 | 0.00241 | 47 | 30 | 0.00073 |
| TW-2 | North Kabul | 104.36 | 0.00227 | 47 | 30 | 0.00080 |
| MW-1 | North Kabul | 95.66 | 0.00239 | 47 | 27 | 0.00084 |
| AF 10 | North Kabul | 89.20 | 0.00251 | 47 | 30 | 0.00127 |
| AF 09 | North Kabul | 98.22 | 0.00252 | 47 | 30 | 0.00135 |
| AF 08 | North Kabul | 96.67 | 0.00246 | 47 | 32 | 0.00132 |
| AF 06B | North Kabul | 93.60 | 0.00223 | 47 | 30 | 0.00141 |
| AF 06A | North Kabul | 98.18 | 0.00230 | 47 | 25 | 0.00127 |
| AF 05 | North Kabul | 92.10 | 0.00236 | 47 | 30 | 0.00141 |
| AF 04 | North Kabul | 92.26 | 0.00243 | 47 | 24 | 0.00133 |
| KM 01 | North Kabul | 90.63 | 0.00231 | 47 | 26 | 0.00120 |
| KM 02 | North Kabul | 95.91 | 0.00244 | 47 | 33 | 0.00141 |
| UN 01 | North Kabul | 95.28 | 0.00238 | 47 | 37 | 0.00132 |

## V. RESULTS

The proposed method was applied to 14 sets of pump test data collected from North Kabul Sub-Basin wells. For each set of data the variation of s/t against t is plotted based on values of drawdown data (s) and associated time intervals (t) given for each set in tables. A smooth best-fit curve is drawn through the points using SigmaPlot software and the peaks of the curves are determined. Using the peak values (s*/t* and t*) the aquifer parameters (T&S) are estimated. The reliability of estimated parameters is judged using the criterion of standard error of estimate (SEE). For this purpose, again by using the estimated parameters the drawdown data are calculated with the help of Theis Equation and the table containing the well function W (u) and u values.

After calculating the drawdown using estimated parameters the ESS for each set of data is determined. The table 3 summarizes the results of analysis of 14 pump test data done in analysis part.

For 14 data sets in table 3 you can see that the transmissivity estimated using present method shows a little difference between each other. The minimum value for transmissivity is 89.2m^2/day and the maximum value is 104.36m^2/day. This small difference is because of their far location from each other. In the future to nominate a transmissivity to a new well penetrating in this sub basin, the average value of transmissivity can be taken as 95.18 m^2/day. The storage coefficient values estimated by present method show a little difference between each other. Well OW-1 having the maximum of the storage coefficient of 0.00255 and the AF06B has the minimum storage coefficient of 0.00223. In the future if a new well is going to be penetrated in this sub-basin or a investigation about volume of water in the aquifer is going to be conducted, we can directly nominate an average value of 0.00239 as storage coefficient. While the accuracy of the parameters depend on accuracy of locating of the peak in curve and points which have u=0.44, thus the parameters are estimated so accurate because the curve is drawn and the peak is determined by SigmaPlot software with the best accuracy and there are too many points having u values>= 0.44 in the data sets.

The estimation of confined aquifer parameters by present method are very economical and needs little time and resource than the other existing methods in the literature. As it is shown in column 5 and 6 of the table 3 the duration of pump test required and considered for the estimation of aquifer parameters are so less than the other existing methods. From the actual data sheets of each well we have chosen only 47 drawdowns or 150min duration out of 48 and sometimes 72 hours of constant discharge pump tests. This shows that present method is very economical and need less time compared to other existing methods. While it needs less duration of time for pump test, definitely it needs less budget and resource compared to other methods. As it mentioned in the 6th column of table 3, the required number of drawdown data for estimation of aquifer parameters with the same accuracy in the results is less than the considered values. This again shows less and less time required for duration of pump test but, we have consider this much number of drawdown data to show the reliability of method for estimation of late drawdown using estimated aquifer parameters with only considering early drawdown data.

This method is also applicable on an abundant pump test data because of its less requirements of duration of pump test which are considered insufficient data for other methods. According to the analysis we have done on the data the minimum number of drawdown data needed for estimation of aquifer parameters are 24 or 28min and the maximum is 37 or 50min.

However, we have drawn the curves in SigmaPlot software for determining the peak as accurate as possible but, if we drew the curve manually we will achieve nearly the same results. It means no more subjectivity is included in this method. Every plot can be drawn by hand in this method in the site and accurate values can be achieved through simple calculations using a simple calculator. This shows the site applicability of the method.

The reliability of this method on estimation of confined aquifer parameters is judged by Standard Error of Estimate (SEE). The low values shown in the last column of the table 3, indicating the reliability of the present method. The minimum value for the SEE is 6.1*10^-4 and the maximum value is 1.41*10^-3. These values show that the present method is more reliable than the other existing methods. No such method is available to have such a low SEE values.

According to the geological investigation about Kabul Basin aquifers, the aquifers of Kabul Basin contain fossil water with more than 1000 years old and there in no leakage with unconfined aquifer and also there is no recharge boundary exist. The impervious boundary cannot be located because all the wells are located far from the boundaries and there is no observation well is near to the boundary to facilitate the determination of impervious boundary.

## VI. Conclusions

The main conclusions drawn from the study are:

- A simple method is chosen from the existing methods in the literature for estimation of confined aquifers of North Kabul Sub-Basin, Afghanistan.
- This method is chosen to estimate the parameters, locate the location of boundaries of aquifer and its effect on estimation of parameters, leakage if any, with high accuracy and short duration of pump test and also to be compatible with time and source constraints.
- This method is applied on 14 sets of the data collected from Kabul Basin aquifers.
- The Transmissivity estimated by this method is about 95.18m^2/day in average in the North Kabul sub-basin.
- The Storage coefficient estimated by this method is 0.00239 in North Kabul sub-basin.
- The parameters are estimated more accurately because the accuracy of the estimated values depend on the accuracy of placing the peak of curve and at least there will be 3 points among points of (time,drawdown) with u values of greater or equal to 0.44 to locate the peak accurately. As in this study the best-fit curve through points are drawn by SigmaPlot software and the peak is also determined by it, so there in no doubt on the accuracy of the placing of peak and also in these data sets more points had the u values greater or equal to 0.44.
- The estimation of confined aquifer parameters by present method are estimated very economically and needed short time and resource than the other existing methods; for this study the minimum duration of pump test proved 28min and the maximum 50min.
- The reliability of this method on estimation of confined aquifer parameters is judged by Standard Error of Estimate (SEE). The minimum value for the SEE is 6.1*10^-4 and the maximum value is 1.41*10^-3. These values show that the present method is more reliable than the other existing methods.
- According to the geological investigation about Kabul Basin aquifers, the aquifers of Kabul Basin are like fossil and there in no leakage and recharge boundary. The impervious boundaries cannot be determined because of unavailability of data in the observation wells near to the boundary, so there is no effect on estimation of aquifer parameters due existing of boundaries.
- The present method has high site compatibility. Because the curve fitting can be done manually also with negligible error and the parameters can be achieved by simple calculation with a calculator.

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