



Determination of Confined Aquifer Parameters by Sushil K. Singh Method

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Abstract: For the evaluation of confined aquifer parameters, namely, transmissivity T , storage coefficient S and hydrological boundaries, from pump-test data a simple method by Sushil K. Singh has been presented. The method does not require curve matching, initial guess of the parameters, etc.,. Early drawdown data, for which the argument u of the well function is >0.01 , have often been considered unimportant in evaluating aquifer parameters. This paper shows that these early drawdown data, especially in the neighborhood of $u=0.43$, can yield accurate values of aquifer parameters. Using the present method the confined aquifer parameter of Darlaman Sub-Basin of Kabul Basin is estimated in only one point. The transmissivity of confined aquifer of Darlaman is estimated about $94.76\text{m}^2/\text{day}$ and the storage coefficient is 0.00241 . The reliability of these values is judged by calculation of the Standard Error of Estimate (SEE) considering variations of observed and computed drawdown for early as well as late drawdown data. As the confined aquifer of Kabul 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 location of the observation and pumped wells far from the boundary and no well is located near to the boundary.

Keywords: Aquifer parameters, Transmissivity, Storage coefficient, Confined aquifer, early pump drawdown data

I. Introduction

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. The total volume of fresh groundwater stored on earth is believed to be in the region of 8 million km^3 to 10 million km^3 which is more than two thousand times the current annual withdrawal of surface water and groundwater combined. This is a huge volume, but where are these fresh-water buffers located???

As our purpose is to evaluate the parameters of the aquifers, here we start from the formations which store water (referred as aquifers). A geological formation that will yield significant quantities of water has been defined as an aquifer. An aquifer may be defined as a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs. 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. 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. For mathematical calculations of the storage and flow of groundwater, aquifers are frequently assumed to be Ideal which is homogeneous and isotropic. A homogeneous aquifer possesses hydrologic properties that are everywhere identical. An isotropic aquifer's properties are independent of direction.

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.

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.

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 and the term transmissivity T is widely employed in groundwater hydraulics. It may be defined as the rate at which water of prevailing kinematic viscosity is transmitted through a unit width of aquifer under a unit hydraulic gradient. The most reliable method for estimating aquifer transmissivity and Storage Coefficient is by pumping tests of wells based on observations of water levels near pumping wells. 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

$$\frac{\partial^2 h}{\partial r^2} + \frac{1}{r} \frac{\partial h}{\partial r} = \frac{S}{T} \frac{\partial h}{\partial t} \quad (1)$$

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 $t \geq 0$, the solution is obtained as;

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

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

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

$$u = \frac{Sr^2}{4Tt} \quad (3)$$

The equation 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 equation 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.

II. Study Area (Darlaman Sub-Basin of Kabul Basin)

Afghanistan with an area of 647,500 Km^2 is a land-locked country in south central Asia. It is bordered by Pakistan, Iran, Turkmenistan, Uzbekistan, Tajikistan, and China. The climate is arid to semi-arid with cold winters and hot summers. Its terrain is dominated by the Hindu Kush Mountains and associated mountain ranges extending across the north-central part of the country in a northeast to southwest arc.

The Kabul Basin is an 80-kilometer-long valley, formed by the Paghman Mountains to the west and the Kohe Safi Mountains to the east that contains Kabul City and surrounding communities in Afghanistan. Sub-basins of the Kabul Basin, formed by inter-basin ridges (Mountain ranges) and river drainages, include Central Kabul ($419 km^2$), Paghman and Upper Kabul ($348 km^2$), Logar ($190 km^2$), Deh Sabz ($464 km^2$), Shomali ($785 km^2$) and Panjsher (unknown), with total area of about 2206 km^2 excluding Panjsher sub basin. The boundaries for the six areas generally coincide with drainage basins and encompass the major rivers flowing through the Kabul Basin.

The Study Area covers a part of the Kabul Basin where the Kabul City exists with current population of 4.5 million in (2010). The Kabul Basin is located between longitude $68^\circ 59' 30.9''$ and $69^\circ 22' 27.4''$ E and from latitude $34^\circ 24' 18.0''$ to $34^\circ 36' 33.1''$ N (from 500500 to 534200 E and from 3807750 to 3830300 N in UTM zone 41N), with an area of around 480 km^2 . 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) as shown in Figure 1. 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. In this paper our focus is on Darlaman Sub-Basin of Kabul Basin.

The water-table surface generally mirrors topography, and ground water generally flows in the directions of surface-water discharge. Steep gradients exist along mountain-front recharge areas and in the upper reaches of the Kabul, Logar, and Paghman valleys. Gradients decrease across the area beneath central Kabul, in the agricultural and village zones and in the sparsely populated Deh Sabz area.

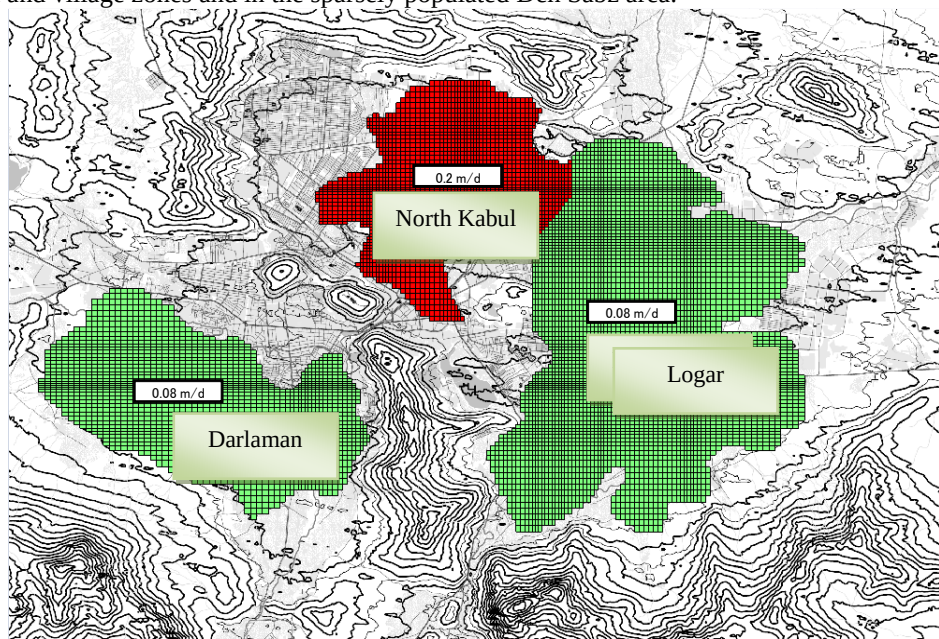


Fig. 1: Darlaman sub-basin and other sub-basins in the study area (Central Kabul Basin)

Average annual precipitation (1957–77 and 2003–06) in the Kabul Basin is about 330 mm/yr (millimeters per year). Depths to water in unconfined aquifers of the Kabul Basin range from less than 5 m to more than 60 m below land surface. Chemical and isotopic analysis of surface-water and groundwater samples indicates that shallow groundwater (less than 100 meters below land surface) typically is 20 to 30 years old, whereas groundwater in deeper aquifers or confined aquifers likely is thousands of years old.

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 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 Neo-gene Aquifer or Confined 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 in the maximum[JICA].

III. Data Collection

The data collected from the Kabul City were pump test data of more than 200 wells but some of these wells are drilled in unconfined aquifers and some of them are not penetrated in full thickness of confined aquifer. So, finally we have chosen about only one well penetrated in full thickness of confined aquifer in Darlaman Sub-Basin of the Kabul Basin. The name of well, its location and its depth is given the table 1.

Table 1: Names of well with its depth in deep aquifer

Name of Well	Depth (m) Below GL	Location
TW-4	850	Darlaman

IV. Analysis of the Pump Test Data

The method (Sushil K. Singh) described in the last part has been applied on one set of pump test data collected from Darlaman Sub-basin of Kabul Basin. For this 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 2 and 3. The values of the above parameters are given

on the top part of each data set table. 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 table.

Here the detail of the pump test data of well TW-4 is given. For this well the pump test data, graph and procedure is discussed fully. This well is located in Darlaman sub-basin. The table 3 shows the Pump Test data collected in an observation well located in a radial distance of 26.5m from pumped well. The value of the constant discharge is $(Q) = 0.378 \text{ m}^3/\text{min}$. 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.

Table 2: Pump Test data of TW-4 well

Constant Discharge (Q) (m^3/min) =		0.378	Transmissivity (m^2/day)=	94.15534
Observation Well Distance (m) =		26.9	Storage Coefficient=	0.002579
Peak Details of the Curve	t^* (min)=	16.41	$(s/t)^*$ (m/min)=	0.01815
$s^*=t^* \times (s/t)^*$ (m)=	0.2978415	$a=t^*/r^2$ (min/ m^2)=	0.015536095	
t (min)	s (m)	s/t (m/min)	Computed Drawdown (s')	
0	0.000	#DIV/0!	0.000	
1	0.011	0.01100	0.010	
2	0.025	0.01250	0.026	
3	0.040	0.01333	0.039	
4	0.055	0.01375	0.056	
5	0.070	0.01400	0.069	
10	0.160	0.01600	0.159	
20	0.385	0.01925	0.384	
22	0.398	0.01809	0.399	
24	0.410	0.01708	0.409	
26	0.430	0.01654	0.429	
28	0.445	0.01589	0.446	
30	0.462	0.01540	0.461	
32	0.477	0.01490	0.477	
34	0.487	0.01432	0.487	
36	0.498	0.01382	0.498	
38	0.508	0.01336	0.508	
40	0.518	0.01294	0.517	
45	0.538	0.01195	0.538	
50	0.548	0.01095	0.547	
55	0.568	0.01032	0.567	
110	0.688	0.00625	0.687	
120	0.698	0.00581	0.699	
130	0.718	0.00552	0.717	
140	0.738	0.00527	0.737	
150	0.748	0.00498	0.749	

In the fourth column the computed drawdowns using estimated parameters (T&S) are given. About 47 drawdowns or in other word 150min of the pump test duration is chosen (which is not shown fully) from actual data sheet of this pump test. 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 2.

Well TW-4

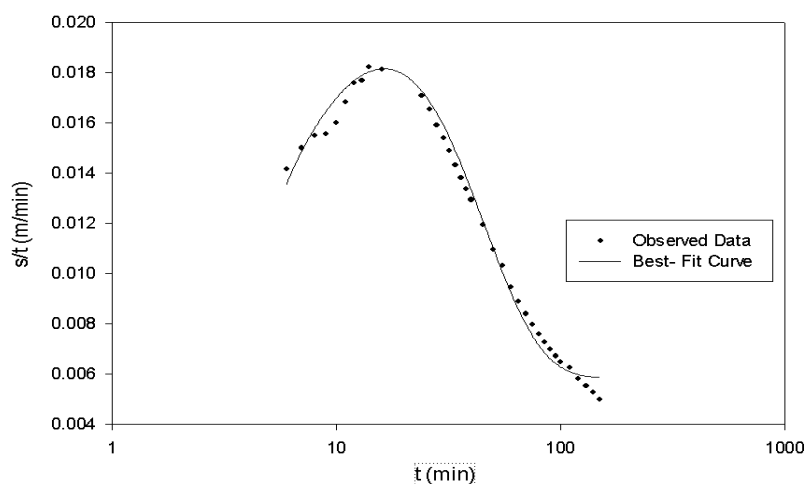


Fig. 2: Variation of s/t with t (Data of well TW-4)

The figure 2 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 drawdowns. But, we have chosen this much drawdown to show the reliability of this method for estimation of

late drawdown. Here about 18 drawdown or about 18min 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 2. The peaks of the curve is situated on $t^*=16.41\text{min}$ and $(s/t)^*=0.01815\text{m/min}$. By using these values α is calculated and then the values of T and S are calculated using Equations 2 and 3 respectively. The values of $T=94.15534\text{m}^2$ and the $S=0.002579$. 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 not 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 enough far from the impervious boundaries of the aquifer, to be effected by presence of the boundary. The SEE value is calculated as 0.0007761729 which show the better reliability of this method.

V. Results

The table 3 summarizes the result of analysis of pump test data done in the last part.

Table 3: Aquifer parameters estimated by Present method with SEE values

Name of Well	Location	Estimated parameters		Considered Drawdowns No.	Actually Required Drawdowns	SEE
		Transmissivity (m^2/day)	Storage Coefficient			
TW-4	Darlamam	94.16	0.00258	47	18	0.00078

VI. Discussion about the Results

For this set of data in table 3 you can see that the transmissivity estimated using present method is $94.16\text{m}^2/\text{day}$ and the Storage Coefficient estimated as 0.00258. The accuracy of the estimated parameters are depended on the accuracy of placing the peak of curve in s/t vs. t plot and also it depend on the points having $u=0.44$. At least there will be 1 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 is 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 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. 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 4, 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 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 18 drawdowns or 18min.

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 4, indicating the reliability of the present method. 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 is no leakage with unconfined aquifer and also there is no recharge boundary exists. 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.

VII. 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 Darlamam Sub-Basin of Kabul 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 one set of the data collected from Kabul Basin aquifers.
- The Transmissivity estimated by this method in average basis is $94.16\text{m}^2/\text{day}$.

- The Storage coefficient estimated by this method is 0.00258 in the Darlaman sub-basin in average basis.
- 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 is 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 so, the estimated parameters are accurate.
- 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 18min and the maximum 18min.
- The reliability of this method on estimation of confined aquifer parameters is judged by Standard Error of Estimate (SEE). The SEE value is 7.8×10^{-4} . These values show that the present method is more reliable than the other existing methods.
- 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.

VIII. References

- [1] Ajayi, Owolabi and T. O. Obilade., (1989). "Numerical Estimation of Aquifer Parameters Using Two Observation wells." *Journal of Hydraulic Engineering*, Vol. 115, ASCE, 982-988.
- [2] "Availability of Water in the Kabul Basin, Afghanistan[2010]", USGS, p(1-4).
- [3] Bayless, Kristi and Avdhesh K. Tyagi, (2005). "Aquifer Parameters in Confined Porous Media." *School of Civil and Environmental Engineering, Oklahoma State University*. Published on ASCE.
- [4] Çimen, Mesut (2009). "Effective Procedure for Determination of Aquifer Parameters from Late Time-Drawdown Data." *Journal of Hydrologic Engineering*, Vol. 14, ASCE, 446-452.
- [5] Çimen, Mesut (2008). "Confined Aquifer Parameters Evaluation by Slope-Matching Method." *Journal of Hydrologic Engineering*, Vol. 13, ASCE, 141-145.
- [6] M. Amin Akbari, Mohammad Tahir, David W. Litke, and Michael P. Chornack "Ground-Water Levels in the Kabul Basin, Afghanistan, 2004-2007", USGS, p(1-25)
- [7] Matanga, G. B. Member (1995), "Characteristics in Evaluating Stream Functions in Groundwater Flow" *Journal of Hydrologic Engineering*, Vol. 1, ASCE, 49-53.
- [8]. Mohammad Hassan Saffi (2011), "Groundwater natural resources and quality concern in Kabul Basin, Afghanistan" *DACAAR*, 1-14.
- [9] Ojha, C. S. P., (2003). "Aquifer Parameters Estimation Using Artesian Well Test Data." *Journal of Hydrologic Engineering*, Vol. 9, ASCE, 64-67.
- [10] Papadopoulos, Istavros S. An Cooper, Hilton J., (1967). "Drawdown in a Well of Large Diameter." *Water Resources Division, U.S. Geological Survey Washington, D.C.*, Vol. 3, 241-244.
- [11] Raghunath, H. M., (2007). *Groundwater*. 3rd edition., New Age Publishers, New Delhi
- [12] Robert E. Broshears, M. Amin Akbari, Michael P. Chornack, David K. Mueller, and Barbara C. Ruddy 2005, "Inventory of Ground-Water Resources in the Kabul Basin, Afghanistan", USGS, p(9-25)
- [13] Sen, Zekai, (1996). "Volumetric Leaky-Aquifer Theory and Type Straight Lines" *Journal of Hydraulic Engineering*, Vol. 122, ASCE, 272-280.
- [14] Singh, Sushil K., (2009). "Simple Method for Quick Estimation of Leaky-Aquifer Parameters." *Journal of Irrigation and Drainage Engineering*, Vol. 136, ASCE, 149-153.
- [15] Singh, Sushil K., (2003). "Storage Coefficient and Transmissivity from Residual Drawdowns." *Journal of Hydraulic Engineering*, Vol. 129, ASCE, 637-644.
- [16] Singh, Sushil K., (2002). "Aquifer Boundaries and Parameter Identification Simplified." *Journal of Hydraulic Engineering*, Vol. 128, ASCE, 774-780.
- [17] Singh, Sushil K., (2001). "Identifying Impervious Boundary and Aquifer Parameters From Pump-Test Data." *Journal of Hydraulic Engineering*, Vol. 127, ASCE, 280-285.
- [18] Singh, Sushil K., (2000). "Simple Method for Confined Aquifer Parameter Estimation." *Journal of Irrigation and Drainage Engineering*, Vol. 126 (6), ASCE, 336-338.
- [19] "The Study on Groundwater Resources Potential in Kabul Basin." *Japan International Cooperation Agency (JICA)*, all reports (1-6).
- [20] Todd, David K., and Larry W. Mays (2005). *Groundwater Hydrology*. 3rd ed, Wiley, New York.
- [21] Ward, Nicholas Dudley and Fox Colin, (2011). "Identification of Aquifer Parameters from Pumping Test Data with Regard for Uncertainty." *Journal of Hydrologic Engineering*, Vol. 17, ASCE, 769-781.
- [22] "Water for Kabul Consultants 2011", "Extension of the Kabul Water Supply System.", p(1-161).
- [23] Wikramaratna, R. S., (1985). "A New Type Curve Method for the Analysis of Pumping Tests in Large-Diameter Wells." *Water Resources Research*, Vol. 21, American Geophysical Union. 261-264.