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HYDRAULIC TRANSMISSIVITY DETERMINATION FOR THE GROUNDWATER EXPLORATION USING VERTICAL ELECTRIC SOUNDING METHOD IN COMPARISON TO THE TRADITIONAL METHODS

Muhammad Arshad[1,*], Aamir Shakoor[1], Ijaz Ahmad[2] and Matloob Ahmad[1]

[1]Department of Irrigation and Drainage, University of Agriculture, Faisalabad, Pakistan;
[2]Water and Sanitation Agency, Faisalabad, Pakistan
***Corresponding author's e-mail: arsmrz@yahoo.com**

An important aquifer characteristic, transmissivity significantly contributes to the development of local and regional groundwater resources and solute transport management. Estimation of this property allows quantitative prediction of the hydraulic response and solute transport of the aquifer to recharge and pumping. This study presents the three techniques, used to compare transmissivity determination by Vertical Electric Sounding (VES) over the traditional techniques. The validation of VES was compared with the old widely used methods such as grain size distribution and pumping test techniques. Grain size distribution analysis was carried out to determine transmissivity. Pumping test was performed to determine transmissivity using the type curves solution for unconfined aquifer and taking into account the delayed yield. In resistivity imaging survey, the soil layers were detected through interpretation of resistivity data. Formation factor for each layer was determined with the relation of aquifer soil resistivity and ground water resistivity. The estimated transmissivities though grain size distribution, pumping test and resistivity survey were 0.588, 0.578 and 0.756m^2/min, respectively. The results emphasized the potential of the resistivity survey for aquifer transmissivity determination.
Keywords: Transmissivity, electrical resistivity, pumping test, grain size distribution

INTRODUCTION

Groundwater is a rich source of irrigation in Pakistan. During the drought period, groundwater was the main cause for the survival of irrigated agriculture in Pakistan. WAPDA (2009) estimated that 62 billion cubic meter of groundwater is being pumped annually to supplement surface water supplies. The tubewells not only provide additional water but also add flexibility to water supplies to match the crop water requirements. Most of tubewell installation has taken place in Punjab due to intensive agricultural development. Due to excessive development of groundwater, there is a danger of under mining and intrusion of saline water into fresh water aquifers. The saline water up-coning is very common in the central part of doab (land between two rivers). However, sustainable freshwater extraction is possible if proper groundwater and solute transport data are developed.

In groundwater hydrology, transmissivity (T), an important aquifer parameter, greatly facilitates the development of local and regional water resources (Huang *et al*., 2011). Often the investigations are carried out using conventional geotechnical methods only, which is costly and only provide information in discrete points. Pumping test, grain size distribution analysis and Vertical Electrical Sounding (VES) is a non-destructive method for exploring an aquifer. Arshad *et al*. (2007) carried out a VES survey to determine groundwater conditions such as depth, thickness and location of the aquifer along the Jhang Branch canal and found VES satisfactory. Pumping test is a traditional and conventional technique for determining the aquifer characteristics. Transmissivity at a certain site can be estimated by conducting a pumping test and analyzing the resulting data by special type curves developed by Boulton (1954) and Boulton (1963) including delayed yield phenomenon. Grain size distribution analysis is an alternative to determine the hydraulic conductivity of an aquifer using soil grading analysis. Sieve analysis is performed and specially developed empirical formulae are used to estimate the hydraulic parameters of aquifer. However, these traditional methods are time-consuming and invasive (Khalil *et al*., 2009).

The use of resistivity meter makes the groundwater exploration survey easy to estimate quantity and quality of groundwater. It gives prior information regarding hydrological and geological conditions of aquifer. The available groundwater resources can be estimated after preparing lithological logs and utilized usefully to supplement the canal water supplies. Geological information in the form of layer parameters can be obtained after interpretation of VES curves and using this information groundwater quality and transmissivity can be determined. The main objective of the study was to compare VES method to the time consuming traditional methods of hydraulic conductivity and transmissivity determination.

METERIALS AND METHODS

The study was conducted at Chak No. 73/RB (Khurrianwala), Tehsil Jaranwala, District Faisalabad-Pakistan as shown in Figure 1. The site is located approximately 20 kilometers away from Faisalabad city. The study area has the Latitude, 31^o 25′ N and Longitude, 73^o 06′ E and is located in Rechna Doab. Average altitude of the area above mean sea level is about 214m and soil type of the area is silty clay to silty loam.

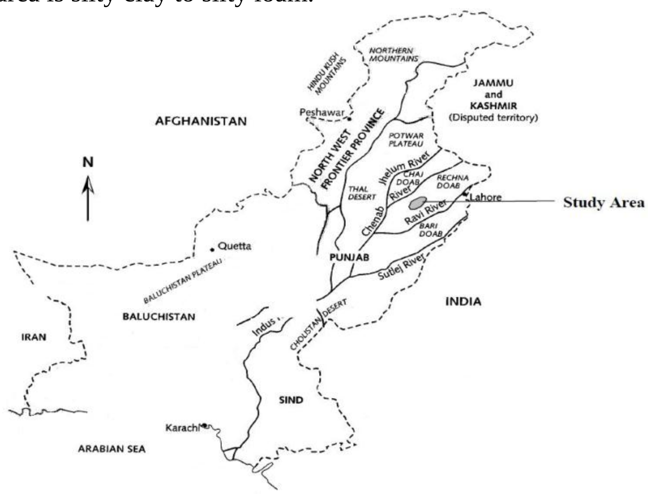


Figure 1. Study area (Khurrianwala)

***Grain size distribution analysis*:** The grain size distribution analysis was carried out for the soil samples, collected at each 1.52m depth during the drilling operation. Cumulative percentages of passing from each sieve versus sieve diameter were plotted on semi-log graph paper for each sample. Ten percentile of grain size (d_{10}) for each curve were estimated. Hydraulic conductivity was calculated using the (Hazen, 1892) equation (1), by substituting the d_{10} value of graph curve.

$$K = C\,(d_{10})^2 \qquad (1)$$

Where; K is hydraulic conductivity of aquifer, C is constant ranging from 100-150 for fine to course sand and d_{10} is ten percentile of soil grains. Salarashayeri and Siosemarde (2012) concluded that hydraulic conductivity was related to soil particle diameter and found that d_{10}played a significant role.

***Pumping test*:** A four strainers skimming well was used to conduct the pumping test at the site (Fig. 2). The upper excavated dug well was up to the depth of 6m with 2.44m diameter. Four observation wells at a distance of 8, 18, 28 and 40m from the centre of skimming well were installed in the vicinity of skimming well to measure the water level behavior caused by pumping operation of skimming well. The skimming well was run continuously for 700min to determine the drawdown values in observation wells at the selected time intervals.

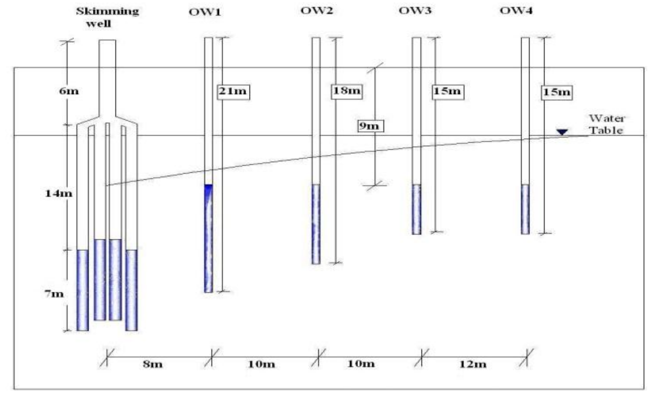


Figure 2. Layout of four strainer skimming well and observation wells

Pumping test data were then analyzed using Boulton (1954, 1963) type curve solution for unconfined aquifer, in which allowance was made for delayed yield from storage due to slow gravity drainage.

***Resistivity survey*:** The resistivity survey was conducted using Schlumberger Array Method (Keller, 1966). The instrument used to conduct the Vertical Electrical Sounding (VES) was "ABEM- SAS 1000 Terrameter". Four electrodes were chosen at any one time for resistance measurement. Currents were injected into the ground via two current electrodes located to the exterior of the potential electrodes. The potential difference between the potential electrodes was measured and the resistance of the ground was calculated. The Equation (2) and (3) were used to calculate the resistivity (ρ) and geometric constant (K_g), respectively.

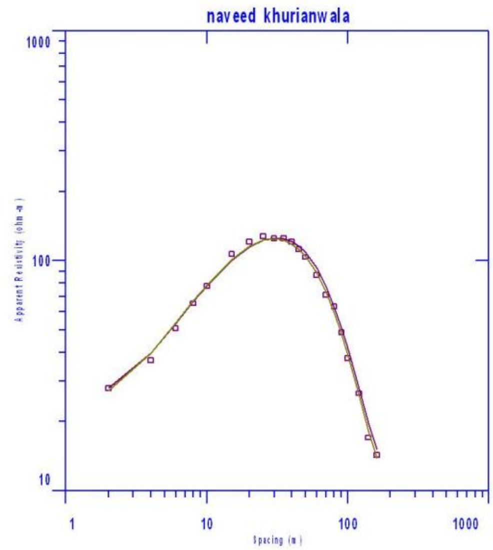
$$\rho = K_g \times \text{resistance of earth} = K_g \times (V / I) \qquad (2)$$

$$K_g = \{\Pi\,(AB/2)^2 - (MN/2)^2\}/MN \qquad (3)$$

Where; ρ is apparent resistivity (ohm-meter), V is voltage (Volt), I is current (Ampere), K_g is geometric constant, AB is spacing between current electrode (m) and MN is spacing between potential electrode (m). The central point of the electrode array remained fixed, but the spacing between the electrodes was increased and more information about the deeper sections of the subsurface was obtained. The Schlumberger electrode configuration with current electrode (AB/2) distance was kept 2, 4, 6, 8, 10, 15, 20, 25, 30, 35, 40, 45, 50, 60, 70, 80, 90, 100, 120, 160 meters. The potential electrode spacing (MN/2) was taken 1, 4, 10 and 20 meters.

The geometric factor (K_g) was calculated on the basis of field observations. The apparent resistivity values were calculated by multiplying the geometric factor with resistivity data (Arshad *et al*., 2007). The values of apparent resistivities obtained from measurements were then plotted against half the current electrode spacing on the log-log graph paper (Figure 3a) in order to analyze the resistivities and thickness of the subsurface layers. The VES resistivity values 'ρ' were determined from 1X1D, interpex, computer software (Fig. 3b) and groundwater resistivities 'ρ_w' were determined through water samples obtained from bore hole data (Fig. 4).

(a)



(b)

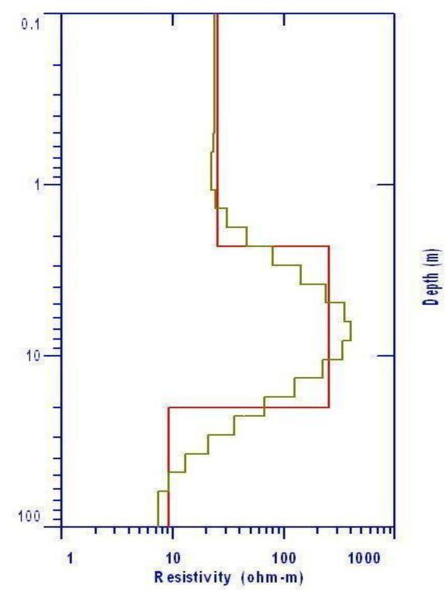


Figure 3. (a) Logarithm plot between electrode spacing and apparent resistivity (b) VES interpreted curves through computer software 1X1D, interpex

Salem (2001) published a formula for calculating hydraulic conductivity by using formation factor (Equation 4). Formation factor was determined using linear relationship is often referred to as Archie's Law (Archie, 1942) and presented in equation 5.

$$K = 7.7 \times 10^{-6} \times F^{2.09} \text{ (m/s)}$$
$$= 0.66528 \times F^{2.09} \text{ (m/day)} \quad (4)$$
$$F = \rho / \rho_w \quad (5)$$

Where; K is hydraulic conductivity, F is formation factor, ρ is resistivity of bulk formation and ρ_w is resistivity of pore water of formation.

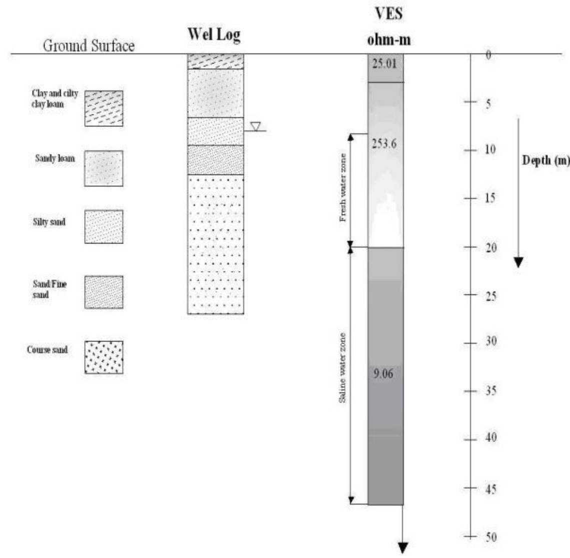


Figure 4. Correlation between Sounding Curves and Subsurface Lithology

RESULTS AND DISCUSSION

***Grain size distribution analysis*: **The soil samples collected at 9.14, 12.20, 15.24, 18.30 and 21.34m plots depths were passed through mechanical sieve apparatus. Semi-logarithm graphs were drawn between cumulative percentage of passing and sieve diameter. The values of d_{10} for 9.14, 12.20, 15.24, 18.30 and 21.34m plots were 0.09, 0.13, 0.16, 0.17 and 0.19mm, respectively. The calculated values of hydraulic conductivity and transmissivity from gain size distribution analysis are shown in Table 1.

The average estimated values of hydraulic conductivity and transmissivity for all soil samples were 0.021m/min and 0.588m^2/min, respectively (Table 1). The lower values of K and T in upper depth were due to the silty clay soil and high values in deeper soil were due to course soil type. The increased values of both parameters were increased for deeper soil sample depth was due to the increased in sand percentage in deeper soil texture.

Pumping test: The measured time-drawdown values for all observation wells were plotted on log-log graph papers and then drawdown curves were drawn for each observation well as shown in Figure 4. These curves were superimposed on the Boulton type curve and best fit curves were taken. The estimated values of hydraulic conductivity and transmissivity from pumping test data are shown in Table 2.

Table 1. Hydraulic conductivity and Transmissivity from grain size distribution analysis

Soil depth (m)	9.14	12.20	15.24	18.30	21.34	Average
K (m/min)	0.0073	0.015	0.023	0.026	0.033	0.021
T (m^2/min)	0.204	0.42	0.644	0.728	0.924	0.588

Table 2. Hydraulic conductivity and Transmissivity from pumping test data

Observation Well No.	Hydraulic conductivity (m/min)		Transmissivity (m^2/min)	
	Early Time-drawdown	Later Time-drawdown	Early Time-drawdown	Later Time-drawdown
OW1	0.014	0.026	0.383	0.739
OW2	0.015	0.019	0.414	0.545
OW3	0.018	0.022	0.493	0.609
OW4	0.023	0.028	0.646	0.796
Sub average	0.019	0.024	0.484	0.672
Average	0.022		0.578	

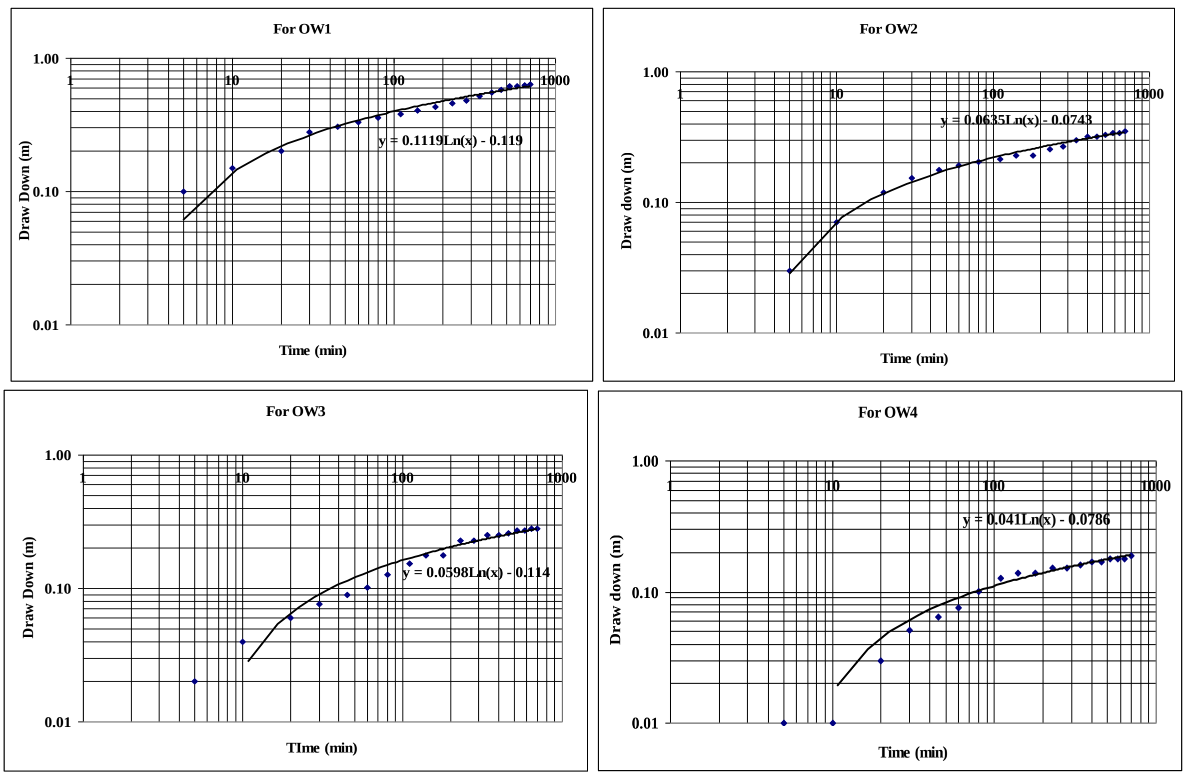


Figure 5. Drawdown vs time plot on log-log graph paper for OW1 to OW4

The aquifer thickness was taken equal to the depth of skimming well, which is 28m. The drawdown values of OW1, OW2, OW3 and OW4 at five minutes were 0.1, 0.03, 0.02 and < 0.01m, respectively, as shown in Figure 5.

The average hydraulic conductivity and transmissivity for the entire aquifer was estimated 0.022m/min and 0.578m^2/min, respectively. The lower values of K and T in early time were due to the less response of groundwater level to the pumping rate because groundwater was at rest when well was just started. Also in early time of pumping the drawdown was difficult to observe for short time intervals. Afterward the values of both parameters were increased because of good response of groundwater level.

***Resistivity Survey*:** The VES interpreted data gave three-layered stratification. The resistivity of first, second and third layer was 25.01, 253.6 and 9.06 Ohm-m, respectively (Table 3). The high resistivity value of second layer showed that good quality of water was present. The decreasing trend

Table 3. Hydraulic conductivity and Transmissivity from VES method

Sr. No.	Thickness of Layers (m)	VES resistivity (Ohm-m)	Existence of water	Groundwater resistivity (Ohm-m)	Formation factor (F)	Hydraulic conductivity (m/min)	Transmissivity of aquifer (m^2/min)
1	2.30	25.01	Un-saturated	-	-	-	-
2	17.69	253.60	Saturated	27.57	9.20	0.048	1.344
3	80.01	9.06	Saturated	3.91	2.32	0.006	0.168

in resistivity from second layer to third layer revealed that groundwater quality was being deteriorated because more salts present in saline groundwater and current pass through it quickly than fresh water. The VES results obtained in the form of layered model were compared with the well log for the same site. The estimated values of hydraulic conductivity and transmissivity from VES data are shown in Table 3.

The estimated formation factors for second and third layers were 9.20 and 2.32, respectively. The estimated average value of hydraulic conductivity and transmissivity through formation factors were 0.027m/min and 0.756m^2/min. The results showed that hydraulic conductivity was directly proportional to the formation factor. The first unsaturated layer has a silty clay loam formation with 25.01Ohm-m resistivity. The resistivity of second layer has a value of 253.60ohm-m indicated that a fine and course sand formation, as high resistivity value showed existence of good quality water. Similarly third layer having resistivity 9.06ohm-m indicates a course sand formation. The low resistivity value indicated the presence of saline water. Shevnin *et al*. (2006) determined the hydraulic conductivity using VES was 0.074 and 0.012 m/min with 0.002 and 0.005 clay contents, respectively. Ijeh (2012) determined transmissivity using VES and reported that T_{max} and T_{min} was 0.0055 and 2.01m^2/min. The results were also in good agreement with those reported by Khalil (2009) and Opara *et al*. (2012).

***Conclusions*:** The estimated transmissivities though grain size distribution analysis, pumping test and resistivity survey were 0.588, 0.578 and 0.756m^2/min, respectively. Results of this study revealed that the value of aquifer transmissivity determined by grain size distribution analysis, pumping test and VES was found very closer to each other. The good agreement between aquifer transmissivity calculated from the interpreted resistivity soundings and those deduced from grain size distribution and pumping test analysis emphasizes the contribution of the geophysical methods in the determination of the aquifer parameters. The use of VES surveying technique was proved useful and time saving to investigate aquifer characteristics. It was an inexpensive method for characterizing the groundwater conditions of study area. VES survey provided prior and discrete information about subsurface geology.

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