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SUBSURFACE INVESTIGATION FOR GROUNDWATER FORMATION IN DISTRICT RAHIM YAR KHAN (PAKISTAN) USING VERTICAL ELECTRICAL TECHNIQUES

Akhtar Ali[1], Hafiz Umar Farid[1,*], Zahid Mehmood Khan[1], Aamir Shakoor[1,*], Muhammad Nadeem[2], Muhammad Usman Ali[1], Faisal Baig[1], Hafiz Usman Ayub[1] and Huzaifa Shahzad[1]

[1]Department of Agri. Engineering, Bahauddin Zakariya University, Multan, Pakistan; [2]Department of Engineering, Faculty of Agriculture, Dalhousie University, Truro, Canada.
[*]Corresponding author's e-mail: hufarid@bzu.edu.pk

The vertical electrical resistivity (VES) survey technique is most widely used to explore the groundwater because, it is a quick, less expensive and reliable geophysical tool. The VES were carried out at 80 locations in the district Rahim Yar Khan, Punjab, Pakistan, using resistivity meter. The Schlumberger electrode configuration was used with the half current electrode spacings (AB/2) ranging from 2 to 180 m and potential electrode spacings (MN) 1 to 40 m. The collected field data were interpreted using the computer software "Interpex 1X1D". The outputs of VES interpretations were verified by using the borehole data collected at various six locations selected from the district. Using the combination of VES results along with borehole data, longitudinal conductance values of the first and second layers were estimated in the range of 0.03-0.48 S (Ω^{-1}) and 0.004-29 S (Ω^{-1}) respectively. These values indicated the presence of good quality fresh groundwater in second layer. Moreover, the fresh groundwater having aquifer resistivity of more than 40 Ω m was found in the North-West side of the district Rahim Yar khan along with the Indus River Bank and thickness of fresh groundwater layer was in the range of 10-100 m below the ground surface which can be pumped to minimize the secondary salinization whereas, the brackish groundwater was found in desert area of the district and this brackish water may produce salinity effects throughout the region.
Keywords: Aquifer characteristics, borehole, groundwater, irrigation, resistivity surveys.

INTRODUCTION

Groundwater is a most reliable resource and is used for irrigation, drinking as well as for industrial purposes all over the world (Shakoor *et al.,* 2018a). It is used mostly for drinking purposes. In Pakistan, ground water is a rich source of irrigation. Groundwater pumping and use on commercial scale began since 1960's by launching of Salinity Control and Reclamation Projects (SCARPs). The pumped ground water was inserted into canal system for conjunctive use of groundwater along with canal water to increase the irrigation supplies (Irfan *et al.,* 2014; Qureshi *et al.,* 2004). It is estimated that 62 billion cubic meter of groundwater is being pumped annually to supplement surface water supplies (WAPDA, 2009). At this time about 1 million small capacities private tubewells are in operation in the country including 0.85 million in Punjab (PES, 2012).

Due to the lack of ground water management rules and regulations, farmers are blindly installing the tubewells on their farmlands without prior permission and groundwater investigation. This uncontrolled and unregulated use of groundwater affects the aquifer potential (Shakoor *et al.,* 2017). Moreover, huge numbers of dug wells have dried and ultimately water table is declining in these areas that results in deteriorating the ground water quality. Depletion of groundwater from no-canal feed areas (southern Punjab) is getting worse with the passage of time. These areas are at the tails of many canals with limited water supply (Shakoor *et al.,* 2018b; Qureshi *et al.,* 2008). Shakoor *et al.,* (2018b) monitored the groundwater level in these areas and concluded that, the water table is decreasing rapidly. It's the need of hour to evaluate the groundwater conditions before designing any water related project in these areas. Even in this modern age, the farmers are still using the traditional method (hit and trail) for groundwater investigation, which is laborious, time consuming, expensive and all above just provide the discrete point information.

Resistivity survey could be considered as best alternate method for groundwater estimation (Farid et al., 2017; Khalil et al., 2009). It would be the most economical, quick and reliable source of estimating the groundwater characteristic.

Keeping in view the above discussion the current study was designed to explore the groundwater aquifer to assess the groundwater quality of the study area. Based on this assessment, we developed the guidance for tubewell installation in the study area. This study will help the farmers to install the tubewell at recommended location without changing the aquifer situation.

MATERIALS AND METHODS

***Study area*:** The study was conducted at various villages and towns of district Rahim Yar Khan, Punjab, Pakistan. The district lies between 27°40'-29°16' N and 60°45'-70°01'E (Fig.1). The general weather of the district Rahim Yar Khan (study area) is hot as well as dry, during the season of summer whereas cold and dry during the winter season. The duration of summer season is April to October, whereas, winter from November to March. The average rainfall is approximately 100 millimeters (3.9 inch). The district Rahim Yar Khan has three main geographic portions (Fig. 1). The Riverside area of the district covers the southern side of the Indus River. Its major portion belongs to river bed. The canal-irrigated area is situated on the south and is isolated by Minchan Bund. The Cholistan area is found on the south of the irrigated area and continued up to the Indo-Pak border (Fig.1).

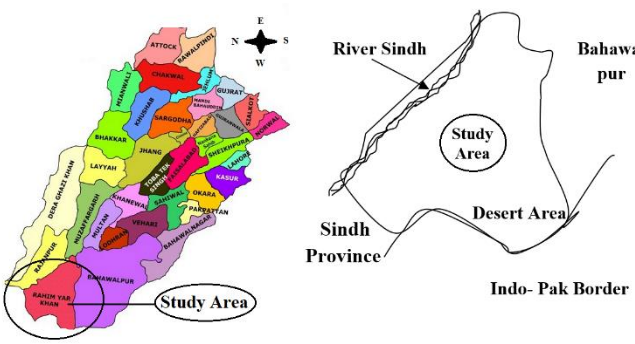

Figure 1. Location of study area on provincial map of Punjab.

***Resistivity survey method*:** Electrical resistivity survey, a geophysical survey technique has proved to be an effective and reliable tool in locating viable aquifers for continuous and regular water supply (Todd and Mays, 2005). The instrument used to measure the Vertical Electrical Sounding (VES) was Terrameter SAS 4000 (ABEM, Sweden). The meter is the property of Department of Agricultural Engineering, Field Wing, District Rahim Yar Khan, Govt. of Punjab. The targeted sites were investigated with contribution of this department.

The Schlumberger electrode technique was employed for the measurement of Vertical Electrical Sounding (VES) at 80 different locations at the study area. In this method all the four electrodes were placed in a straight line and distance between inner electrodes was fixed at some stations while the distance between the outer electrodes was changed for each measurement (Fig. 2). In resistivity survey, Schlumberger electrode array was selected, keeping current electrode gap (AB/2) of 2, 4, 8, 10, 15, 20, 25, 25, 30, 35, 40, 45, 50, 50, 60, 70, 80, 90, 100, 100, 120, 140, 160, 180 and 200 meter. The increment in potential electrode spacing was made at similar spacings of 25, 50 and 100 m.

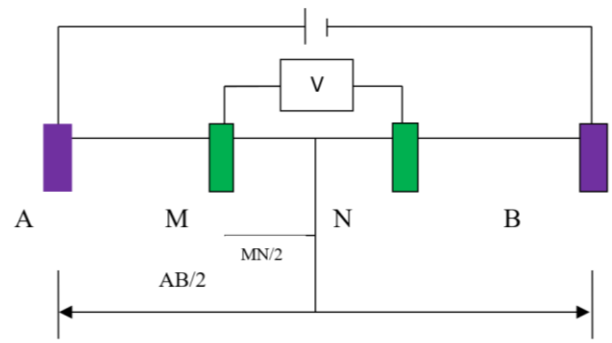

Figure 2. Layout of Schlumberger electrode Array.

In overlapping as well as extending over segments, mostly the Schlumberger data are employed because at each station of electrode spacing (AB/2), the resistivity meter shows poor sensitivity (Sikandar, 2009). So in this situation the MN gap was increased and measuring the two values for the same AB/2 was taken, one reading at the shorter and other at the larger MN spacing. The spacings between the potential electrodes (MN/2) were increased step wise at 0.5, 5, 10 and 20 meters. The resistance of earth at separate spacings was estimated using resistivity meter at different electrode spacings in district Rahim Yar Khan. The values of apparent resistivity of the medium below the electrodes can be obtained by multiplying the earth resistance with the geometric constant (K). In case of Schlumberger electrode arrays the value of geometric constant (K) can be calculated as (Arshad *et al.*, 2007; Sikander, 2009).

$$\rho_a = K \times R \qquad (1)$$

Where; ρ_a= Apparent Resistivity in Ohm meter (Ω m), V=Voltage, potential drop, in milli-Volt (mV), I = Current in milli-ampere (mA) and K = Constant of proportionality

$$K = \pi \frac{(AB/2)^2 - (MN/2)^2}{MN} \qquad (2)$$

Where, AB = Spacings between two outer electrodes (m) and MN= Spacings between two inner electrodes (m)

***Aquifer parameters*:** Formation factor is very important parameter and is computed by the following expression;

$$F = \rho a / \rho_w \qquad (3)$$

F is known as the formation factor and its value remains same for pure sand. F was calculated by the layer wise values of groundwater and aquifer resistivity. The layer wise hydraulic conductivity can also be computed using following relationship given by Yadav, (1995).

$$F = 21.18F - 4.48 \qquad (4)$$

Longitudinal conductance and transverse resistance are two the most important parameters regarding the aquifer characteristics. These elements were also estimated through VES resistivity survey data. The transverse resistance was determined using:

$$TRi = \rho \times Hi \qquad (5)$$

The longitudinal conductance was also determined using:

$$LC_i = EC \times Hi \quad (6)$$

RESULT AND DISCUSSION

***Electrical resistivity survey data collection and processing*:** The resistivity survey data was interpreted by the use of the 1-D inversion technique (IX1D, Interpex, USA). The software gave the output in the form of resistivity model which fits the obtained field data with the least possible root mean square (RMS) error between the synthetic data of model and actually observed data. In order to obtain the least and constant fitting errors between synthetic model curve and field data, the method of iteration was used.

With the help of computer software (1X1D), the field data were interpreted by plotting the true resistivity against electrode spacing shown in figure 3. The model output also gave the thickness, depth of all interpreted layers.

These results were correlated/compared with borehole data at

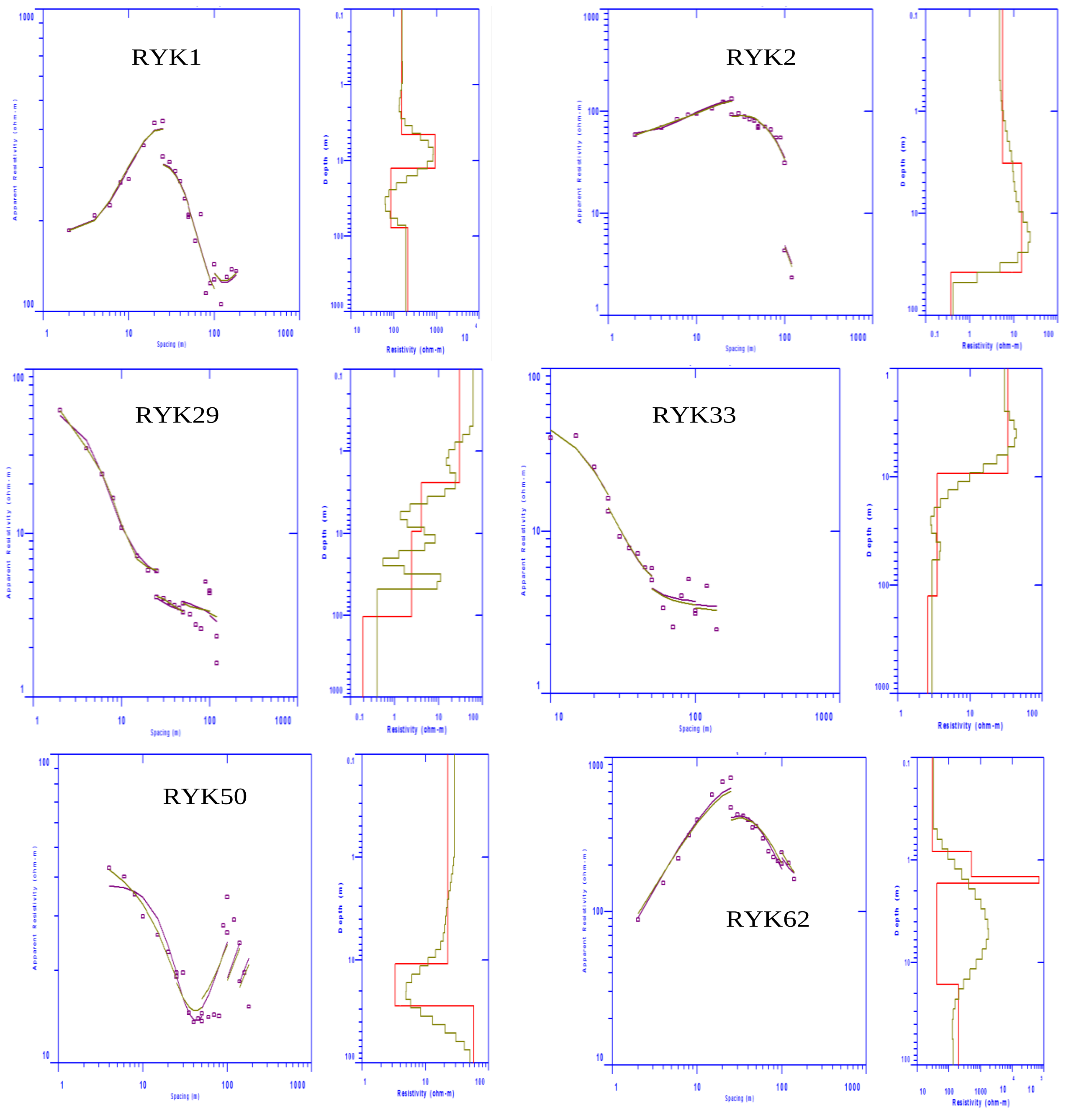

Figure 3. Model Output of 1X1D computer software at six sites.

all selected six sites. The resistivity survey results and soil samples collected from drilled boreholes at six sites (RYK1, RYK2, RYK29, RYK33, RYK50, and RYK62) are given in Figure 4. A total of six well logs (one at each site) were prepared up to 90m, 90m, 90m, 100m, 100m and 90m depth. The results from the analysis of borehole data and VES data interpretation results are matched closely with each other. The first layer had resistivity value of 155 Ω m at RYK1, correlates to the top soil (loam) which extends up to the depth of 5m from the ground surface. Between 5- 13 m depth, the resistivity increased to 936 Ω m, indicating coarse sand. The third layer from 13-78 m, shows decreasing trend in resistivity of 85 Ω m whereas fourth layer from 78m depth shows resistivity of 212 Ω m, represent the coarse sand with alternate thin layer of clay containing good quality fresh groundwater. Similarly a close agreement was also found in other selected sites and shown by the figure below.

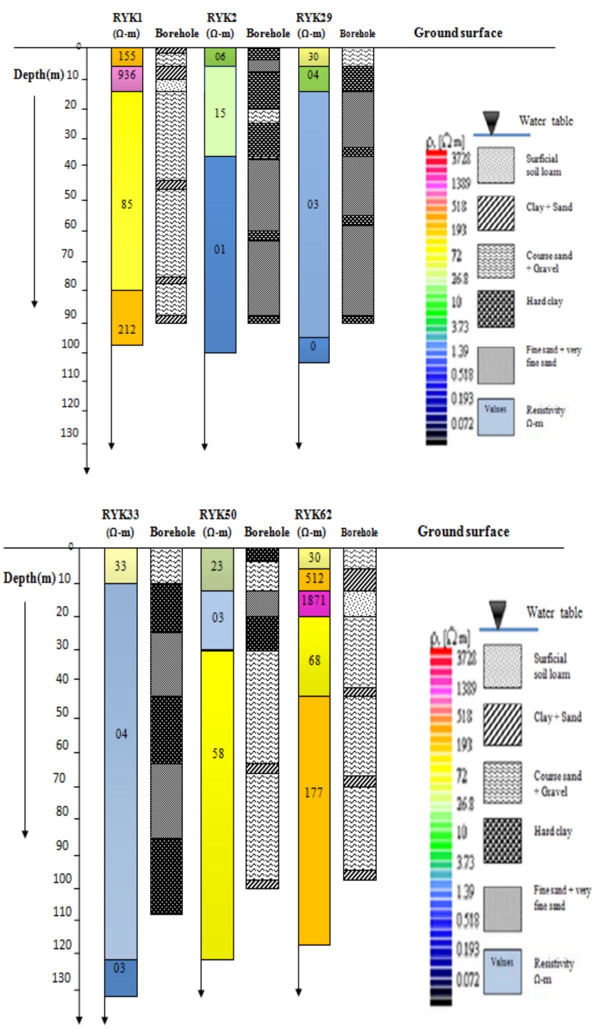

Figure 4. **Correlations of resistivity results with subsurface lithology.**

The aquifer resistivity obtained from the interpretation of VES data and the associated values of EC, SAR and RSC obtained from the hydro chemical analysis of water samples collected from the borehole drilling are shown in Table 1. The table shows that EC values generally increases by increasing the depth below ground surface. However, the irrigation water suitability criteria developed by WAPDA (1977), shows that resistivity values more than 20 Ω m, EC values less than 2.5 dS/m and SAR values less than 13 indicate fresh groundwater. The values of electrical conductivity (EC) of the water samples collected from all six sites (RYK1, RYK2, RYK29, RYK33, RYK50 and RYK62) were correlated with the aquifer resistivity obtained from the interpretation of the apparent resistivity data at the same sites.

The values of aquifer resistivity (Ω m) of all the selected sites were plotted along X- axis and water quality (dS/m) of the corresponding layers along Y-axis to get the relationship between the aquifer resistivity and groundwater quality (Fig. 5). This curve gave the value of coefficient of determination, $R^2 = 0.911$ and shown in Figure 5.

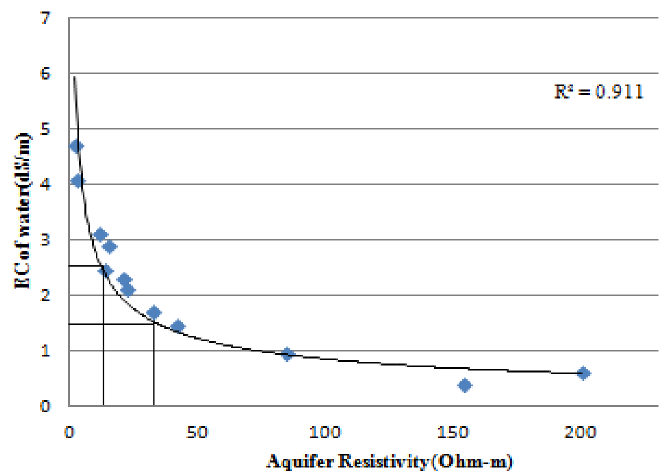

Figure 5. **Relations between aquifer resistivity and electrical conductivity (EC) of groundwater**

Thus, using the relation developed between EC of groundwater and aquifer resistivity, the fresh and saline groundwater layers were identified on the basis of the criteria developed by WAPDA. So, the groundwater layer having resistivity values more than 40Ωm was declared as fresh groundwater zone whereas resistivity values less than 40Ωm shows saline/brackish water zone.

***Aquifer parameters*:** The values of aquifer resistivity (ρ_a), groundwater resistivity values (ρ_w) and their corresponding values of formation factors (F) at six sites are given in table 1. From the table, it is evident that values of formation factor vary greatly depending upon the variation in the resistivity values. The more value of formation factor shows the presence of the resistive particles in the soil of larger diameter

Table 1. Formation factor.

Name of VES	Thickness Ti(m)	VES Resistivity (Ω m)	Remarks	Groundwater Resistivity (Ω m)	Formation Factor (F)
RYK1	5	155	Unsaturated		
	8	936	Saturated	0.80	1170.00
	65	85	Saturated	0.77	110.40
		212			
RYK2	3	6	Unsaturated		
	35	15	Saturated	0.32	46.88
		1	Saturated	0.32	3.13
RYK29	2	30	Unsaturated		
	7	4	Saturated	0.04	100.00
	95	3	Saturated	0.021	150.00
		0			
RYK33	9	33	Saturated	1.68	19.64
	116	4	Saturated	1.25	3.20
		3			
RYK50	11	23	Saturated	0.71	32.39
	17	4	Saturated	0.63	6.35
		58			
RYK62	1	30	Unsaturated		
	2	512	Unsaturated		
	7	1871	Unsaturated		
	27	68	Saturated	0.86	79.00
		177	Saturated	0.77	229.87

indicating the sand and gravel particles, the low values of formation factor indicate the presence of finer particles of soil. The hydraulic conductivity values computed from formation factor ‘F’ was 13554.96m/day, 525.13m/day, 2643.02m/day, 237.40m/day, and 405.78m/day and3266.45m/day of RYK1, RYK2, RYK29, RYK33, RYK50 and RYK62, respectively. The transverse resistance (TR=Layer thickness × resistivity) was determined using equation (5), while the longitudinal conductance (LC = Layer thickness/ resistivity) was also determined using equation (6) and interpreted layer parameters were taken from Table 2. The higher values of transverse resistance represent the aquifer layer having more values of resistivity thickness, while the more values of longitudinal conductance are representing low resistivity values that indicate the poor quality of groundwater. The longitudinal conductance values of the first and second layers were estimated (Table 2) in the range of 0.03-0.48 Siemens and 0.004-29 Siemens respectively whereas values of transverse resistance were in the range of 18-775Ωm^2 and 28-7488Ωm^2 respectively. The greater value of transverse resistance in the second layer shows that fresh groundwater of good quality is available in that layer.

***Conclusions*:** Following conclusions are drawn on the basis of geological data . It was observed that the resistivity survey technique has the potential to detect fresh groundwater layers and subsurface lithology at the study area because evaluation based on the borehole data has close agreement with the resistivity survey data.

The aquifer characteristics such as longitudinal conductance and transverse resistance were computed by using aquifer resistivity (ρ) and thickness of respective layers. The longitudinal conductance values of the first and second layers were estimated in the range of 0.03-0.48 Siemens and 0.004-29 Siemens respectively whereas values of transverse resistance were in the range of 18-775Ωm^2 and 28-7488Ωm^2 respectively. The greater value of transverse resistance in the second layer shows that fresh groundwater of good quality is available in that layer. The hydraulic conductivity values computed from formation factor ‘F’ was 13554.96m/day, 525.13m/day, 2643.02m/day, 237.40m/day, and 405.78m/day and3266.45m/day of RYK1, RYK2, RYK29, RYK33, RYK50 and RYK62, respectively.

1. The empirical relationship between resistivity of interpreted subsurface layers and electrical conductivity (EC) of groundwater samples gave value of R^2=0.911, these informations may be helpful for further studies of resistivity survey in district Rahim Yar Khan.
2. The fresh groundwater having aquifer resistivity of more than 40 Ωm was found in the North-West side of the district Rahim Yar Khan along with the Indus River Bank. It was also noted that the thickness of fresh groundwater layer was in the range of 10-100m below the ground surface which can be pumped to minimize the

Table 2. Longitudinal conductance and transverse resistance.

Name of VES	Thickness Ti(m)	VES Resistivity (Ω m)	Remarks	Longitudinal Conductance (Siemens)	Transverse Resistance (Ω m^2)
RYK1	5	155	Unsaturated	0.030	775
	8	936	Saturated	0.009	7488
	65	85	Saturated	0.760	5525
		212		Undefined	Undefined
RYK2	3	6	Unsaturated	0.50	18
	35	15	Saturated	2.33	525
		1	Saturated	Undefined	Undefined
					71.63
RYK29	2	30	Unsaturated	0.07	60
	7	4	Saturated	1.75	28
	95	3	Saturated	31.67	285
		0		Undefined	
RYK33	9	33	Saturated	0.27	297
	116	4	Saturated	29	464
		3		Undefined	Undefined
RYK50	11	23	Saturated	0.48	253
	17	4	Saturated	4.25	68
		58		Undefined	Undefined
RYK62	1	30	Unsaturated	0.030	30
	2	512	Unsaturated	0.004	1024
	7	1871	Unsaturated	0.004	1309
	27	68	Saturated	0.400	1836
		177	Saturated	Undefined	Undefined

secondary Salinization. On the other hand, the brackish groundwater was found in desert area of the district and this brackish water may produce salinity effects throughout the area.

Based on the results obtained of the research work, it is recommended that North West side of the district Rahim Yar khan along with the Indus River Bank is suitable for tubewell installations regarding the pumping of fresh groundwater for irrigation purposes.

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