INTERNATIONAL JOURNAL OF AGRICULTURE & BIOLOGY
1560–8530/2007/09–1–143–146
http://www.fspublishers.org

Determination of Lithology and Groundwater Quality Using Electrical Resistivity Survey

MUHAMMAD ARSHAD[1], J.M. CHEEMA AND SHAFIQUE AHMED†
Department of Irrigation and Drainage, University of Agriculture, Faisalabad–38040, Pakistan
†*Assistant Agricultural Engineer, Punjab Agriculture Department, Thoker Niaz Baig, Lahore, Pakistan*
[1]Corresponding author's e-mail: arsmrz@yahoo.com; Tel # 092-041-9200161-70 Ext. 3005; Fax 092-041-9200764

ABSTRACT

A resistivity survey was carried out in order to study groundwater conditions along the Jhang Branch canal, such as depth, thickness and location of the aquifer and the type of water. Vertical electrical soundings by Schlumberger array were conducted out at 9 locations up to a depth of 200 m. The resistivity data confirm that the aquifer consists of an alluvial aquifer. These data were used to determine the lithology and the groundwater quality of the aquifer. Interpretation of the VES tests indicates the presence of an alluvial aquifer that mainly consists of sand and clay. The resistivity of the aquifer between 30 to 140 m showed the increasing value, which indicated the existence of fresh groundwater. The groundwater after 140 m and up to 200 m possesses marginally fit quality having larger TDS values than the upper zone.

Key Words: Resistivity; Groundwater; Aquifer; Electrical sounding

INTRODUCTION

The monitoring of the groundwater level exhibits a decreasing trend of water level. The main reason for this decline in the groundwater table is that wells pumping from groundwater resource have exceeded natural recharge in the recent years. It is important to get an overview of the ground conditions in early stages of planning and design of water related projects. Often the investigations are carried out using conventional geotechnical methods only, which is costly and only provide information in discrete points. The use of resistivity meter makes the groundwater explorating survey to estimate quantity and quality of groundwater. It can be said to be an alternative of a trial boring to some extant. The available groundwater resources can be estimated after preparing lithological logs and utilized usefully to supplement the canal water supplies for municipal and agricultural productions in order to remove the shortage of water.

In geophysical investigations for water exploration, depth to bedrock determinations, sand and gravel exploration etc, the Electrical Resistivity Meter (ERM) method can be used to obtain, quickly and economically, details about the location, depth and resistivity of sub-surface formations. Emenike (2001) tested the groundwater potential and a correlation of the curves with the lithologic log from a nearby borehole and suggested that the major lithologic units penetrated by the sounding curves were laterite clay sandstone and clay. The sandstone unit, which was the aquiferous zone had a resistivity range between 500 ohm-m and 960 ohm-m and thickness in excess of 200 m.

ERM uses an artificial source of energy, rather than the natural fields of force, such as are used in gravity surveying and so the source detector separation can be altered to achieve the optimum separation, which effectively controls the depth of measurement. The water exploration survey with the help of ERM is low cost, easy for operation, speedy and accurate. Liu (2004) used ERM method for imaging changes of moisture content in the vadose zone. The ability of the integrative approach was tested by directly estimating moisture distributions in three-dimensional, heterogeneous vadose zones. This survey can also be used for geotechnical and environmental purposes. ERM is generally employed for groundwater studies, such as quality, quantity, mapping fresh water lenses, investigation of salt water intrusion and determination of the extent of contaminants.

The ERM solves the problems of groundwater in the alluvium formation aquifer as an inexpensive and useful method. Some uses of this method in groundwater are: determination of depth, thickness and boundary of an aquifer, determination of interface saline water and fresh water porosity of aquifer, hydraulic conductivity of aquifer, transmissivity of aquifer, specific yield of aquifer, contamination of groundwater (Choudhury *et al*., 2001). Contamination usually reduces the electrical resistivity of pure water due to increase of the ion concentration (Frohlich & Urish, 2002). However, when resistivity methods are used, limitation can be expected if ground inhomogeneties and anisotropy are presented (Matias, 2002). However, the use of geophysics for both groundwater resource mapping and for water quality evaluations has increased dramatically over the last 10 years in large part due to the rapid advances in microprocessors and associated numerical modeling solutions.

The purpose of this paper is to use the resistivity data and interpreting geoelectrical soundings to study the aquifer conditions, such as depth and nature of the alluvium, boundaries and location of the aquifer and groundwater quality. This study can be used to protect groundwater supplies as a unique source of water for this area.

MATERIALS AND METHODS

The Lower Rechna Doab aquifer, which lies in the central part of the Punjab province of Pakistan, is characterized by semi-arid climate. This area faces a serious water supply challenge driven by scarce water resources and rapid population growth. The Lower Rechna Doab aquifer is the major exploited aquifer in the region and it is an alluvial deposit aquifer. The study area lies on the left bank of Jhang Branch Canal at RD of 223, 227, 231, 235, 239, 255, 259, 261 and 275 (9 sites) about 12 km North-West of Faisalabad city. The total length of the belt for the survey is approximately 15 km. The schematic diagram of the location sites of the resistivity survey is given in Fig. 1.

Electrical resistivity meter. Traditional methods for characterizing protective layers include test hole drilling and analyses of log, with the objective being to characterize thickness and/or lateral extent of the protective layer. Disadvantage of such investigations are that can be labor-intensive and expensive. The ERM method has proved very popular with groundwater studies due to simplicity of the technique. The Terrameter SAS/4000 was employed to conduct resistivity survey.

Terrameter SAS/4000. SAS stands for Signal Averaging Systems, a method whereby consecutive readings are taken automatically and the results are averaged continuously. The Terrameter SAS/4000 can operate in different modes (resistivity, self potential & induced polarization). A useful facility of the SAS/4000 is its ability to measure in four channels simultaneously. This implies that as well resistivity and induced potential measurements as voltage measurements can be performed up to four times faster. The electrically isolated transmitter sends out well defined and regulated signal currents, with strength up to 1000 mA and a voltage up to 400 V. The receiver discriminates noise and measures voltages correlated with transmitted signal current and also measures un-correlated DC potentials with the same discrimination and noise rejection. The micro processor, monitors, controls operations and calculates results. This makes it suitable for all sorts of resistivity surveys. SAS results are more reliable in resistivity surveying mode, it comprises a battery powered, deep penetration resistivity meter with an output sufficient for a current electrode separation of 200 m under good survey conditions. The ratio between voltage and current V/I is calculated automatically and displayed in digital form in ohms or millions.

The “Schlumberger” and “Wenner” array configurations are two electrode layouts those are widely employed in the resistivity surveys. Furman (2003) using the analytic element method investigated the spatial sensitivity of different electrical resistivity tomography (ERT) arrays. The different arrays (Wenner, Schlumberger & double-dipole) were compared using the absolute value of the sensitivity and its spatial distribution. On a per measurement basis, there was almost no difference between the Wenner and the Schlumberger surveys. However in this study, Schlumberger array layout was used.

Electrical resistivity method using a terrameter SAS 4000. Resistivity measurements with ERM are one of the simplest methods to be used in geophysics. By putting two electrodes into the ground and inducing an electric current through the ground, a potential field is created. Two additional electrodes are used to measure the potential at some location. Increasingly deeper measurements are achieved by using a bigger separation between the current electrodes. Moving the current electrode and having the potential electrode fixed is named the “Schlumberger” method.

For this setup, a direct current was introduced into the ground through two current electrodes A and B. The potential electrodes M and N were inserted in the ground between the outer current electrodes A and B, where the potential difference was measured across these two potential electrodes. By measuring the current (I) between the two current electrodes A and B and the associated potential difference (V) between the potential electrodes M and N, the apparent resistivity (ρ_a) was computed by the Eq 1 as given below:

$$\rho_a = K \frac{V}{I} \qquad (1)$$

Where

K is the geometric factor of the electrode arrangement in case of Schlumberger electrode configuration, which is given by Eq 2:

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

By repeating the Schlumberger measurements with the entire setup moved one step to the side, vertical electrical soundings (VES) were performed continuously and the resistivities along a profile were measured.

Data collection. Since the values measured in the field correspond to resistances or potentials the first step when processing the data was to calculate the apparent resistivities. These were computed using the formula relevant to the electrode configuration. ERM was used in the study area. The resistivity survey was carried for 9 locations along the Jhang Branch Canal during August 2005. The Schlumberger electrical profile configuration is presented in Fig. 2.

The Schlumberger soundings were carried with maximum current electrode spacing (AB) 400 m (AB/2 = 200 m). The field data acquisition was generally carried out by moving two or four of the electrodes used, between each measurement.

RESULTS AND DISCUSSION

Using Schlumberger Configuration, field data of resistance values up to 200 m depth at all points was recorded by electronic instrument. The apparent resistivity was calculated on the basis of field observations plotted on log-log paper. The true resistivities of different sub-surface layers were calculated and interpreted in terms of lithology on the basis of field geology. The VES curves of the 9 sounding stations obtained by plotting the apparent resistivity against electrode spacing.

Fig. 3 shows that at RD-223, the apparent resistivity is increasing as the spacing of the current electrode increases and at a spacing of 50 m it reaches the apex value of 141.58 ohm-m and then becomes constant with an average value of 105 ohm-m. The apparent resistivity for RD-227 ranged from 26.49 to 117.24 ohm-m, it increases at a constant rate upto the electrode spacing of 35 m and after that it almostly becomes constant showing the same pattern of the curve as at RD-223.

The apparent resistivity at RD-231 has a high value (312.26 ohm-m) in the surface layers and declines to a value of 86.69 ohm-m at electrode spacing of 15 m and then achieves an average value of about 80 ohm-m.

The apparent resistivity at RD-235 ranges from 113.39 to 258.89 ohm-m. The apparent resistivity at this location is very high (258.89 ohm-m) in the top layer, after that it declines and achieve an average value of about 120 ohm-m. The apparent resistivity at RD-239, RD-255, RD-259 and RD-261 has the same pattern of apparent resistivity distribution. The apparent resistivity in the top layer has small values and the increases at a constant rate with the increase of electrode spacing, respectively.

The apparent resistivity curves indicate that there were three sub-surface layers in the study area. These layers consist of surface layer (top soil), alluvium layer and saturated (bottom soil) layer. Depth, thickness and type of all the layers were identified. The average resistivity of the surface, alluvium and saturated layers ranged 19 to 94, 56 to 205 and 32 to 146 ohm-m, respectively.

Keeping in view, the results of the VES interpreted through 1X1D Interpex USA software, the sub-surface lithology at 9 sites is given in Table I.

The lithology based on VES tests as presented in Table I indicates that fresh groundwater exists upto a depth of 140 m but after that for a depth from 140 to 200 m the groundwater was found to be marginally fit as the total dissolved salts (TDS) for this depth ranged from 700 - 800 ppm. The lithology at RD-227 presents the same results as were found at RD-223.

At RD-231, the upper part of the top layer was dry but

Fig. 1. Schematic diagram of the location of test sites

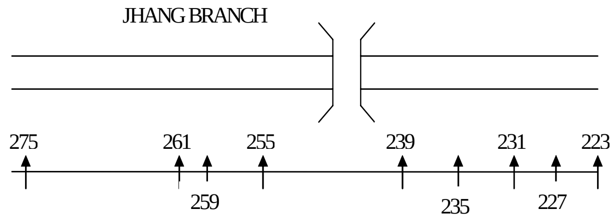


Fig. 2. The schlumberger electrical profile configuration

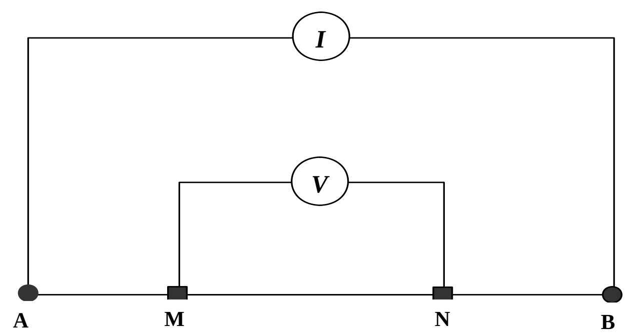
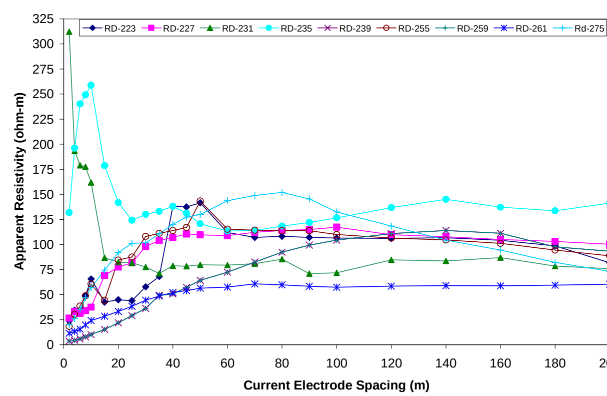


Fig. 3. Current bectrode spacing versus apparent resistivity



low moisture contents were found by the increase in depth. At a depth from 25 to 200 m the TDS were about 500 ppm, a pocket of fresh groundwater was found in this depth. The lithology pattern, at RD-235 was very similar to RD-231. The sub-surface lithology at RD-239 indicated that all the layers except the top layer contain the fresh groundwater. The sub-surface lithology at RD-255, RD-259, RD-261 and RD-275 indicated that the zone of sub soil between 30 to 140 m contained an adequate volume of fresh groundwater.

The reason for the existence of fresh groundwater in the sub-soil was that the strata contained a mixture of sand and clay with TDS 400 to 450 ppm. As apparent resistivity for this sub-soil zone was high, this showed the existence of good quality groundwater. Moreover, this zone of soil received the seepage water from the canal having good quality.

Table I. Sub-surface lithology based on electrical resistivity survey

Location	Depth (m)	Resistivity (ohm-m)	Lithology
RD-223	0-5	30.1	Surface material with low moisture
	5-30	52	A mixture of sand & clay >650 ppm
	30-140	126	A mixture of sand & clay 400-450 ppm
	140-200	32	700-800 ppm
RD-227	0-6	32	Surface material with low moisture
	6-33	63.4	A mixture of sand & clay >600 ppm
	33-130	135	A mixture of sand & clay 400-450 ppm
	130-200	34	700-800 ppm
RD-231	0-8	90.4	Dry zone
	8-25	198	Dry sand with low moisture
	25-200	125	450-500 ppm
RD-235	0-8	94	Dry zone
	8-27	205	Dry sand with low moisture
	27-200	146	450-500 ppm
RD-239	0-6	33	Surface material with low moisture
	6-25	56	A mixture of sand & clay 400-450 ppm
	25-200	140	A mixture of sand & clay 400-450 ppm
RD-255	0-7	40	Low moisture zone
	7-28	70	A mixture of sand & clay >650 ppm
	28-130	144	A mixture of sand & clay 400-450 ppm
	130-200	38	600-850 ppm
RD-259	0-15	19	Dry zone
	15-40	38.4	
	40-140	113.6	A mixture of sand & clay 450-500 ppm
	140-200	80.1	A mixture of sand & clay 450-500 ppm
RD-261	0-11	90.4	Dry zone
	11-60	198	A mixture of sand & clay >650 ppm
	60-200	125	A mixture of sand & clay 400-500 ppm
RD-275	0-7	34	Surface material with low moisture
	7-140	156	A mixture of sand & clay 400-500 ppm
	140-200	45	A mixture of sand & clay >650 ppm

CONCLUSIONS

Nine sites were used to evaluate the sub-surface hydrogeological conditions to a depth of about 200 m. Based on the interpretation of geoelectrical data, the following conclusions were drawn: the use of geoelectrical soundings provides an inexpensive method for characterizing the groundwater conditions of the region. Interpretation of the VES tests indicates the presence of an alluvial aquifer that mainly consists of sand and clay. The resistivity of the aquifer between 30 to 140 m showed the increasing value, which indicated the existence of fresh groundwater. VES tests also revealed three sub-surface geo-electric layers consisting of surface layer (top soil), alluvium layer and saturated (bottom soil) layer, depth, thickness and type of all the layers were identified.

Recommendation. Keeping in view the results of Electrical Resistivity Surveys, it was concluded that the zone of sub-soil between 30 - 140 m contains adequate volume of fresh groundwater, which may be exploited by installing tubewells for its utilization. The groundwater after 140 m and up to 200 m possesses marginally fit quality having larger TDS values than the upper zone.

REFERENCES

Choudhury, K., D.K. Saha and P. Chakraborty, 2001. Geophysical study for saline water intrusion in a coastal alluvial terrain. *J. Appl. Geophysics,* 46: 189–200

Emenike, E.A., 2001. Geophysical Exploration for Groundwater in a Sedimentary Environment: A Case Study from Nanka over Nanka Formation in Anambra Basin, Southeastern Nigeria. *Global J. Pure Appl. Sci.*, 7: 1

Frohlich, R.K. and D. Urish, 2002. The use of geoelectrics and test wells for the assessment of groundwater quality of a coastal industrial site. *J. Appl. Geophysics,* 50: 261–78

Furman, A., T.A. Ferré and A.W. Warrick, 2003. A Sensitivity Analysis of Electrical Resistivity Tomography Array Types Using Analytical Element Modeling. *Vadose Zone J.,* 2: 416–23

Liu, S. and T.J. Yeh, 2004. An Integrative Approach for Monitoring Water Movement in the Vadose Zone. *Vadose Zone J.,* 3: 681–92

Matias, M.J.S., 2002. Squary array anisotropy measurements and resistivity sounding interpretation. *J. Appl. Geophysics,* 49: 185–94

(Received 31 July 2006; Accepted 05 December 2006)