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Groundwater resource characterization using geo-electrical survey: a case study of Rawlakot, Azad Jammu and Kashmir

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Abstract

The present study is focused on the subsurface mapping for groundwater accumulation in an area located southwest of Rawlakot city, Azad Kashmir to model groundwater condition using geo-electrical measurements. Vertical Electrical Soundings are conducted using a Schlumberger electrode configuration with AB/2 ranging from 1.5 to 250 m. The results of Vertical Electrical Sounding data are interpreted qualitatively using iteration software IPI2win which indicates four distinct lithological units, i.e., shale, clayey shale, clay and weathered clayey sandstone. Based on the Vertical Electrical Sounding data it is inferred that the top soil is mostly composed of 15 m thick shale to clay beds of Quaternary alluvium having apparent resistivity between 18-70 Ωm. With an increase in the depth, the shale and clay beds are gradually replaced by sandstone beds (100-300 Ωm) from a depth of 40-100 m. The generated apparent resistivity section, pseudo section and spatial distribution of apparent resistivity map at 30 m, 40 m, 60 m and 80 m are in agreement with the geology and hydrological conditions of the study area. The results inferred that the favourable aquifer conditions are present in the 20-50 m thick weathered sandstone beds having intercalation of clays. The apparent resistivity sections show that the North-East and North-West regions have comparatively good reservoir potential for groundwater.

Keywords: Geo-electrical survey, Apparent resistivity, Statistical distribution, Pseudo section.

1. Introduction

Groundwater is the largest, easily accessible and an important natural resource of water. Groundwater is enclosed in intricate joints and fracture system of rocks and tiny pore spaces of soils, and together these combine to form an immense volume (e.g., Lutgens et al., 2014). Groundwater provides half of all the drinking water worldwide and is generally considered free from bacteriological pollution and is therefore, safe for human consumption (Elizondo and Lofthouse, 2010; Siebert et al., 2010; Smith et al., 2016; Okafor and Mamah, 2012). Annually, the world wide extraction rate of groundwater is 982 km^3 where agriculture sector utilizes 70 % of it (Margat and Van der Gun, 2013). With the increase in population at an enormous rate, the supply of groundwater is expected to reach about 37,000 m^3/day by 2025 from 15,000 m^3/day at present (Maury and Balaji, 2014). Hence, in order to overcome the demand of water, the demarcation of subsurface geology is essential to identify potential aquifers.

There are several methods in practice for the assessment of hydro geological conditions, and among these the geo-electrical resistivity techniques are effective, reliable and feasible (Martinelli, 1978; Oseji et al., 2006; Khalil, 2010; Sikandar et al., 2010; Joshua et al., 2011). These techniques have been widely used for the subsurface mapping, groundwater exploration, assessment and salinity demarcation based on the resistivity contrast (Barseem et al., 2013; Choudhury et al., 2001; Khaled and Galal, 2012). The integration of different subsurface parameters extracted from resistivity measurements can be effective as electrical resistivity properties correlated with the hydraulic properties depend on the grain size distribution, structures, fabric and heterogeneities (DeLima et al., 2005; Hubbard and Rubin, 2005; Niwas et al., 2006). The most effective method of electrical resistivity used in the groundwater resource estimation and exploration is Vertical Electrical Sounding (VES) (Balaji et al., 2010; Khalil, 2010).

The groundwater investigations incorporating the geophysical techniques in the study area have not been carried out previously to cope for groundwater potential. The inhabitants mostly rely on piped water supply and springs. In this context an attempt has been made to evaluate the groundwater potential, depths and thicknesses of various subsurface layers and their water yielding capabilities using the VES. The study area, Androt is located at a distance of 20 km from Rawlakot city, District Poonch, Muzaffarabad Division, Azad Jammu and Kashmir, Pakistan, in the sub Himalayas, a part of the Hazara Kashmir syntaxes (Thakur et al., 2010). The area lies between Longitudes 73° 43′ 50″ to 73° 50′ 00″ east and Latitudes 33° 48′ 20″ to 33° 53′ 00″ north covering parts of Survey of Pakistan toposheet No. 43 G/9 (Fig. 1). The topography of the area is extremely rugged with steep hills and valleys having a diverse landscape with an average elevation from the sea level of 1500 m. The main lithological units exposed in the area are Kamlial Formation of Middle to Early Miocene, having purple gray to dark red, medium to coarse bedded sandstone with intercalation of purple-red mudstone to conglomerate, underlain by Murree Formation of early Miocene time (Walliullah et al., 2004, Fig. 1). The top soil is shaley to clayey in composition with an average thickness of 15 m and due to the poor infiltration capacity; it halts the down flow of water to recharge the aquifer.

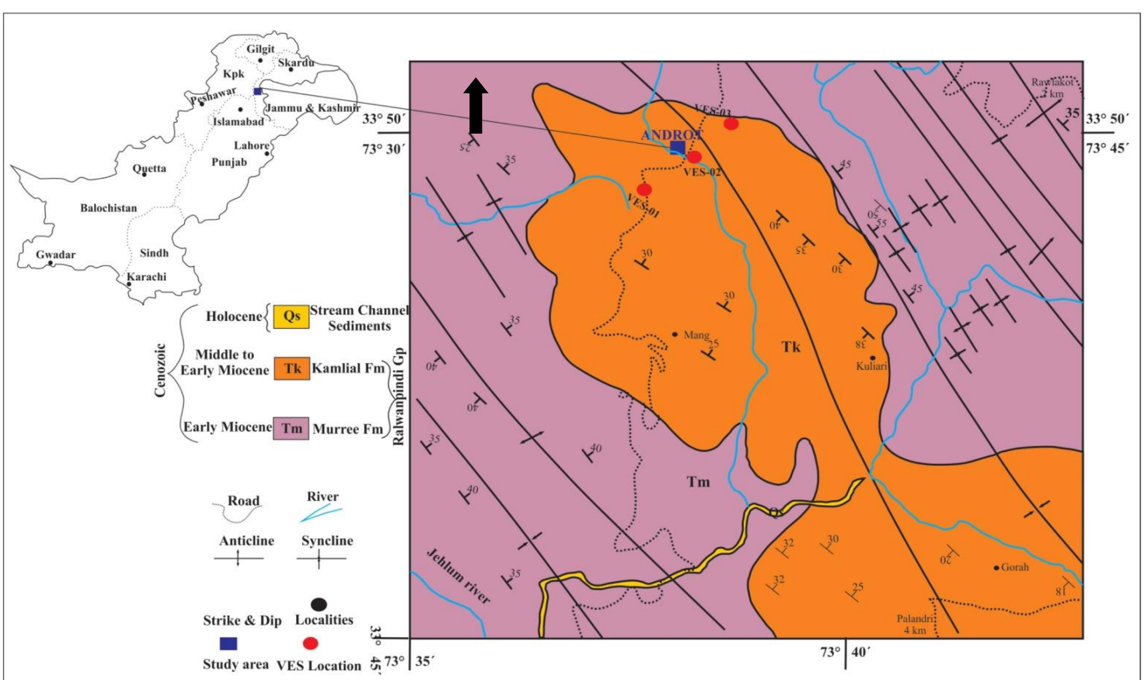

Fig.1. Regional tectonic map of and location of the study area modified after (Walliullah et al., 2004).

2. Materials and methods

2.1. Geoelectrical data acquisition

The geo-electrical data is acquired in the study area by conducting three VES surveys, arranged in NE-SW direction, using TSQ transmitter and RDC-10 receiver of Scintrex Canada along with its accessories (Fig. 2). The data is acquired in the time domain mode having t=2 sec for both transmitter and receiver. The Schlumberger electrode configuration is used with half current electrode spacing AB/2 from 1.5 to 250 m and potential electrode (MN) from 1 to 50m. The process of acquiring geo-electrical data using VES requires the measurement of resistance by changing the distance between the current electrode while keeping the trend of potential constant (Mares, 1984). The depth of current penetration is a function of current electrode spacing (Frohlich, 1974). The measurement is planned in order to acquire maximum coverage of the area to properly demarcate the underground geology and structures.

The equation used for the estimation of resistivity, ρ of the underlying medium is:

$$\rho = k\left(\frac{\Delta V}{I}\right)$$

Where, ΔV is the potential difference across the potential electrodes (MN) and I is the current applied to the current electrode (AB) and k is the geometric factor. For any linear systematic array of potential (MN) and current (AB) electrode with Schlumberger configuration, the geometric factor, k is calculated using the equation:

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

2.2.Quantitative interpretation

Different methods are used for the quantitative interpretation of geo-electrical data based primarily on the graphical and analytical techniques (Hewaidy et al., 2015). Analytical methods, however, are the recent and sophisticated, utilizing computer oriented programs. In this study, analytical method is used for analyzing geo-electrical data, an iteration software, IPI2win (Bobachev, 2002). The obtained data is analyzed manually and fed into the software for analysis. The program deals with the VES curves and draws the theoretical and field curves by dividing it into different layers together with the Rho (ρ) model curve. The resulting sounding curves are produced with a low RMS (root-mean-square) relative error of maximum 2%. The end results of quantitative interpretation of VES data are to determine the thicknesses, true resistivity values and depth of successive strata underlying different observation sites. The different lithological units are identified based on the resistivity contrast of different geological materials (Telford et al., 1990, Fig. 3). The IPI2win is a graphical oriented program which iterates the VES data using inverse and forward modeling, showing the results in the shape of sounding curves by plotting the apparent resistivity values against AB/2 spacing on semi log graph. The Pseudo section, resistivity section and trend analysis curves of resistivity are also prepared using the software to interpret the change in resistivity and the overall trend of resistivity distribution in the study area. The resistivity distribution at a potential depth of (AB/2) 30 m, 40 m, 60 m and 80 m are prepared using the Golden software, Surfer 11. The last results of the analysis were used to construct the geo-electrical sections, showing different geological units of the study area.

3. Pseudo section

The resistivity pseudo section of apparent resistivity is constructed for VES points 01-03 up to a depth of 250 m using IPI2win software that indicate a periodic change in resistivity values with depth (Fig. 4). Based on resistivity values corresponding to different formations (Table 1) four distinct litho-geo-electrical units are identified. The top soil is comprised of shaley soil (SS) resistivity ranging 35-45 Ωm underlain by shaley-clayey soil (CSS). The third unit is comprised of clayey soil (CS) resistivity ranging from 55-70 Ωm and the fourth layer is clayey sandstone (CS.st) inferred as a productive aquifer zone. This 60 m thick zone (75-95 Ωm) is encountered at a depth 50m along VES01 which is bounded at the top and bottom by low resistivity clayey soil (50-67 Ωm). The zone thickens out along VES02 where the high resistivity values are between 95-105 Ωm. Along VES03, generally low resistivity values are encountered between 40 and 65 Ωm interpreted as intercalations of clay and shale beds.

Fig. 2. TSQ transmitter and RDC-10 receiver of Scintrex Canada along with accessories used for VES.

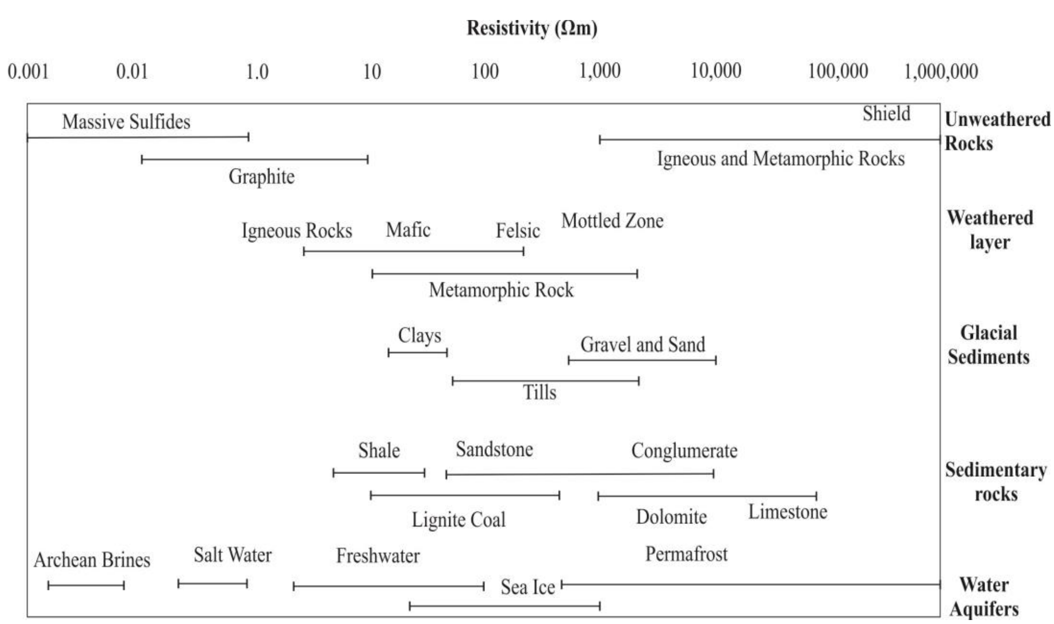

Fig.3. Approximate Resistivity values of common rocks (Telford et al., 1990).

Table.1. Summary of VES Analysis.

VES N0	Layer	ρ (Ωm)	Thickness(m)	Depth (m)
1	Shale	40	1.5	3
	Clayey S.st	120	5	8
	Shale	20	7	15
	Clayey S.st	302	20	35
	Shale	10	60	95
	Clayey Soil	100		
2	Shaley Clayey soil	70	4	
	Clayey S.st	320	5	9
	Shale	18	8	17
	Clayey S.st	206	13	30
	Shaley Clayey Shale	67		
3	Clayey Soil	90	2	
	Shale	30	3	5
	Clayey Shale	40	32	37
	Weathered S.st	120	70	107
	Clayey Shale	50		

4. Resistivity section

The IPI2win software is used to find out the true resistivity of each layer below the focus of the three VES points. The true resistivity section is prepared to a potential depth of 120m in order to correlate the pseudo section and resistivity section of each layer (Fig. 5). The resistivity section strongly correlates with the pseudo section, following the same periodic trend of the resistivity. Along resistivity section VES-01, a decrease in resistivity is observed from 100 Ωm near the surface to 20 Ωm at 18 m depth, characterized as weathered clayey sandstone. A zone between 15-35 m sandstone beds is characterized by high resistivity values between 270-350 Ωm and is inferred as an aquifer. With further increase in depth the resistivity value changes to 70 Ωm at 60 m and 150 Ωm at 150 m showing the presence of clayey soil and clay-sandstone beds respectively. At VES-02 a zone of high resistivity is recorded (100-350 Ωm) going from top to a depth of 45m and is inferred as fractured sandstone beds, a good reservoir for groundwater. These sandstone beds are underlain by mixed clay-sandstone beds up to a depth of 100 m, showing resistivity values from 100-190 Ωm. Along VES-03, low resistivity values (10-20 Ωm) are encountered from the ground surface to 15m depth, interpreted as thick shale beds underlain by thick, high resistivity, clay-sandstone beds (50-140 Ωm) and clayey shale bed (70-100 Ωm). Overall the resistivity values measured in the area show an increased downward trend, indicating the presence of sandstone beds at a greater depth. The lithological units, interpreted on the basis of resistivity that are showing good potential for the groundwater are mixed clayey sandstone to fractured sandstone beds of Kamlial Formation having resistivity between 140 to 350 Ωm. Whereas the presence of impermeable clay and shale beds may contribute to the factors that halt the vertical recharge of the aquifers.

5. Statistical distribution curve (SDC)

In order to interpret the overall trend of resistivity due to the changes in the subsurface geology with increasing depth, the statistical distribution curve (SDC) is plotted by using IPI2win software. The software compares the resistivity values acquired along VES 01-03 to capture the trend of resistivity with changing subsurface geology with depth AB/2 (Fig. 6).From SDC it is inferred that at a depth (AB/2) 0-3 m, there is a steep downward trend with resistivity values between 75-60 Ωm, showing a presence of clayey shale as a topsoil. As the depth increases, a linear, horizontal trend is observed from a depth 3-9 m with a resistivity value of 55 Ωm, inferred as shale. At a depth ranging between 9-30 m, the curve follows a dome shape trend, showing first an increase and then decrease, where resistivity values vary between 55-70 Ωm, interpreted as clay to shale. A steep upward trend is observed at a depth range of 40-100 m where resistivity value rises from 55 Ωm to 90 Ωm showing the presence of clayey sandstone which is inferred as a potential reservoir for groundwater. At a depth of 100 m the resistivity shows a gentle downward trend with resistivity value drop to 65 Ωm at a depth of 250 m and is interpreted as mixed clayey to shaley beds. Overall, SDC shows an increase upward trend in resistivity with increasing depth, which indicate that the dominant lithology near the surface is clay to shale, that changes gradually to sand rich lithologies (i.e. from clayey sand to sandstone) beyond 40 m depth.

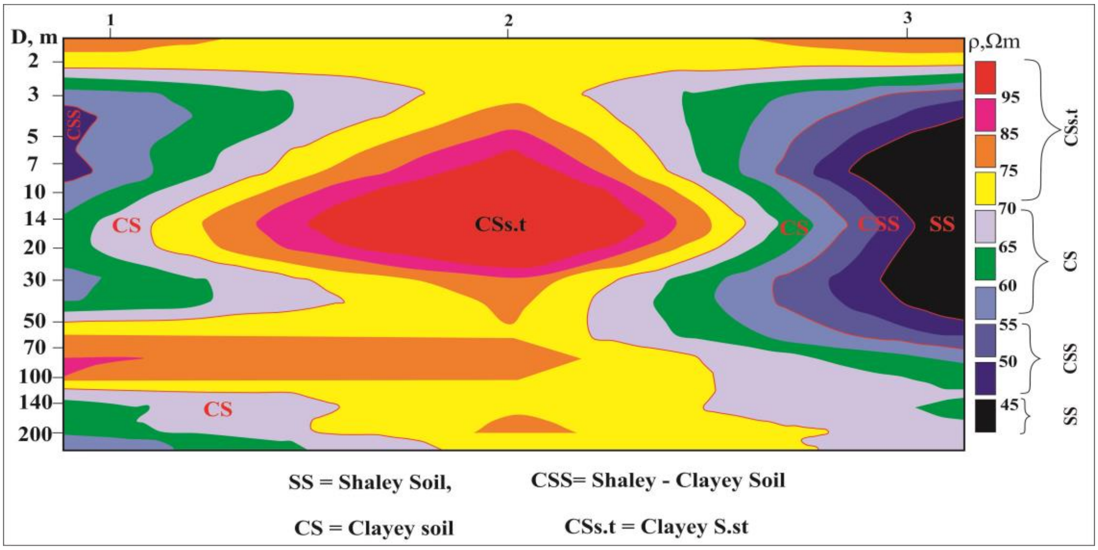

Fig. 4. Pseudo section of VES01 VES03 and VES03.

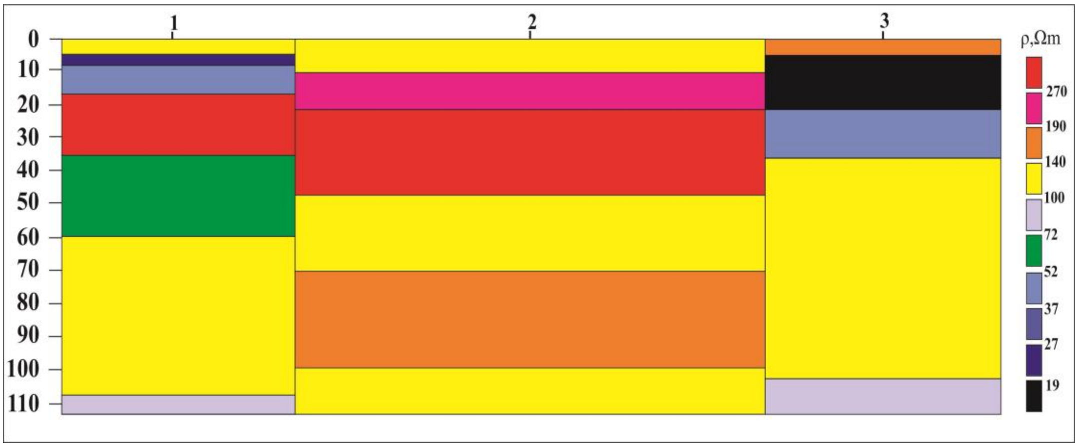

Fig. 5. Resistivity cross section of VES01 VES03 and VES03

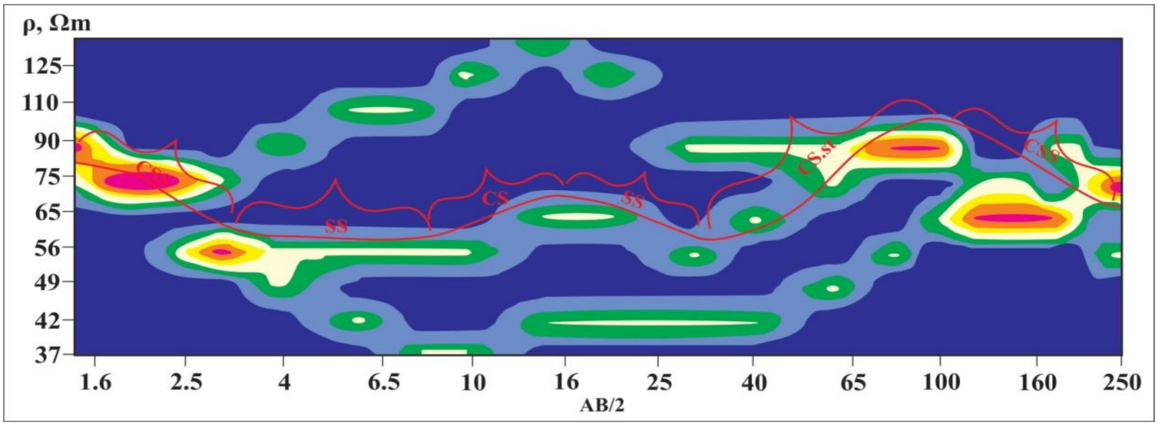

Fig.6. Statistical Distribution curve of the study area

6. Spatial model of apparent resistivity (SMR)

Based on the three resistivity profiles, VES01-03, the pseudo section and resistivity section rendered a clear picture of the subsurface resistivity distribution, which is helpful for their quantitative distribution. To present the wide subsurface lithological variations and to demarcate different geological formations, spatial distribution of apparent resistivity models are drawn using Surfer 11 software at depths AB/2, 30 m, 40 m, 60 m, and 80 m in order to show the spatial change in resistivity values across various depths.

The apparent resistivity values at a depth of 30 m and 40 m show the presence of clay to shale rich lithologies with resistivity range between 42-78 Ωm (Fig.7). The average arithmetic range of resistivity value is 60 Ωm showing clayey shale of Kamlial Formation of middle Miocene age. The apparent resistivity at (AB/2) 60 m and 80 m, the resistivity values rise from 60-85 Ωm (Fig. 8), with average arithmetic resistivity value 72 Ωm, and inferred as weathered, clayey sandstone, present in the lower beds of the Kamlial Formation.

In general, the trend of the apparent resistivity distribution in Kamlial Formation increases with depth and is in agreement with Pseudo section and resistivity section. Form the spatial distribution of apparent resistivity section, the increase in resistivity values is attributed to the increase in sandstone. The potential aquifer, interpreted from the section is shown in the NE and NW side of the section in the form of weathered sandstone beds with the intercalation of clay.

7. Geo-electrical section

Geo-electrical lithological sections have been prepared from the resistivity curves derived from the computer iteration software of the study to a depth of 250 m for the comparison of resistivity values and lithology (Fig. 9). These sections are in agreement with the geology, characterizing groundwater potential in fractured weathered clayey sandstone layers. However, confirmatory well should be drilled up to this depth in order to make it ascertain. The top soil is mostly shaley to clayey in composition with an average thickness of 3 m and resistivity 70-100 Ωm, which is mostly unsaturated, showing only surficial water content. The second layer is predominantly composed of shale, having resistivity values between 20-40 Ωm with an average thickness of 3 m.

The potential layer of the groundwater aquifer is characterized by weathered clayey sandstone. In VES 01 and 02, this layer follows a gentle slope with a value of 120-320 Ωm and the average thickness is 15 m at depth of 15 m from the ground surface. Whereas in VES 03, the productive zone starts at a depth 37 m and its thickness increases to 70 m. These sandstone beds are underlain predominantly by soils of shaley to clayey in composition with resistivity of 50-70 Ωm.

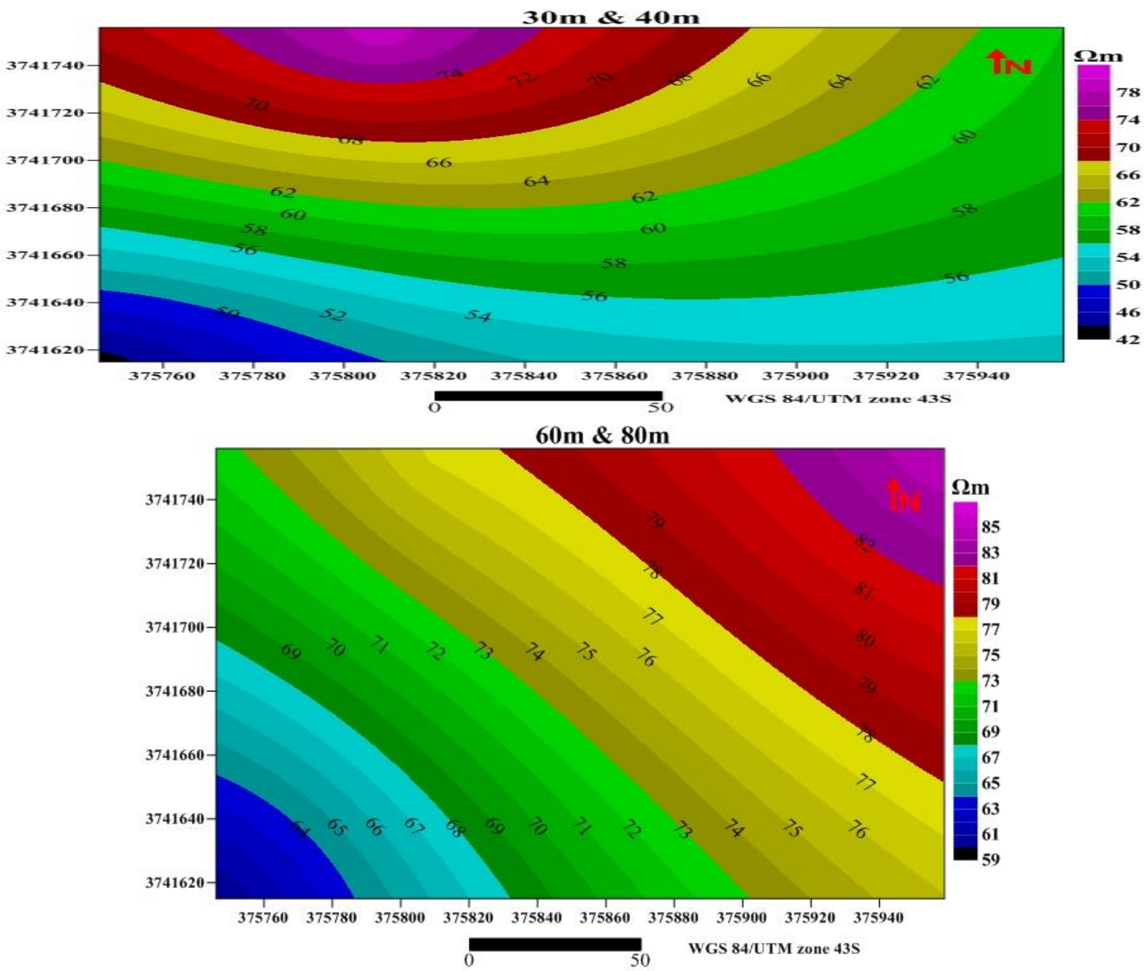

Fig.7. SMR at (AB/2) 60 m and 80 m of the study area.

8. Discussion

From the 2D-layered model, generated using IPI2win resistivity software, the resistivity values associated with each layer were derived together with corresponding thicknesses (VenkataRao et al., 2014). The thicknesses, depths and corresponding resistivity values of different layers interpreted from sounding curves are summarized in Table 1. The results obtained from the analysis of geo-electrical data revealed the underlying sedimentary strata that is in agreement with the geology of the study area. The resistivity data, after applying quantitative analysis using iteration software, concludes four sedimentary units based on resistivity contrast and that are; shaley soil, shaley-clayey soil, clayey soil and clayey sandstone. The potential reservoir rock in the study area is inferred to be weathered sandstone with intercalation of clay at a depth ranging from 20 m to 50 m. The sandstone lithology alternated with the clayey and shaley layers, as interpreted from pseudo section and resistivity section, may halt the vertical recharge of the aquifer. With the increase in depth, the sandstone content increases and clay content decrease, and this should be confirmed by carrying out exploratory boreholes in order to ascertain the productivity of groundwater. The top soil is mostly shaley to clayey in composition, formed from the weathering of quaternary to recent deposits, forming an impermeable cover having an average thickness of 15m. From the spatial distribution of apparent resistivity, it is interpreted that the favorable reservoir is in the sandstone beds of Kamlial Formation

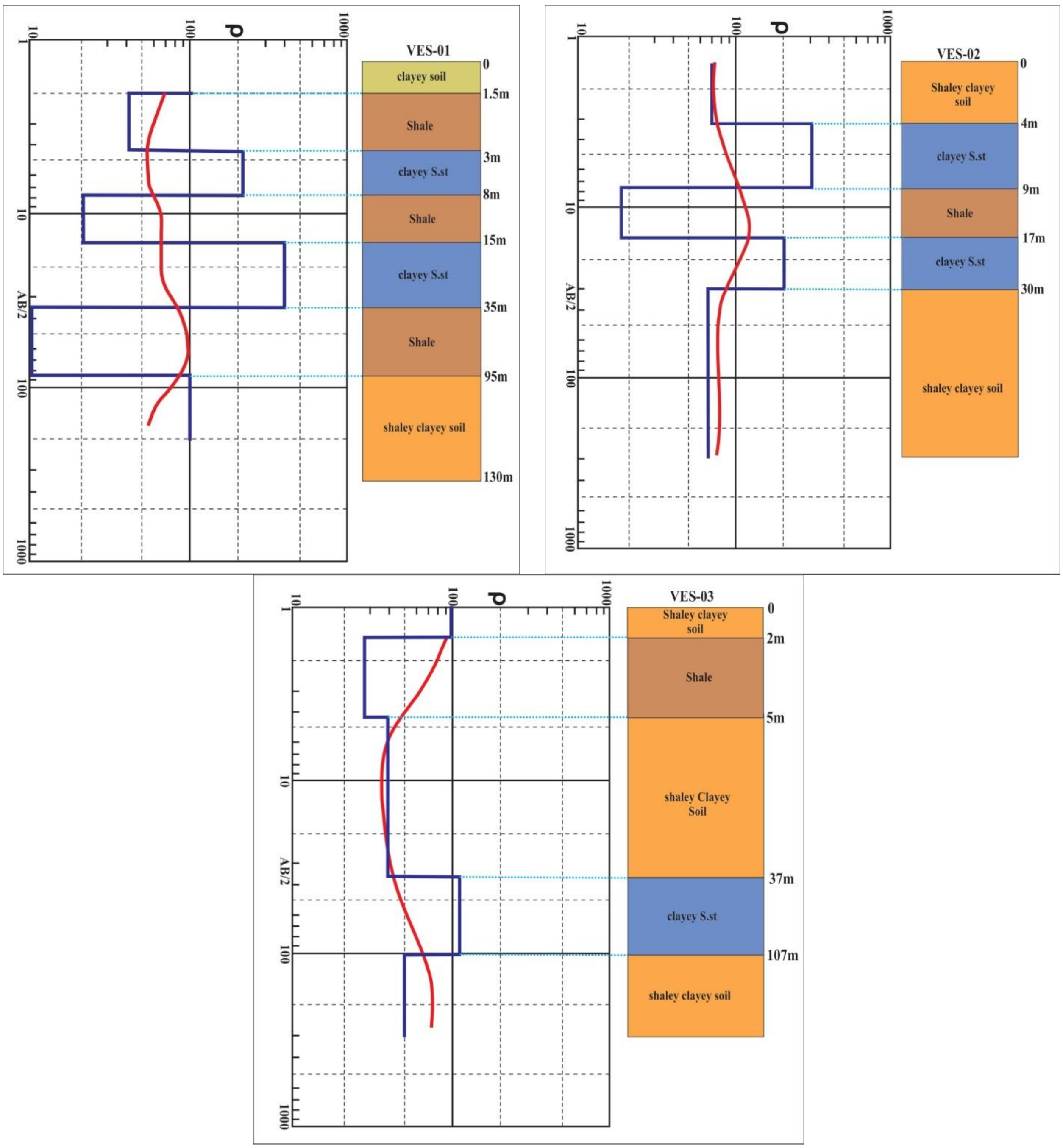

Fig.8. Geo-electrical section of the study area using IPI2WIN software

9. Conclusions

On the basis of VES results and prevailing knowledge about the geology of the study area, the conclusion are summarised:

- The area is primarily composed of four basic geological units; fractured sandstone, clayey shale, clays and shale beds.
- The zones having shale and clay beds give resistivity values between 10-45 Ωm and 50-70 Ωm respectively, but due to their low permeability, these zones may not be productive.
- Porous and fractured sandstone is the main zone of water accumulation and therefore a potential groundwater reservoir as inferred from the apparent resistivity value of 80-100 Ωm. However, a confirmatory borehole is required at VES-02 in sandstone with clay intercalation to a depth of 30 m from the ground surface.
- The presence of clay intercalations might halt the infiltration of water due to their poor permeability of this strata and hence groundwater recharge could be the main concern in the case of extended drought periods.
- Lateral extent of the aquifer and its recharge will remain the main consideration, even if the productivity at the particular site is proved. However, deep drilling up to 80 m would be useful in order to puncture the entire fractured sandstone zone for good recharge and permeability.
- The outcomes of this study may be helpful for the technical groundwater management as the reasonable borehole locations can be distinguished for long haul groundwater prospecting in the study area.

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Authors' contribution

Mehboob Ur Rashid involved in field survey and drafting of the manuscript. Waqas Ahmed helped in interpretation and reviewing the manuscript. Sohail Anwar and Syed Ali Abbas were involved in field survey. Muhammad Waseem and Sarfarz Khan worked in manuscript drafting.

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