

## A Comparison Between Schlumberger and Wenner Configurations in Delineating Subsurface Water Bearing Zones: A Case Study of Rawalakot Azad Jammu and Kashmir, Pakistan

Abrar Niaz,<sup>1</sup> Arbab Manzoor Awan,<sup>1</sup> Tehmina Bibi,<sup>1</sup> Sabit Rahim<sup>2\*</sup>, Javed Akhter Qureshi,<sup>3</sup> Fahad Hameed,<sup>1</sup> Arshad Ali Shedayi<sup>4</sup>

<sup>1</sup>Institute of Geology University of Azad Jammu & Kashmir Muzaffarabad, Pakistan

<sup>2</sup>Department of Computer Sciences, <sup>3</sup>Department of Earth Sciences, <sup>4</sup>Department of Biological Sciences, Karakoram International University, Gilgit, Pakistan

\*Email: [sabit.rahim@kiu.edu.pk](mailto:sabit.rahim@kiu.edu.pk)

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**Abstract:** The Schlumberger and Wenner Electrical Resistivity Survey techniques have been used in comparison for the determination of groundwater potential in District Rawalakot, Azad Jammu and Kashmir. The terameter SAS4000 with accessories was used for data acquisition. The data were processed by employing IPI2WIN software to determine the depth, thickness and true resistivity of the subsurface layers. The present study indicated the subsurface depth coverage of Schlumberger configuration is greater than Wenner configuration. The apparent resistivity maps using both Wenner and Schlumberger techniques at the same locations have been prepared at 3m, 4m, 9m, 10m, 27m, 30m, 50m, 51m, 100m, and 150m depths respectively for groundwater assessment. The differences in resistivity contour closures, in both types of maps, arise due to lateral variations of subsurface lithology. Longitudinal conductance, transverse resistance and anisotropic maps were also prepared. The different contour closures in the Wenner map were due to mixed lithology of alluvium with variable water contents. The subsurface geology i.e. clay, sandstone boulder clay, and dry sandy soil were interpreted which are in close agreement with the surface geology of the area. The aquifers of the project area are designated as confined and unconfined good water potential indicated by low values of resistivity. The water-bearing strata consist of sand, gravel, boulder clay and sandy clay.

**Keywords:** Electrical resistivity survey (ers), Wenner technique, Schlumberger technique, correlations.

### Introduction

Water is a basic need of life. With the increase in population and industrialization, freshwater resources are declined or polluted. The aquifers are the significant sources of groundwater in the arid zone of Pakistan and these resources are yielding water in drought environment. The study area is densely populated and mostly depends upon the groundwater for both irrigation and domestic uses. A quantitative explanation of the aquifer has become vital to conclude the hydrological complications in the area (Asfahani, 2007; Ekwe et al., 2010; Kumar et al., 2007).

A detailed investigation of aquifers is required to accommodate the challenges of groundwater scarcity. The different methods used to estimate the hydrological parameters are costly and time-consuming. Geophysical techniques provide a cost-effective measurement to estimate aquifer parameters and groundwater potential (Khalil, 2009; Niaz et al., 2013; Oseji et al., 2005). These techniques are common dynamic scientific lines that govern the hydrogeological investigation. They are not only restricted to the hydrological parameters like longitudinal conductance, transverse resistance, bedrock depth, but also give indications about the occurrence of freshwater (Khan et al., 2018; Niaz et al., 2016; Niaz et al., 2018).

This study aims to determine the groundwater potential by using integrated Schlumberger and

Wenner configurations of the Electrical Resistivity Survey (ERS) method. For this purpose, geophysical surveys with four (4) electrode configuration the methods proposed by Wenner and Schlumberger were used. The survey was carried out to compare both applications in terms of their use and handling in the field. The Schlumberger configuration is employed for measuring the vertical alteration of resistivity variations in the subsurface while the Wenner configuration is used for measuring horizontal variations of the resistivity in the subsurface (Aning et al., 2014; Hemeda, 2013; Kim et al., 2005).

This study would be beneficial for future researchers to use and integrate the techniques introduced for groundwater exploration. Both methods have been applied at the selected sites to evaluate groundwater potential and lithology identification as well as comparison of both techniques has also been made for better results. A total of 56 ERS points using Schlumberger (28) and Wenner (28) arrays were acquired in the project area. Quantitative interpretation based on the analysis of field data by applying the curve matching technique is carried out for the delineation of true resistivity and the thickness of each station. The results of this study will help in fulfilling the emerging needs of water throughout the affected area.

### Geology of the Study Area

The project area is part of the Sub-Himalayan fold and thrust belt of northeastern Pakistan. It is located in

Rawalakot, district Poonch of Azad Jammu, and Kashmir. It lies between latitude 33°50'23.4" N and longitude 73°44'3.4"E (Fig. 1) on toposheet no. 43 G/9. The area is comprised of hills and valleys that generally vary between 500 to 2250 m from the sea level. The main source of groundwater recharge of the area is rainfall of 476 mm on average in the summer season.

The study area mainly comprises of classic sedimentary rocks in three distinct lithological units: i.e. clay, shale, and sandstone in varying proportions from shale to clayey sand and compacted to fractured sandstone. The superficial geology is mostly comprised of Quaternary sand, shale, silt, and gravel underlain by the Murree Formation of the early Miocene age. The Murree formation consists of a cyclic deposition of clay, siltstone, and sandstone (Wadia, 1931; Wnuk et al.).

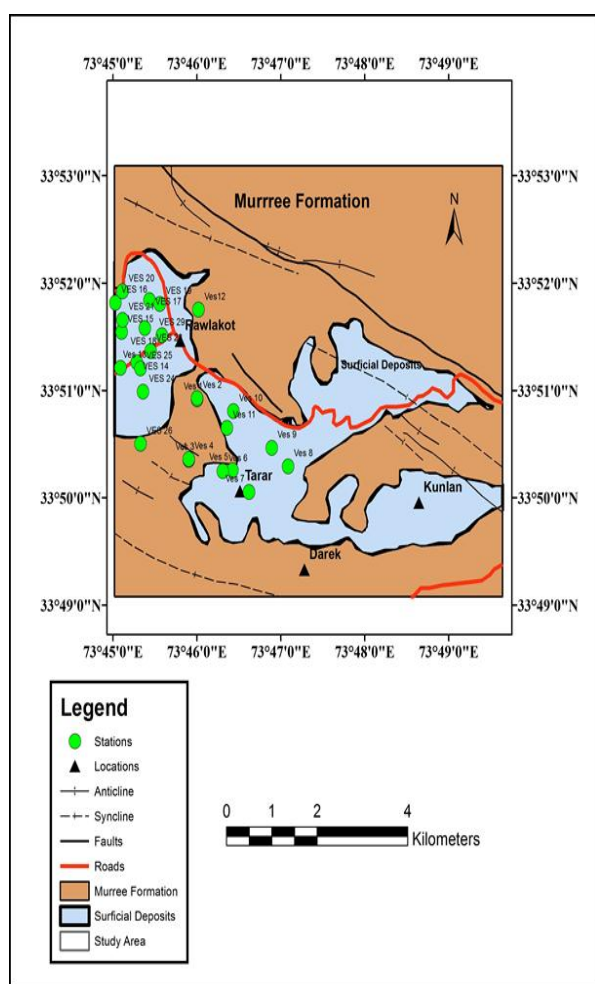


Fig. 1 Geological map of the study area using.

### Materials and Methods

In the electrical resistivity method, the artificial source was used for current injection into the earth with the help of electrode pair namely current electrodes and the generated potential is measured with the other pair of electrodes known as potential electrodes. Direct current (DC) or alternating current (AC) with low frequency was used in this technique. The current electrodes were kept outside the potential electrodes

while applying the methods. The electrical potential distribution was prejudiced by the resistivity of subsurface sections. Potential dissemination was affected by current flow due to the change in subsurface resistivity of the strata. Apparent resistivity was described by potential and current difference as well as electrodes geometry (Arulprakasam et al., 2014; Niaz et al., 2017).

Integrated data from the electrical resistivity method was employed using Wenner and Schlumberger electrode configurations to identify the subsurface features and location of water (McGrath et al., 2002; Vasantrao et al., 2017). Geophysics, particularly geoelectrical resistivity techniques have been extensively used for a wide variety of geotechnical and groundwater problems. Moreover, it can be used either in the form of vertical electrical soundings (VES's) or horizontal profiling to search for groundwater. The resistivity method is less costly and very suitable for the demarcation of subsurface water-bearing strata and feasible sites for the installation of water bores (Adeyemo et al., 2017; Niaz et al., 2013).

The data were acquired using both techniques at the same location to observe similarities, to compare both the techniques for field usage and handling. In the Schlumberger method, two electrodes can be moved at a time, but in Wenner technique, all the electrodes were moved for each reading. In the current study, 28 different stations were selected for taking resistivity measurements. A total of 58 electrical resistivity sounding (ERS) and horizontal profiling, using 28 by Schlumberger and 28 by Wenner array were done in the same area for resistivity data acquisition. The data sets were also used for making an iso-resistivity map of the area and for calculating the geo-electrical parameters. The attained data consist of AB/2 values and apparent resistivity. The maximum electrode spacing at various locations ranged up to 200 meters. The data were also employed for the development of longitudinal transverse and anisotropy maps of the area to observe the effects of homogeneity (Alisiobi and Ako, 2012; Ariyo et al., 2011; Niaz et al., 2013; Niaz et al., 2017).

### Results and Discussion

The apparent resistivity maps at different electrode spacing were prepared by using the surfer V. 11 software. The apparent resistivity was helpful in the identification of subsurface groundwater profiles in depth (Arulprakasam et al., 2014; Pal and Majumdar, 2001). Kriging technique was preferred, during contouring, because of the complex topography of the study area. Apparent resistivity map at 3m, 4m, 9m, 10m, 27m, 30m, 50m, 51m, 100m, and 150m were prepared using Wenner and Schlumberger techniques respectively.

**Apparent Resistivity Maps at 3m Spacing (Wenner) and 4m Spacing (Schlumberger)**

The apparent resistivity map of the study area was developed at 3m electrode spacing by using the Wenner method. The resistivity values at this map range from 0 Ωm to 400 Ωm (Fig. 2) and show two prominent high resistivity contour closures. One in the northern periphery of the area that ranges from 60 Ωm to 260 Ωm, while the other is in the southwestern periphery of the area that ranges from 40 Ωm to 140 Ωm. These contour closures indicate comparatively high resistivity materials (dry clays and boulders).

The apparent resistivity map developed at 4m electrode spacing by using the Schlumberger method in the study area ranges from 0 Ωm to 500 Ωm (Fig. 2). The contours of 50 Ωm to 150 Ωm cover nearly the whole map excluding the eastern part of the study area. On this map two prominent resistivity contours closure were obtained, one in the northern part of the area which ranges from 100 to 250 Ωm, whereas the other in the western part of the area ranging from 100 Ωm to 400 Ωm.

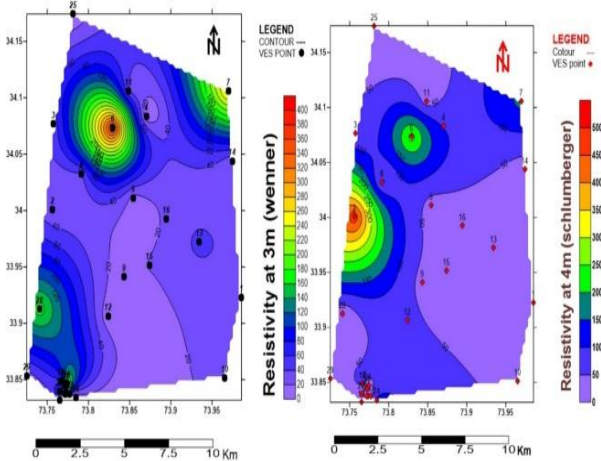


Fig. 2 Apparent resistivity map of Wenner and Schlumberger at 3m and 4m electrode spacing, respectively.

The low apparent resistivity values in the northern part of the study area indicate the presence of water in the near-surface strata or alluvium (Niaz et al. 2018). Comparing the two images, it is concluded that the VES points that lie in between the resistivity of 0 to 50 Ωm contains water-saturated zones. The information on both the maps in near-surface layers shows a similar response of geology (alluvium).

**Comparison of Depth Resolution for Wenner and Schlumberger Techniques**

The apparent resistivity acquired by Wenner and Schlumberger methods has been subjected to IPI2Win V. 3.0.1 software for the determination of depth thickness and true resistivity of the different subsurface layers. The maximum depth determined by the partial curve matching technique was 75.6 meters in the Schlumberger method (Fig. 3), whereas the Wenner

technique demarcated 23.71-meter depth at the same location.

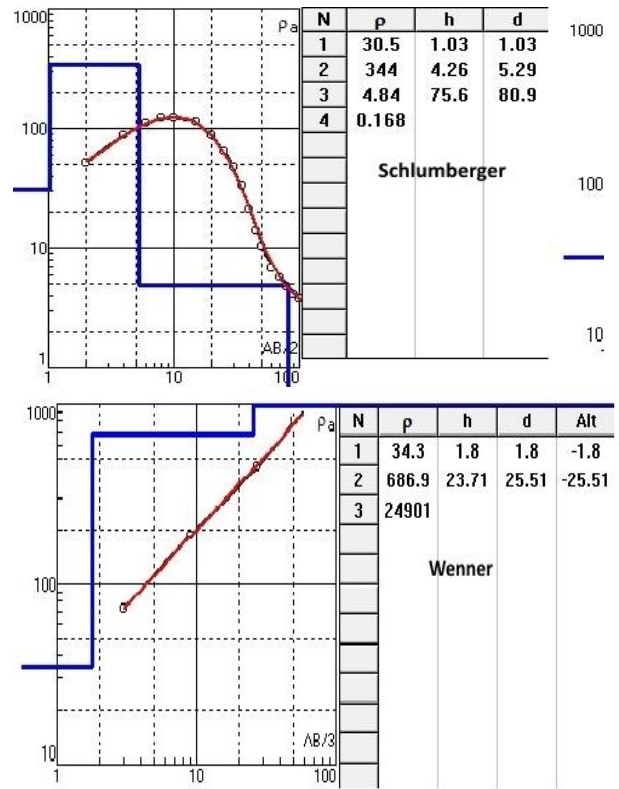


Fig. 3 Comparison of IPI2Win curves for Wenner and Schlumberger techniques.

In another station, resistivity curve by using the Schlumberger method shown the depth of 94.1 meters, while at the same location, the maximum depth delineates to 21.4 meters. It was also concluded from the study that the Schlumberger technique gives better depth resolution than the Wenner configuration, whereas the Wenner configuration has better results for measuring lateral variation in geology.

In the Schlumberger method, the potential electrodes remained at a fixed location, therefore, effects of near-surface lateral variations in resistivity can be minimized. But, in Wenner all electrodes are moved for each reading, this method can be more susceptible to near-surface, variations in resistivity. These near-surface lateral variations could potentially be misinterpreted in terms of depth variations in resistivity. The present study delineated that up to 3 layers were detected by both techniques, while deeper

layers were not detected by the Wenner method. The curve types and number of subsurface layers using both techniques were tabulated in Table 1. Therefore, it is interpreted that the Schlumberger method covered more depth as compared to the Wenner method. The depth resolution results are evident from quantitative interpretation, the presence of alluvium and low resistivity values represent the presence of groundwater. The high resistivity of the majority of base layers

indicates the presence of compact sandstone at these layers. Unconfined aquifers (VES points 1, 5-10, 12, 14 16-23, 27) with top layer sand and gravel were identified. The water-bearing strata are sand and gravel, boulder clay and sandy clay. Most of the area comprises clay deposits.

Table 1. Curve types and no subsurface layers using Schlumberger and Wenner techniques at the same locations.

VES	CURVE TYPE (Schlumberger)	LAYERS (Schlumberger)	CURVE TYPE (Wenner)	LAYER S (Wenner)
1	H	3	K	3
2	A	4	H	3
3	Q	6	A	3
4	H	4	A	3
5	K	4	A	3
6	A	4	Q	2
7	H	4	H	3
8	H	3	K	3
9	Q	3	K	3
10	K	3	K	3
11	Q	4	HQ	2
12	Q	3	A	3
13	Q	2	H	2
14	K	3	H	3
15	H	4	A	2
16	K	3	H	3
17	K	3	H	3
18	K	4	H	4
19	K	4	K	3
20	H	4	H	2
21	Q	4	H	4
22	A	4	A	3
23	K	4	K	3
24	K	3	K	3
25	A	3	H	3
26	Q	5	H	4
27	H	3	Q	3
28	H	4	K	3

**Geo-Electrical Parameters**

Homogeneous characteristics of the rocks and anisotropy cause variation in resistivity values. The number of geological parameters was used to measure these variations. Different rocks showed deviation from homogenous behaviours and perfect anisotropy. Observing the end goal to quantify the discrepancy of resistivity because of homogeneity and anisotropy of the subsurface layers, large numbers of geo-electrical parameters were calculated. These parameters represent the specific rock unit from perfect behaviours of homogeneity and isotropy.

**Longitudinal Conductance (S)**

It is defined as the conductance along the bearing of the bedding plane through a section of 1 m. It was denoted by "S" and its unit is Ω (Nwanko et al. 2011; Ozebo et al. 2008).

$$S = \sum_{i=1}^n h/\rho I$$

Where "ρ" is the resistivity and "h" denotes the thickness of layers. Higher longitudinal conductance values generally showed a comparatively thick succession and should pay a greater impact in terms of groundwater potential and vice versa (Nisar1 et al., 2018). The Ohm's Law measured the current flow, while Darcy's Law directed acceptable relationship and groundwater flow between hydraulic and electric parameters (Slater, 2007).

Figure 4 represents the total longitudinal conductance map of the study area. The conductance value ranges from 0 to 100 Siemen. Since the resistivity naturally increased and the conductance decreased attributing to fewer groundwater aquifers (Gowd, 2004; Mogaji et al., 2007). The values of conductance increased towards the northern part of the study area. In Wenner longitudinal conductance value ranges between 0 to 10 Siemen. The values of conductance increased towards the western part of the project area.

Comparison of the conductance map of Wenner and Schlumberger shows that conductance values increased towards the northern and western parts.

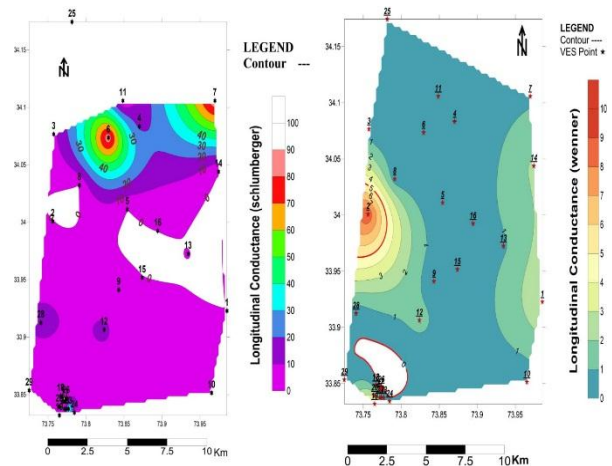


Fig. 4 Longitudinal conductance maps.

**Transverse Resistance (T)**

Transverse resistance is defined as the total resistance through one meter column cut perpendicular to the bedding plane. It is denoted by 'T' and its unit is Ω/m (Niaz et al., 2013).

$$T = \sum_{i=1}^N hi\rho_i$$

$$T = \sum_{i=1}^N Ti \tag{2}$$

Where "ρ" is the resistivity and "h" denotes the thickness of layers and 'T' is the transmissivity. Higher values of T relate to the greater transmission of the aquifer.



The transverse resistance map of the study area showed the values ranging from 0 Ω/m to 26000 Ω/m (Figure. 5). There is only one loop in this map on the south portion, where the maximum values of transverse resistance are present, while rest of the map depicts low resistance values. The values of conductance increase in the southern part of the project area. If the values of resistivity decreases, the conductance increases, as shown in the potential groundwater aquifers (Gowd, 2004).

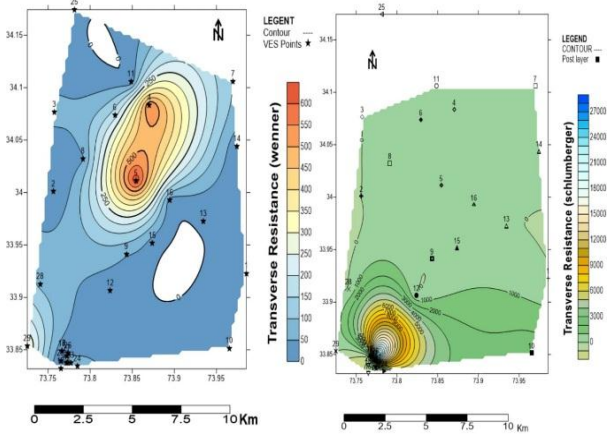


Fig. 5 Transverse resistance maps.

The transverse resistance map using the Wenner technique of the study area ranges from 0 Ω/m to 600 Ω/m (Figure.5). The value of conductance increases towards the centre of the map where the maximum contour of 500 Ω/m is present. The different contour closures in the Wenner map are due to the mixed lithology of alluvium with variable water contents.

**Longitudinal Resistivity (L)**

Longitudinal resistivity is the resistivity of the rock unit parallel to the bedding plane. It is indicated by "L" and the unit of longitudinal resistivity is ohm-m (Coker, 2012). Mathematically, it is expressed as,

$$\rho I = H / S \tag{3}$$

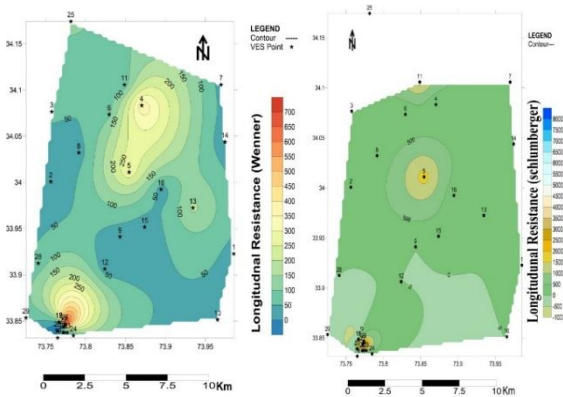


Fig. 6 Longitudinal resistivity map.

Where "S" represents longitudinal conductance and "H" represents the total thickness of the section (Coker, 2012).

Figure 6 shows that mostly map has low resistivity ranges. These low values indicate groundwater accumulation in the study area. One closure with a high resistivity is found in the extreme central northern part of the map with no or less potential for groundwater.

The map of longitudinal resistivity through Wenner showed that contour ranged from 0 Ωm to 700 Ωm (Fig. 6). The variation of resistivity in the Wenner map is due to lateral effect of resistive dry alluvium. But in the Schlumberger map almost similar resistivity values are due to presence of Murree Formation sandstone and clay. These low values indicated the groundwater accumulation in the study area.

**Anisotropy (A)**

The rock is called anisotropic when the resistivity of the rock mass differs with the direction of the current flow. This is an important parameter because effective resistivity thickness is measured by anisotropy. The low values of the anisotropy coefficient is due to structural elements such as fractures, joints, and faults thus contributing to the groundwater potential of the area (Olasehinde & Bayewu, 2011).

Anisotropy depicts that inhomogeneity of the geological layers is important for groundwater development of the area (Bayewu et al., 2014; Raj et al., 2014). Figure 7 presented the co-efficient of the anisotropy calculated by using the Schlumberger technique. The co-efficient of anisotropy values range from 0 to 6 λ. The anisotropy map showed two closures with one of them having high values of anisotropy formed at the southern part of the map.

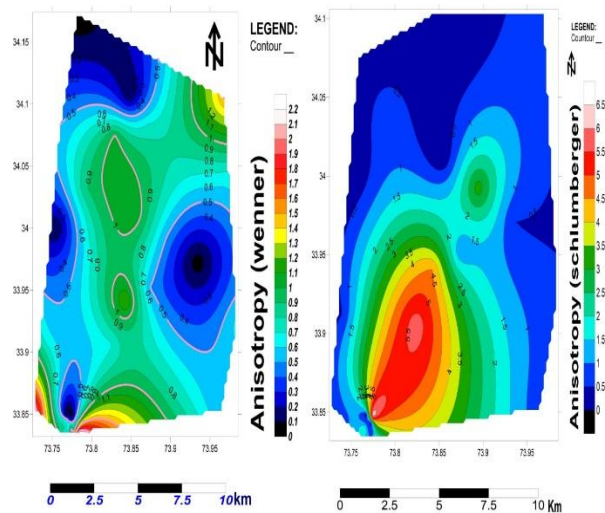


Fig. 7 Anisotropy maps of the area.

In the Wenner anisotropy map, the anisotropic values ranged from 0 to 2.2 λ (Fig. 7). The higher anisotropic values are good indicators of groundwater development

in the area. Both maps demarcating higher values of anisotropy in the central as well as the southern part of the study area indicating the good potential of the groundwater. The resistivity contours developed due to structural variations like faults, syncline, an anticline in the area (Fig. 1).

## Conclusion

The integrated electrical resistivity survey using Schlumberger and Wenner configuration is most effective for groundwater detection. The Schlumberger configuration is more reliable as it covers more depth as compared to the Wenner configuration. The apparent resistivity map at 3m, 4m, 9m, 10m, 27m, 30m, 50m, 51m, 100m and 150m prepared by using Wenner and Schlumberger technique show that there is the potential of water at variable depths. The comparison of apparent resistivity map showed that for near-surface both the maps have a difference in contour closures representing the near-surface inhomogeneity or lateral variation but with increasing depth, both the maps have similar responses. Longitudinal conductance, transverse resistance and anisotropy maps were also prepared. Different contour closures in the Wenner map are due to mixed lithology of alluvium with variable water contents in near-surface layers. Both configurations demarcated similar subsurface geology (clay, sandstone boulder clay and dry sandy soil) which are in close agreement with the surface geology of the area. The aquifers identified in the project area are defined as confined and unconfined. Unconfined aquifers (VES points 1, 5-10, 12, 14, 16-23, 27) with top layer sand and gravel were identified, whereas the remaining part is characterized by confined aquifers.

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