Research Article

Electrical Resistivity Survey by Schlumberger Electrode Configuration Technique for Ground Water Exploration in Pakistan

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Abstract | Aquifer zones had been explored by the geo-electrical method of electrical resistivity survey (ERS) to mark out subsurface formations in terms of groundwater quality and quantity. The main focus was on identification of subsurface litho-logy and aquifer zones by resistivity method in parts of the Havelian Cantt, Abbottabad district, Khyber Pakhtunkhwa (KPK) Province and Sanjwal Cantt, Attock district, Punjab Province, Pakistan. Evaluation of the lithology of subsurface strata was carried out by electrical resistivity survey (ERS) interpreted by software packages 1X1D using ABEM Terrameter SAS-4000. The different 05 sites were selected for ERS after identifying feasible locations. Data acquired was processed using the Schlumberger electrode configuration (SEC) to determine the characteristics of target layer. The results showed that groundwater level (GWL) at Havelian Cantt sites was at 69 ft average depth with resistivity values between 35-56 ohm-m and formation consist of dominance of gravel/boulder mixed with sand/ sand stone and thin layers of clay. GWL at Sanjwal Cantt sites was at 50 ft average depth having low to moderate yield of water and the formation had dominance of sand with alternate layers of clay against resistivity between 25-86 ohm-m. The study concluded that electrical resistivity survey (ERS) is a sound method for measuring GWL in sandy aquifers and boulder clayey formations when GWL is sufficiently deep.

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Introduction

Water is essential element for all life forms of the earth activities. The groundwater resources are widely spread, but not available at the places of our choice. In wetter areas, ground water may be in good quality for surface supply and may provide a reserve against drought, but in arid lands, the only reliable supply lies beneath the earth's surface in the shape of groundwater. So having the knowledge of occurrence of groundwater is crucial in design programs to utilize it practically.

The present study and working is carried out in the field of groundwater investigation through resistivity survey. The main focus is on the groundwater exploration technique for different soil types at various depths to turn out to be more efficient, economical and fruitful. There are some researches previously done in this field through resistivity survey, some of which are as under:

A study was done to identify the aquifer existence in a particular area by selecting 8 points (S1 to S8) for vertical electrical sounding by using schlumberger electrode configuration. The incursion depth of current was approximately 160-170m. The analysis of the results suggested that 150-160m deep drilling in medium to fine grained sand with deeper clay-sand stratum which exists at points S2, S4 and S7 (Sharma, 2021).

A study conducted using separate inversion and two-dimensional joint of data by using, Wenner configuration and Schlumberger, dipole dipole methods on synthetic and real data. The results indicated that utilization of joint inversion is better that separate inversion as it provides higher density of data and uses different current distribution in the subsoil. The high heterogeneity of karstic environments identification is possible if more information on the subsoil is obtained (Villela-y-Mendoza *et al*., 2021).

A study was carried out by by means of geoelectric technique with SEC (Schlumberger Electrode Configuration) to know the Groundwater Potential. The result revealed peat and soil cover layer having resistivity values between 60.42 to 245.84 ohms-m. The second layer had a relatively high resistivity value and was in the shape of peat layer 116.78 to 212.58 ohms-m was the range of resistivity. Clay was the major portion in the third layer, this layer had relatively low resistivity value between 11.31 to 26.53 ohms-m, while fourth layer was composed of sand, the resistivity value lied between 41.99 to 59.50 ohm-m which indicates aquifer layer because it had high water passing characteristic. It was concluded that Geoelectric technique with schlumberger electrode configuration can be utilized effectively in groundwater drilling activities (Rahajoeningroem and Indrajana, 2020).

The main focus of this study was on the hydrological mapping and subsurface geological for identifying the presence of groundwater in the area with vertical electrical sounding (VES) via means of the schlumberger electrode array (SEA) technique ranging between 02-300 m. The results suggested that good aquifer zones were present in the 50–100 m thick fractured sandstone beds and limestone contained interconnection with clay. Accumulation of groundwater was identified by scheming the geological and physiographical structures of the study area (Soomro *et al*., 2019).

To determine the groundwater potential a study was conducted by means of petrographic analysis and method of electrical resistivity. Tape compass clinometers method was used for the measurement of section. The outcome obtained by the 3D and 2D iso-resistivity maps of apparent resistivity for 130, 45 and 15 m spacing's, the measured stratigraphic section of surface rocks and the VES curve types discovered the semi-confined or confined type aquifers within sedimentary formations. The petrographic analysis indicated the clues of the fluid migrations through the rocks secondary and porosity (Niaz *et al*., 2018).

A resistivity analysis was directed to assure aquifer properties besides delineation of vulnerability by using Schlumberger array vertical electric sounding (VES). The results were also checked by chemical investigation of well's water samples and anisotropy mapping of selected area. The results showed that southern halves of the study area and Nither Town have a good infiltration protective capacity while the left over area was vulnerable to infiltrating fluids. The water samples of this area indicated sulphate, chlorides and nitrates salts pollutants (Awan, 2019).

A research study was initiated for the study of groundwater potential by geophysical inversion of electrical resistivity data using combining geostatistical analysis. Calibration and interpretation of the electrical resistivity curves with the geophysical logs and lithologies of boreholes suggested potential detection of unique sedimentary accumulations presence inside the study area. Therefore, the results revealed that low general transmissivity of the sediments, which means that there are deprived conditions for commercial groundwater production in the area. In specific, the main objectives of this study were groundwater potential exploration and 3D modeling of underground resistivity by means of low resistivity zones distribution (Javed *et al*., 2019).

A survey was conducted by using four electrodes, stiffly mounted in the ground for measuring of potential drop between two of the electrodes (potential electrodes), for detection of groundwater using electrical resistivity technique. The values of resistivity obtained was apparent resistivity which later gave true resistivity values and resistivity values were plotted on map through computer software IPI2Win, to generate a resistivity curve that helped in interpretation of subsurface strata. Lithological columns were also made in practice to get knowledge about what was the picture of subsurface lithology and where did fresh water and saline water encountered. Fresh water zones were selected at the end and then proposed which site was most suitable for tube well installation (Javed *et al*., 2017).

This study was conducted in order to understand the behavior of vandose zone over the infiltrating water front, an integrated approach based on resitivity survy and infiltration test was attempted with distinct geomorphology, in a semi-arid granite terrain. The impacts of study on shallow subsurface transient resistivity signature were documented. The proposed method can also be utilized in different geological terrain and can determine the spatial distribution of recharge with limited spot recharge measurements (Andrade and Rangarajan, 2019).

The environmental and engineering impacts of 2-D resistivity assessment of subsurface characterization at southern industrial and logistics clusters (SiLC) was studied in order to obtain the depth of foundation around a construction site. The results were represented by inversion model resistivity with the draw round of the survey line. The inversion model resistivity from L1-L8 obtained was characterized by resistivity range of 1-8000 ohm-m. This range indicated the presence of silt (10-100 ohm-m), clay (10-100 ohm-m), sandy clay (1-100 ohm-m) and sand (100-3000 ohm-m and 100-800 ohm-m), respectively (Nordiana *et al*., 2017).

This study deals with the electrical resistivity prospecting for groundwater in the area with the aim of locating a suitable point for sitting of borehole by using Schlumberger array with maximum speed of 150m. The inferred data illustrate five different subsurface lithologic units as, lateritic clay, Topsoil/sandy layer, weathered basement, fresh basement and fractured basement. The topsoil/sandy layer (av. resistivity (ρ) of 371Ωm) were thin in most sounding points with thickness between 0.4 and 3m. The lateritic layers have resistivity's that ranged from 19 -3918 Ωm with thickness value of 1–14m while the weathered basement and fractured basement were characterized by resistivity values that ranged from 25 -2030 Ωm and 42-1202 Ωm, respectively. The depths ranged between 3m and 134m in the weathered basement while some fractured basement with others undeterminable had ranged 10m–65m. The fresh basement encountered in some of the sounding points represents the bedrock and the fifth layer. The geo-electric curves in the area are complex with HAK and KHK dominant. The curve types signified the occurrence of fractures in the bedrocks of the study area. Based on the interplay of the combinations of overburden materials with the fractured basement VES 3 with fractured layer resistivity of 593 Ωm and undeterminable depth was considered most suitable for drilling of borehole in the study area (Talabi *et al*., 2016).

The main objective of this study is to compare the schlumberger electrical resistivity method with Wenner method for investigation related to groundwater. Wenner and Schlumberger method in which four electrodes pattern of geophysical electrical surveys were conducted out at selected sites to monitor the resemblance in terms of its employ and management on site. Region wise lithologs was prepared for both methods. The comparative study suggested that Wenner method was handier for calculation and interpretation its major constrain was that it required lateral length on the other hand. The application of Schlumberger method was simple but its interpretation was complex. The work fully justify that the water resource evaluation can be determined by the applicability of geophysical technique. It can also be applied in similar geological setup elsewhere (Vasantrao *et al*., 2017).

The traditional methods of ground water explorations were compared with the electrical resistivity method (ERM). The comparison suggested that ERM provides wide-ranging and persuasive output and is optimum in respect of data coverage, price, and time on the other hand conventional technique is only drilling point specific. Some additional information can be obtained from ERM results that include source of water supply, pollutants in groundwater and leachate (Riwayat *et al*., 2018).

Groundwater exploration in a city of Nigeria was carried out to find high yielding aquifers by using a Schlumberger electrode array. The results indicated that southwestern (VESs 13 and 14) and the eastern (VESs 1, 2, 8, 10, and 11) regions were linked with high groundwater yield. Boreholes having depth average equal to 22 m could be drilled on these axes. The groundwater potential of the southern (VES 12), central (VES 9) and northern (VES 5) parts had medium potential. The depth of the borehole drilling coul`d be enhanced to the depth of 30 m, with groundwater yield in medium range. though, the western (VESs 6, 7, 15, and 16) and the northeastern (VES 3 and VES 4) zones were characterized by low groundwater potential. The characterization of aquifer can be done correctly using resistivity sounding (Adagunodo *et al*., 2018).

Study area description

Havelian and Sanjwal Cantt were selected with 2 and 3 sites (**Figure 1**) for this study respectively. Havelian is located on the Karakoram Highway, about 15.5 kilometres south west of Abbottabad. The location coordinates of Havelian Cantt are 34.0359° N and 73.1158° E. Havelian is the second largest municipality in Abbottabad District, Khyber Pakhtunkhwa (KPK). Sanjwal Cantt is located in vicinity of Artillery Centre, at a distance of about 08 kilometres from Attock city, Attock district. The location coordinates of Sanjwal Cantt are 33.7854° N and 72.4169° E. District Attock is in the north-west Punjab Province of Pakistan. Among all 5 sites, site no. 1 was situated at western site of the residential colony in camping ground (Latitude: 34.041033, longitude: 73.134647) and site no. 2 was situated at road side of the residential estate in Sultanpur cantt area (Latitude: 34.034305, longitude: 73.117756) for Havelian while 3 sites at Sanjwal cantt, which was residential area of Sanjwal Cantt with site no. 1 (single E type quarter, (Latitude: 33.798436, longitude: 72.424053), site no. 2 (Welfare club, Latitude: 33.788548, longitude: 72.406008) and site no. 3 (near old market, Latitude: 33.790997, longitude: 72.404615), respectively.

Materials and Methods

The resistivity surveys were conducted at 02 different sites in Havelian cantt and at 03 different sites in Sanjwal cantt (**Figure 3**) for installation of tube well for water supply scheme in the residential area by means of Schlumberger electrode configuration (SEC) technique to assess/ judge the area in such a way that all the sides and central portion of the area could be covered for correlating the subsurface hydrologic conditions.

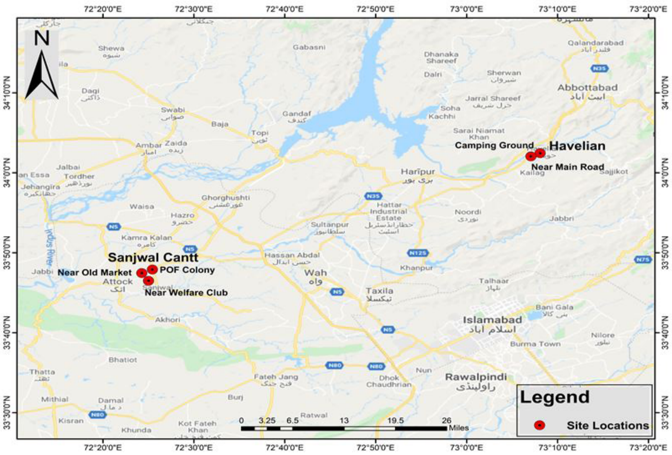

Figure 1: *Study area map (Havelian Cantt and Sanjwal Cantt).*

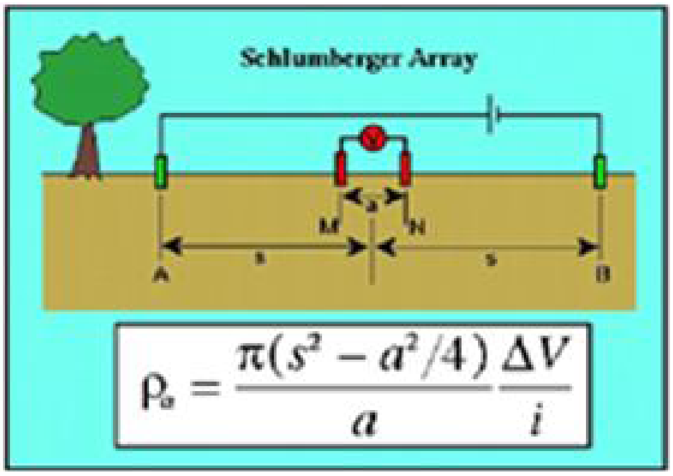

Figure 2: *Schematic diagram for Schlumberger array configuration.*

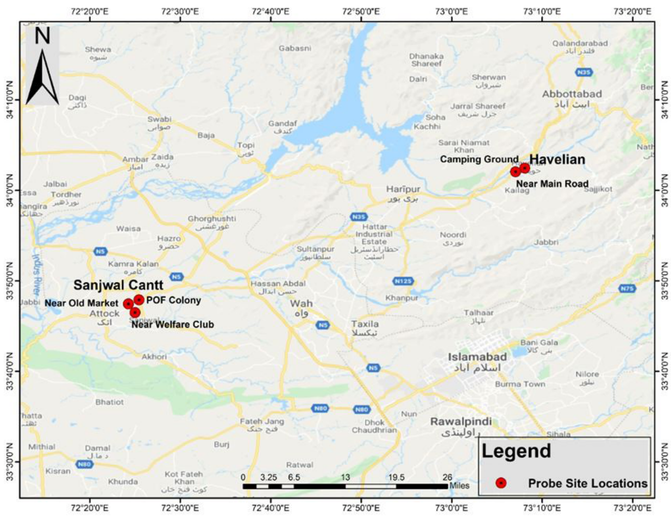

Figure 3: *Electrical resistivity survey probes sites of Havelian Cantt and Sanjwal Cantt.*

The field procedure was that the subsurface resistivity is calculated based on measured voltage drop between the electrodes and given current flow (Figure 2). Results of ERS were derived from the computer generated model in which measurements taken in field are utilized and these results were referred to as the apparent resistivity. The lateral and vertical variations in resistivity of subsurface formation with respect to the groundwater potential are discovered using resistivity profiles. The potential and current value are measured in the field using SARME (Signal averaging resistivity measuring equipment). The plot of apparent resistivity values against depths on a log paper provided the resistivity field curves. After smoothing the plotted curves, the field data was entered in computer for interpretation using 1X1D software. The layer models were calculated by the iteration procedures. The model parameters were adjusted and deviation of corresponding curve from the measured curve was checked during the iteration. Root mean square error (RMS) was used to define the deviation. At the end of calculation, the model, which results in the smaller error, was plotted showing layer's true resistivity with corresponding thickness. The interpreted true resistivity of surface layers of the area was utilized to estimate electrical conductivity of the ground water for the interpreted layers.

Results and Discussion

Electrical resistivity survey (ERS) was conducted at 2 different areas with different 5 sites for getting comprehensive and effect oriented result. 2 sites at Havelian cantt and 3 sites from Sanjwal cantt were taken to conduct ERS.

Electrical resistivity survey at Havelian Cantt sites

ERS result of site No. 1: The result of ERS of site no. 1, which was situated at western site of the residential colony in camping ground, is shown in Table 1 and S-1 is shown in Figure 4.

As the result of site no. 1 is, concerned, top surface of the layer 0-3 ft. was composed of compacted hard clay with conserved moisture which was surficial material. The underground strata of depth 03-26 ft and 26-72 ft. had the true resistivity of 1352.00 and 100.00 ohm-m respectively and composed of layers of hard dry clay with stone/boulder or sand stone in the dry condition being above from the water table.

The formation having the range of 72-460 ft. had true resistivity of 56.00 ohm-m, which indicates presence of dominance of sand-stone mix of sand gravel/boulder with alternate thin layers of clay containing moderate yield of water. The formation had the good porosity and drainage capacity i.e. the moderate permeability which could drain the good quantity of potable water. This was due to the presence of gravel/boulder as major constituents of the formation. This zone also contained the seepage water.

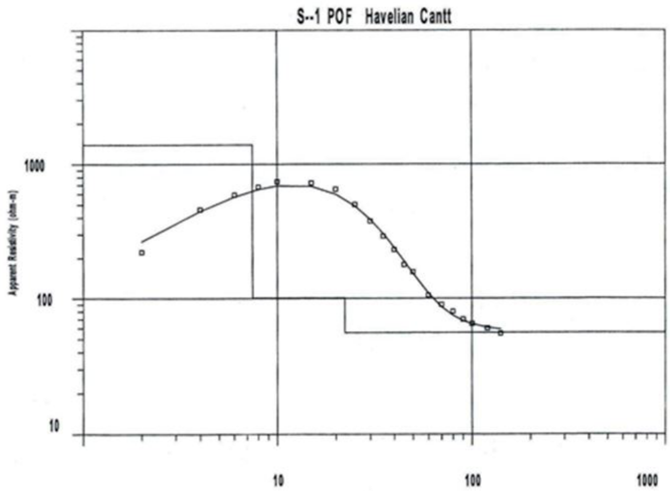

Figure 4: *S-1 of Havelian Cantt site.*

ERS result of site no. 2: The result of ERS of site no. 2, which was situated at road side of the residential estate in Sultanpur cantt area, is shown in Table 2 and S-2 is shown in Figure 5.

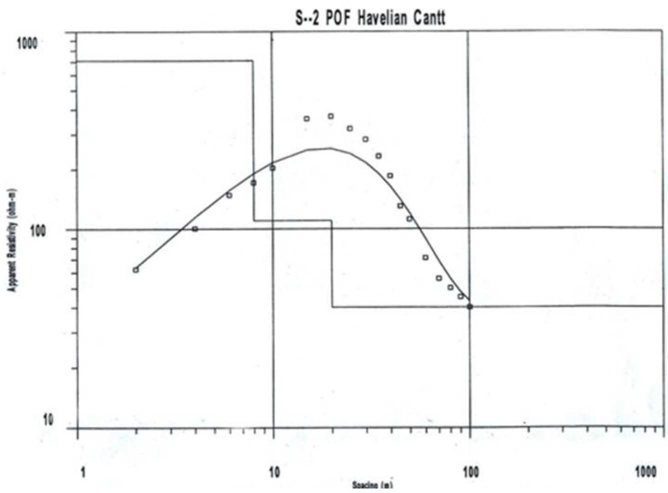

Figure 5: *S-2 of Havelian Cantt site.*

The site no. 2, situated near the main road, had the similar results as site no. 1. The only difference was thickness of water bearing formation. The thickness of water bearing strata at site no. 2 was more than that of site no. 1. Moderate yield of water was available in the zone from 66-460 ft. The deep zone beyond the depth of 66 ft. had the dominance of sand stone

Table 1: *ERS result at site no.1 (camping ground).*

No	Depth (Meter feet)	Resistivity (Ohm –M)	Interpretation
1	0 - 1 to 0 - 3	125.00	Compacted clay with conserved moisture (surficial material).
2	1 – 8 to 3- 26	1352.00	Hard dry stone mixed with clay.
3	8 - 26 to 26-72	100.00	Dominance of dry stone with clay.
4	26-140 to 72-460	56.00	Dominance of sand with gravel and boulder or sand stone with thin layers of clay with alternate position containing water.

Table 2: *ERS result at site no. 2 (near main road side).*

No	Depth (Meter feet)	Resistivity (Ohm –M)	Interpretation
1	0 - 1 to 0 - 3	34.00	Compacted clay with conserved moisture (surficial material).
2	1 - 8 to 3 - 26	710.00	Hard dry stone mixed with clay.
3	8 - 20 to 26-66	110.00	Dominance of sand stone/ sand gravel with clay.
4	20-140 to 66-460	35.00	Dominance of sand with gravel and boulder or sand stone with thin layers of clay with alternate position containing water.

Table 3: *Correlation of resistivity and water content for soil strata.*

Name of zone	Resistivity (Ohm-M)	Correlation with geological formation and water content quality
Low resistivity zone	0 - 30	This zone yields the presence of clay with thin layer of sand-store or gravel /boulder with little ground water potential
Medium resistivity zone	31 – 100	This zone is interpreted as intermix of sand stone/gravel + sand + boulder with clay layers having good quality water with medium yield when below water table
High resistivity zone	100 – 250	This zone reveals existence of boulders, gravels and sand with some impervious material like clay, silty clay with good quality of water with high yield when below water table
Very high resistivity zone	> 250	This resistivity zone indicates presence of dry boulders if above water table and hard rock if below water table. This zone can hardly yield any groundwater potential in this area.

mixed with sand, gravel/ boulder with alternate thin layers of clay containing moderate yield of water. The porosity and drainage capacity of the zone like the previous one was good which could provide the good yield of potable water.

A comparison of both probes sites ERS also shown in the shape of Lithological column,that reflects underground strata. The interpreted lithological column of Havelian Cantt sites (no. 1 and no. 2) are shown in the Figure 6.

Low resistivity values of soil showed presence of water content where as high resistivity values were indicative of hard and dry rock. The comparison of the geological formation against the resistivity values is shown in Table 3.

The site selected for installation of tube well was camping ground mentioned at site no. 1 above, in the light of E.R.S and geophysical study of already installed tube wells. A test well logged at site up to a vertical depth of 105m (344 ft). Bore was drilled up to 360 ft., but due to settling of mud and cuttings at bottom, it was logged up to 344 ft. The detail of it was as:

Filter length 120-0 inch, Blind pipe length 230-0 inch and total lowering 350-0 inch.

Trial test well indicated good hydraulic characteristics of the subsurface material. Aquifers mainly comprised of the gravels, boulders and big boulders encountered at different horizons with good porosity, permeability and capability of storage of groundwater. Recharge ability of groundwater of the area was good due to the Doar River in vicinity. A tube well installed in this area would give high yield. Expected discharge would not be less than 0.75 to 0.85 cusecs.

Table 4: *ERS result at site no. 1 (single E type quarter).*

No	Depth (Meter feet)	Resistivity (Ohm –M)	Interpretation
1	0 - 1 to 0 - 3	317.00	Dry clay with boulder, sand particles containing conserved moisture (surficial material).
2	1 - 18 to 3-59	438.00	Dominance of dry sand, gravel/boulder with alternate thin layers of clay.
3	18-140 to 59-460	86.00	Dominance of sand, gravel and boulder with alternate thin layers of clay containing moderate water.

Table 5: *ERS result at site no. 2 (Welfare club).*

No	Depth (Meter feet)	Resistivity (Ohm –M)	Interpretation
1	0 - 1 to 0 - 3	26.00	Dry clay with sand, sand stone particles containing conserved moisture (surficial material).
2	1-15.5 to 3 - 51	364.00	Dominance of dry sand, gravel/boulder with alternate thin layers of clay.
3	15.5-140 to 51- 460	8.00	Dominance of clay/shale with alternate very thin layers of sand/sand stone containing very/poor yield of water.

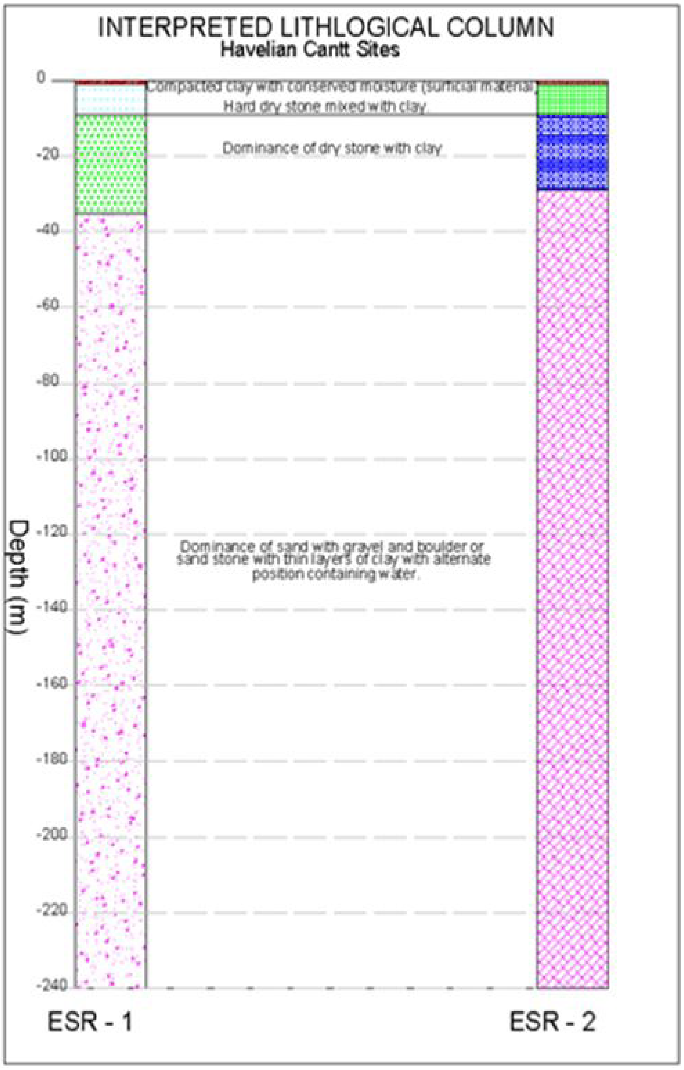

Figure 6: *Interpreted lithological column of Havelian Cantt sites.*

Electrical resistivity survey at Sanjwal Cantt sites

There were 3 sites at Sanjwal cantt where ERS was conducted. All the sites were located in the residential area of Sanjwal Cantt. The detail ERS of each site is shown in Tables 4, 5, and 6. and their, respective S-1, S-2 and S-3 are shown in Figures 7, 8 and 9, respectively.

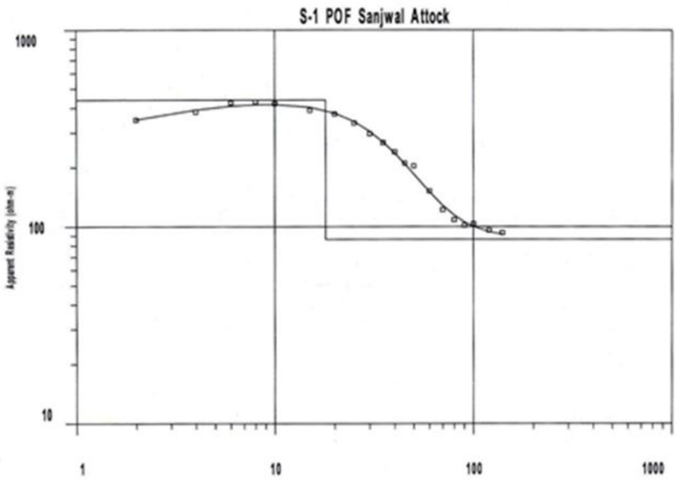

Figure 7: *S-1 of Sanjwal Cantt sites.*

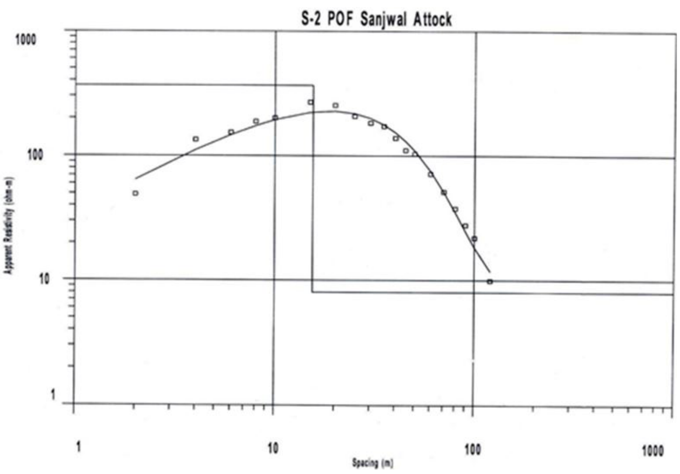

Figure 8: *S-2 of Sanjwal Cantt sites.*

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Table 6: *ERS result at site no. 3 (near old market).*

No	Depth (Meter feet)	Resistivity (Ohm –M)	Interpretation
1	0 - 4 to 0 - 13	128.00	Dry clay with sand, sand stone particles containing conserved moisture (surficial material).
2	4 – 12 to 13- 40	128.00	Dominance of dry sand, gravel/boulder with alternate thin layers of clay/shale.
3	12 - 140 to 40- 460	25.00	Dominance of clay/shale with alternate thin layers of sand/ sand stone containing low to moderate yield of water.

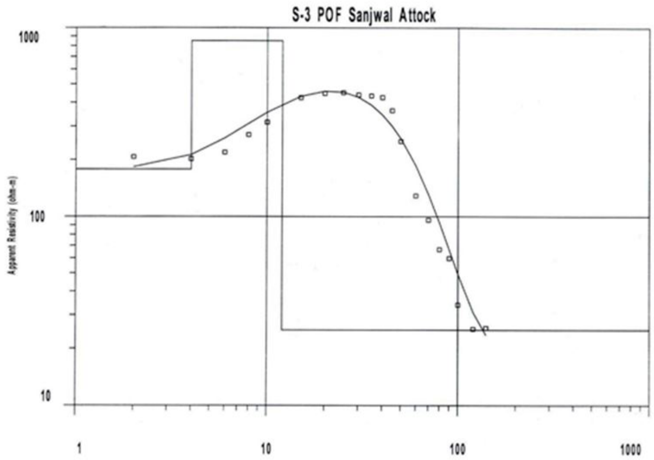

Figure 9: *S-3 of Sanjwal Cantt sites.*

The result of site no. 1 depicted that the top surface of the layer 0-3 ft was composed of dry clay with minute quantity of boulder and conserved moisture which was surficial material. The underground strata 03-59 ft showed the true resistivity of 438.00 ohm-m, composed of layers of dry sand with gravel/boulder and thin layers of clay in the dry condition being above the groundwater table (GWT).

The formation contained the range of 59-460 ft had true resistivity of 86.00 ohm-m, which indicated presence of dominance of sand-stone mix of sand gravel/ boulder with alternate thin layers of clay contained moderate yield of water. The formation had the good porosity and drainage capacity i.e. the moderate permeability which could drain the good quality of potable water. This was due to the presence of gravel/ boulder as major constituents of the formation. This zone also contained the seepage water.

The result of site no. 2 depicted that the top surface of the layer 0-3 ft was composed of dry clay with minute quantity of boulder and conserved moisture which was surficial material. The underground strata 03-51 ft contained the true resistivity of 364.00 ohm-m, composed of layers of hard dry sand with gravel/ boulder or sand stone in the dry condition of clay being above from the groundwater table.

The formation contained the range of 51-460 ft had true resistivity of 8.00 ohm-m, which indicated presence of dominance of sand-stone mix of gravel/ boulder with alternate thin layers of sand contained poor yield of water. The formation had the poor porosity and drainage capacity i.e. the low permeability which could drain the little quantity of potable water. This was due to the presence of sand as major constituents of the formation.

The result of site no. 3 depicted that the top surface of the layer 0-13 ft was composed of dry clay with minute quantity of boulder and conserved moisture which was surficial material. The underground strata 13-40 ft contained the true resistivity of 128.00 ohm-m, composed of layers of hard dry clay with stone/boulder or sand stone in the dry condition being above from the water table.

A lithological comparison for these three probes sites are shown in lithological column, which reflects underground strata. The interpreted lithological column of Sanjwal Cantt sites (no. 1, 2 and 3) are shown in the Figure 10.

The formation of 40-460 ft had true resistivity of 25.00 ohm-m, which indicated presence of dominance of sand-stone mix of sand gravel/ boulder with alternate thin layers of clay contained moderate yield of water. The formation had the good porosity and drainage capacity i.e., the moderate permeability that could drain the good quality of potable water. This was due to the presence of gravel/ boulder as major constituents of the formation. This zone also contained the seepage water.

ERS at sites no. 1 and 3 were underlined by similar type of subsurface litho logy and not much different than each other. Both of the sites had moderate potential of water. These sites can be explored for groundwater development as these sites can provide good yield of continuous groundwater supply to fulfill the drinking water requirement of the clients. But the site no. 2 was bit different than other both the sites and had weak/ low groundwater potential contained low yielding/ water bearing formation because the deep zone of the site had clay/ shale as major content of the formation.

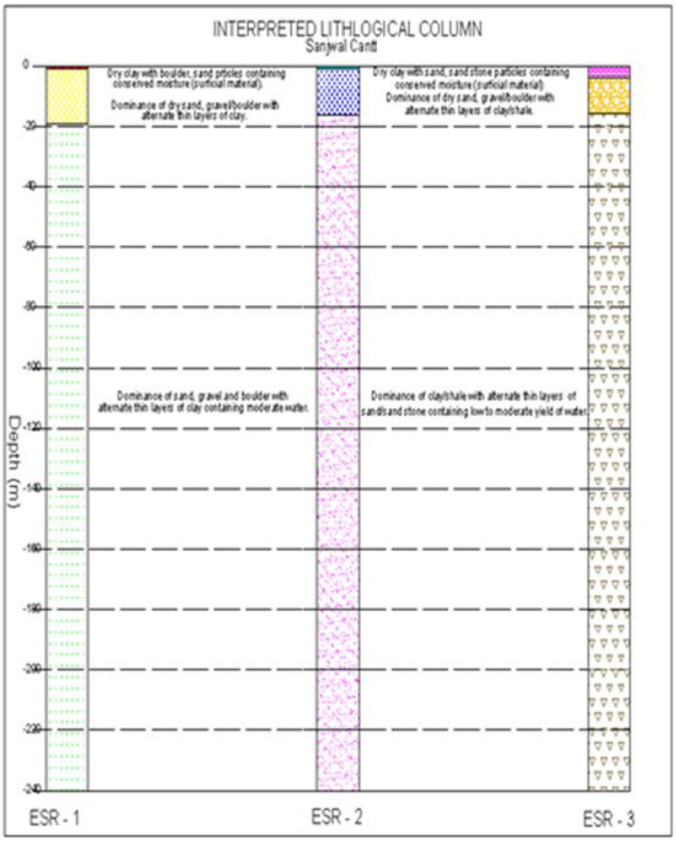

Figure 10: *Interpreted lithological column of Sanjwal Cantt sites.*

Prevailed hydro-geological setting indicated that there was no water quality problem in the area and amount of precipitation as well as physiographic was indicative of good natural annual recharge.

There existed good groundwater potential at sites no. 1 and 3. The groundwater could be exploited by the installation of the deep tube well at these sites. The drilling of deep trial bore was recommended at site no. 3 (near old market) up to depth of 450-500 ft. The potential of water in trial well might be checked with pump if found moderate or good yielding before it might be converted into tube well.

The design of each well may be based on the geophysical well logging for obtained optimum yield for wells. The water samples might be collected from different depths and tested for chemical and biological parameters before utilization.

Electrical resistivity survey at P.M colony Sanjwal cantt

The site of P.M colony was located adjacent to residential colony. ERS indicated that sub surface litho logy was dominated by clay and gravel boulder complex with dominance of sandy soil. The subsurface litho logy along the groundwater channel was almost similar to residential colony. The water quality seems to be very good with TDS in the range of 500 mg/ l.

Keeping in view the foregoing, point near overhead reservoir was recommended for trial bore hole drilling up to a depth of 350 ft followed by electrical logging and yield test to access the ground water potential and quality at that location. The detail was as: Filter length 120-0 inch, Blind pipe length 230-0 inch, Total lowering 350-0 inch. Subsurface lithology of the trial bore is given in Table 7.

Table 7: *Subsurface lithology of a trial bore in Sanjwal Cantt (E.R.S site no. 3).*

Range (m)	Range (ft)	Loca-tion	Description	Lithology
0-27	0-89	-	Blind pipe	Dry clay /Boulder.
27-62	89-205	-	Blind pipe	Mix of coarse, medium sand.
62-104	205-340	210-270	Filter 60 ft	Gravel-Boulder.
do	do	270-290	Blind pipe	---do---
do	do	290-330	Filter 40 ft	---do ---
104-128	340-420	330-340	Bail plug 10 ft	Bed Rock

Trail bore was studied up to the depth of 420 ft (120 m) as depicted by the table. This indicated good hydraulic characteristic of subsurface material. Three types of the lithologies composed of coarse sand mixed with gravel, mix of gravel/ boulder and bed rock in deep zone had been encountered in it. The permeable layers comprised of sand/ gravel/ boulder were encountered at different depths with good quantity and quality of water. E.R.S indicated good water bearing characteristics of soil in the deep horizons and confirmed aquifer in the area. The zone highlighted in the above table had water bearing formation indicating good water bearing capacity. The yield test with air compressor was conducted which resulted about 780 GPh (2 cusecs) of drinking water. Keeping in view the formation and interpreted depths the installation of submersible pump would be the suitable device of pumping purposes.

Conclusions and Recommendations

- The area situated along the Doar River had shallow groundwater level (GWL) and the tube wells installed in this area have minimum chances for being drying up with the passage of time.
- High permeable formation of strata along the Doar River of Havelian Cantt Distt. Abbottabad gave good yield of ground water.
- The areas away from the Doar River has deep groundwater level (GWL) and has more chances for drying up as recharge to the cone of depression is comparatively less in this area.
- The sandy area of Sanjwal Cantt Distt. Attock has deep groundwater level (GWL) and the Tube well installed in this area does not give good yield due to the less permeability of the formation.
- The durability of the Tube well is more due to the boulder clayey structure of the formation in the Havelian Cantt Distt. Abbottabad.
- The upfront cost for the tube well development is very high in the clayey bolder formation of Havelian Cantt as the diamond cutter is used in drilling the bore.
- The sandy area of the Distt Attock involved less finance as percussion drill was used in drilling the bore in the area.
- In the light of this work, further, working might be carried out in the following outlines:
- The corrosion potential in concrete structures can be accurately identified be measuring electrical resistivity of concrete.
- Relation between the electrical resistivity (ERS) at shallow depths and the bearing capacity (BC) of the soil for engineering design purposes of multistory structure.
- The soil salinity in agricultural lands can be detected by measuring electrical resistivity of the soil.
- The Radius of influence of the existing tube wells.

Novelty Statement

Electrical Resistivity Survey (ERS) is a sound method for measuring ground water level (GWL) in sandy aquifers and boulder clayey formations when GWL is sufficiently deep moreover this method can also be applied in finding corrosion potential in concrete structures, soil salinity in agricultural lands and radius of influence of the existing tube wells.

Author's Contribution

Talat Farid Ahmed: Conceived the ideas of research and conducted experiment.
Muhammad Azeem Afzal: Helped in overall management of aricle, revised and improved the article time to time
Hashim Nisar Hashmi: Provided technical input.
Hafiz Muhammad Yousuf: Prepared initial draft, did data collection and statistical analysis.
Shamim-ul-Sibtain Shah: Helped for manuscript improvement.
Muhammad Atiqullah Khan: Reviewed and corrected the final draft.

Abbreviations
ERS, Electrical Resistivity Survey; SEC, Schlumberger electrode configuration; KPK, Khyber Pakhtunkhwa; GWL, Groundwater level; VES, Vertical Electrical Sounding; SiLC, Southern Industrial and Logistics Clusters; TDS, Total dissolved salts; SARME, Signal averaging resistivity measuring equipment,
BC, Bearing Capacity.

Conflict of interest
The authors have declared no conflict of interest.

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