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Groundwater Characterization Studies Using Electric Resistivity Survey (ERS) in Kirana Hills, District Chiniot, Pakistan

Bilal Ahmad Sarwar[2], Faisal Rehman[1], Mirza Naseer Ahmad[2*], Faisal Rehman[3], Rashida Sultana[2]

[1]Earth Sciences Department University of Sargodha, Sargodha Pakistan
[2]Abdus Salam School of Sciences, Nusrat Jahan College Rabwah, Pakistan
[3]Department of Earth sciences, Quaid-i-Azam University, Islamabad Pakistan

* Email: nmirza@njc.edu.pk

Abstract: This study demonstrates an application of resistivity surveys to understand local hydrological conditions and basement configuration in Kirana Hills region of District Chiniot. Schlumberger configuration has been applied to acquire vertical electrical sounding (VES) data. The apparent resistivity curves were calibrated with theoretical curves to compute true resistivity and depth of different layers. Maps of true resistivity at various depths were generated to study the lateral resistivity variation in the area. VES sounding data were compared with available lithological columns to establish relationship of lithology and resistivity. Resistivity values are laterally variable due to lithology and quality of water. Very low resistivity values were observed within alluvial sediments close to the Kirana Hills due to presence of high Total Dissolved Solids in water. Resistivity value layers in unconsolidated sediments increases in the southern and western parts of the area where relatively better quality of groundwater occurs. In the northern and eastern parts of the study area very high resistivity (greater than 100 Ωm) is recorded at depth greater than 40m that indicates hard rock basement. The resistivity survey in the area is useful to differentiate zones of low and high Total Dissolved Solids groundwater and also determine the zones where subsurface basement is shallow. Therefore, resistivity survey in Kirana Hill regions is helpful in solving hydrological issues of the study area.

Keywords; Vertical electrical sounding, tds, electrical conductivity, borehole.

Introduction

The term groundwater is usually reserved for the subsurface water that occurs beneath the water table in soils and geologic formations that are fully saturated (Freeze & Cherry, 1979). Many major cities and small towns in the world depend on groundwater for water supplies, mainly because of its abundance, stable quality and inexpensive to exploit (Morris et al., 2003). During the past few decades' advancement in industrialization and increase in population, environmental changes have caused the stress on groundwater resources. Growing demand of clean water is fulfilled by the extraction of groundwater. However, the unregulated and excessive extraction is causing environmental impacts on the groundwater quality. Therefore, water resource management is inevitable for conservation and protection of groundwater resources. Several studies have been conducted in different areas of Pakistan for investigation of groundwater quality showing adverse effects of contaminants and uncontrolled drilling on groundwater (Ahmad et al., 2020).

Groundwater prediction, characterization and management require systemic techniques and scientific methods. Numerous researchers around the world have conducted studies on sedimentation and groundwater characteristics using integrated approaches based on geophysical or geological data (Hamzah et al., 2006; Uhlemann et al., 2017; Rusydy et al., 2020). Electrical Resistivity technique is well versed and globally excepted for groundwater management and possess strong and simple methodology to delineate and map groundwater resources. Vertical Electrical Sounding (VES) technique is extensively used in electrical resistivity surveys and applied to a horizontally or approximately horizontally layered earth (Ezema et al., 2020). VES demonstrates as one of the best methods to use for exploration of groundwater and basement detection (Kayode et al., 2016; Anomohanran, 2011; Griffiths & Barker, 1993).

Present study focuses on the Groundwater characterization of Rabwah area of district Chiniot. Most of the area relies on groundwater for domestic and drinking use. Kirana Hills are oldest exposed rocks in Pakistan and randomly exposed in the area. According to Ahmad et al., (2016), in areas close to Kirana Hills and areas where basement is shallow, groundwater quality is poor. The prediction of groundwater is challenge and no systematic study has been carried out to model the subsurface water quality. This study attempts to predict the water quality by using electrical resistivity survey. Moreover, comparison is made with the available physical and chemical data of groundwater.

Study Area

Study area is located in district Chiniot of Punjab province, Pakistan (Fig 1). Geologically, the area lies in Punjab Plains with the exposures of Kirana Hills on the Northern edge and Chenab River on the Eastern border. The Kirana Hills belong to the Aravalli Range, which starts from Delhi and covers a part of Rajasthan

Province in India (Khan et al., 1979). These hills are small in extent, but rise in jagged pinnacles 300m above the plains. The exposures generally comprise of meta-sedimentary and meta-volcanic rocks with the intrusions of sills and dykes, which are the remnants of the extensive Precambrian igneous activity (Chaudary et al., 1999).

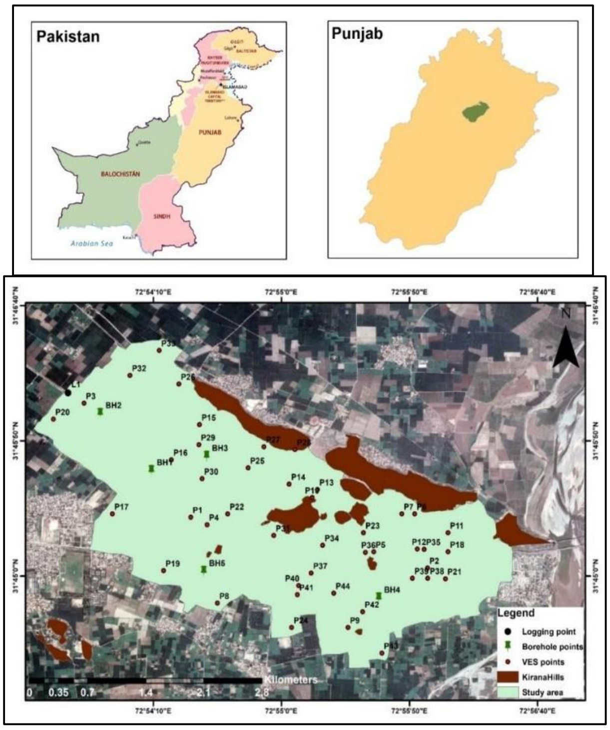


Fig. 1 Study area and locations of resistivity surveys.

Materials and Methods

The VES (Vertical Electrical Sounding) technique was used to collect the resistivity data. This method helped to collect the subsurface geophysical data to the maximum extent and within a short period. VES points were selected according to the availability of suitable places so the spread should be expended to the maximum possible length and it was tried that the study area should be reasonably covered during the survey.

During VES data acquisition, the spread is expended about a fixed central point and electrodes are placed at relative spacing according to selected configuration. VES is widely used to define the overburden thickness in geotechnical surveys and to delineate horizontal zones of porous strata in hydrogeology. The method centers on the principle of four electrodes, which consist of two current and two potential electrodes (Rehman et al., 2016). By gradually increasing the spacing of electrodes according to the selected electrode configuration, the depth of penetration increased. Deep penetration of current provides the apparent resistivity of the deep-seated layers. Common configurations used in the vertical electrical sounding are Wanner, Schlumberger and dipole-dipole arrays.

Resistivity data were acquired on 44 selected sites by using the Schlumberger configuration. PASI (GEA-RM1) equipment was used for VES data collection with a portable battery as a source of electric current. Schlumberger array was selected to conduct geophysical surveys in the field because of its overall effectiveness and field efficiency, especially for the demarcation of groundwater-bearing zones. In the Schlumberger electrode configuration, four electrodes are used. The outer electrodes are current electrodes whereas inner electrodes are potential electrodes. Potential electrodes are placed with a small separation, generally less than 1/5th of the spacing of current electrodes. During the field survey, the separation between the current electrodes is increased, while the distance between potential electrodes remain the same until the observed voltage becomes too small to measure. The Schlumberger array is convenient to use because for each sounding, fewer electrodes are required to be moved and a shorter length of cable is required for potential electrodes. After data collection, the apparent resistivity values were plotted on the log-log scale with IX1D software. The lithology logs were prepared using drill borehole lithology data. Lithology data were compared with electrical sounding data.

Results and Discussion

VES Results

Different acquired VES points show different trends for resistivity. The point P33 is situated in the western part of the study area. The interpreted cross-section of P33 shows four subsurface electrical layers (Fig.2, Table 1). The top most layer has 60Ωm resistivity with the thickness of 3.2m is underlain by very high resistivity layer of 547Ωm which extends to the depth of 11m. Third layer extends to the depth of 42m having resistivity of 20Ωm. The last modeled layer is of 44Ωm resistivity.

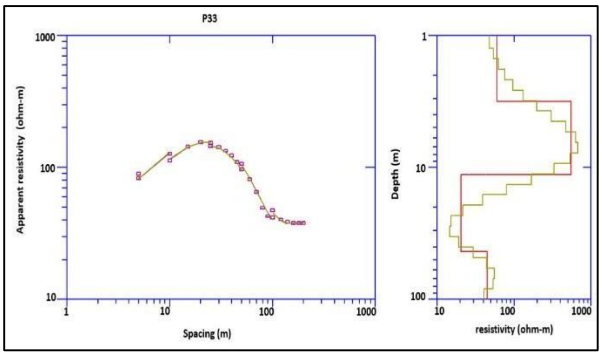


Fig. 2 (a) Resistivity profile (b) red line layered model and green line smooth model.

Table 1 Description of layered model of P33

Layers no.	Resistivity (Ωm)	Thickness (m)	Depth (m)
1	60	3.2	3.2
2	547	8	11.2
3	20	30.6	48.8
4	44		

For interpreting the southwestern part of the study area, P17 was selected. Interpretation of this point revealed four electrical layers (Fig. 3 Table 2). First layer has 15Ωm resistivity and extends to the 1.7m depth. The second layer is very thin (2.1 m) having very low resistivity (5 Ωm). Third layer has relatively high resistivity of 64Ωm and its thickness is approximately 9m. The fourth and last interpreted layer has low resistivity (10 Ωm).

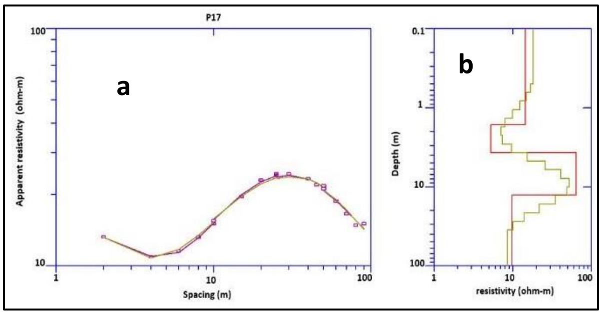


Fig. 3 (a) Resistivity profile (b) red line layered model and green line smooth model of P17.

Table 2 Description of layered model of P17.

Layers no.	Resistivity (Ωm)	Thickness (m)	Depth (m)
1	15	1.7	1.7
2	5	2.1	3.8
3	64	9	12.8
4	10		

Geographically P28 is located close to the Kirana Hills in the central part of the area. Resistivity data of this point indicates four subsurface electrical resistivity layers (Fig. 4, Table 3). Layer 1 has 18Ωm resistivity with the thickness of 2.8m. The resistivity of second layer is 3Ωm and it extends to the depth of 8.5m. The third layer has high resistivity of 49Ωm in comparison to upper layers and stretches to the depth of 23.5m. The fourth layer has extremely low resistivity (2Ωm).

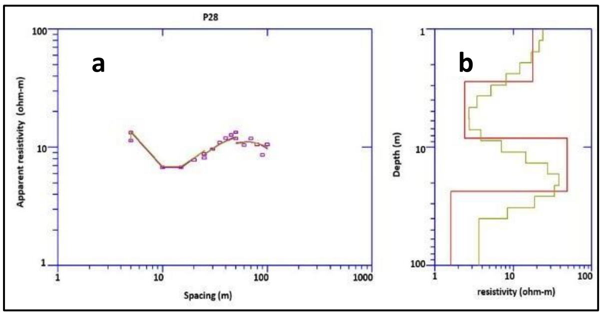


Fig. 4 (a) Resistivity profile (b) red line layered model and green line smooth model of P28.

Table 3 Descriptive layered model at VES point P28

Layers no.	Resistivity (Ωm)	Thickness (m)	Depth (m)
1	18	2.8	2.8
2	3	5.6	8.4
3	49	15.1	23.5
4	2		

Point P18 is located in eastern part of the study area. Interpreted model of this point yields four electrical layers (Fig.5, Table 4). Topmost layer has the 100Ωm resistivity with the thickness of 1.9m and extends to the depth of 1.9m from the surface. Layer 2 ranges from 1.9m to 5.6m depth and has 316Ωm resistivity. Layer 3 stretches to the depth of 59.2m with the resistivity of 10Ωm. Last layer has 49Ωm resistivity.

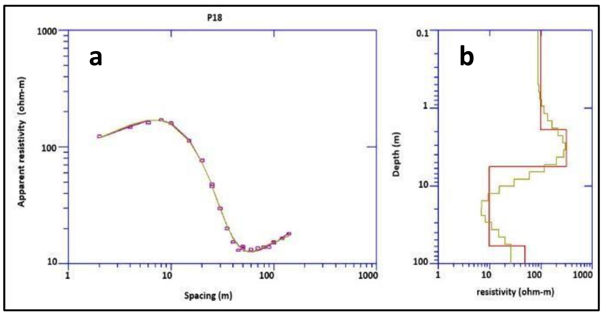


Fig. 5 (a) Resistivity profile (b) red line layered model and green line smooth model of P18.

Table 4 Interpreted layers at P18.

Layers no.	Resistivity (Ωm)	Thickness (m)	Depth (m)
1	100	1.9	1.9
2	316	3.7	5.6
3	10	53.6	59.3
4	49		

As selected points are discussed above, results of remaining points are given in the Table 5.

VES No.	1st layer resistivity(ρ1) (Ωm)	2nd layer resistivity(ρ2) (Ωm)	3rd layer resistivity (ρ3) (Ωm)	4th layer resistivity (ρ4) (Ωm)	1ST layer Depth (D1) (m)	2nd layer Depth (D2) (m)	3rd layer Depth (D3) (m)	RMS layer model	RMS smooth model
P1	4.2	1.6	6.7	-	3.1	11.3	-	5.71	2.99
P2	15.0	7.2	9.2	-	4.3	31.8	-	6.23	3.93
P3	13.8	99.5	20.5	-	2.4	12.6	-	1.04	1.02
P4	7.3	1.1	87.8	4.1	2.2	3.4	6.5	8.64	9.03
P5	20.0	12.3	6.2	10.6	2.0	10.1	47.0	4.96	0.96
P6	36.0	4.8	475.9	-	1.1	14.1	-	5.24	3.68
P7	26.0	10.0	2.4	7.6	0.9	5.6	14.8	1.69	1.68
P8	23.0	75.7	41.9	8.0	2.7	8.6	32.4	3.36	3.24
P9	6.4	0.6	146.3	0.9	1.8	4.3	10.0	26.60	27.64
P10	7.2	1.7	525.6	14.4	2.3	8.9	44.0	11.56	11.57
P11	6.8	3.2	130.6	5.9	4.2	21.2	3258	5.87	5.62
P12	51.1	325.0	6.0	-	0.8	3.1	-	2.67	2.48
P13	4.9	15.8	1.3	10.0	0.6	4.8	24.8	4.37	5.38
P14	41.4	124.8	32.4	1.7	1.1	3.6	29.0	4.53	4.68
P15	5.9	35.9	7.3	-	7.8	16.2	-	4.92	4.07
P16	54.1	159.2	12.7	3.5	1.5	9.1	48.6	15.60	14.85
P17	14.5	5.2	63.7	9.9	1.6	3.7	12.6	2.09	2.73

P18	100.0	316.3	9.9	48.8	1.9	5.6	59.2	3.81	3.92
P19	32.6	5.0	155.3	1.6	1.0	3.1	8.2	7.21	8.84
P20	17.2	282.7	18.1	-	1.3	8.0	-	3.71	5.92
P21	20.8	42.8	9.7	-	0.8	16.6	-	5.08	5.05
P22	8.4	2.0	7.2	12.0	2.7	5.7	66.8	2.43	1.97
P23	25.7	4.5	14.6	-	3.1	44.6	-	6.64	6.29
P24	18.1	127	31.5	15.5	0.8.	2.8	13.4	3.39	3.70
P25	6.6	2.3	23.7	7.0	3.6	7.3	14.3	4.83	5.08
P26	24.7	1.9	227.4	-	2.7	17.4	-	5.70	6.48
P27	11.9	2.2	20.8	5.4	2.5	6.6	14.6	4.19	4.57
P28	17.7	2.4	48.9	1.6	2.8	8.4	23.5	6.98	7.62
P29	7.3	1.4	46.2	-	3.9	9.1	-	4.40	4.30
P30	7.7	1.8	9.9	3.7	2.6	8.5	34.7	2.54	2.44
P31	14.0	4.4	462.2	-	6.2	56.8	-	3.51	2.41
P32	70.4	317.0	23.1	-	4.8	13.3	-	2.23	2.12
P33	59.9	547.2	20.5	44.5	3.2	11.3	43.2	2.90	2.88
P34	4.2	11.8	2.9	351.0	2.2	4.2	55.2	8.81	8.58
P35	8.2	1.9	7584	21.7	16.8	33.9	157.9	7.43	7.06
P36	1266	208.6	10.2	-	6.2	11.9	-	12.01	13.51
P37	13.3	9.3	16.3	-	11.7	39.7	-	3.21	1.18
P38	38.1	10.1	21.8	-	6.0	60.3	-	3.07	2.24
P39	13.7	6.3	19.0	-	7.4	26.9	-	3.70	1.16
P40	5.1	50.3	6.7	-	1.5	5.0	-	7.61	7.42
P41	16.5	3.2	127.8	-	6.0	36.7	-	3.88	4.02
P42	18.1	6.7	31.2	-	6.5	28.2	-	2.84	1.37
P43	8.6	262.8	-	-	18.1	-	-	2.92	2.14
P44	3.5	15.6	-	-	5.0	-	-	10.91	10.87

Comparison of Borehole and VES data

Comparison of four boreholes with the near most VES points is given below.

Comparison of Borehole (BH1) with VES point (P16)

Borehole (BH1) was drilled in the central western part of the study area (Fig. 1). VES point that was acquired near this borehole is P16. Correlation is given in the Figure 6. The extension of current electrodes AB/2 for P16 was 100m. Layer model of P16 shows four distinctive layers. Layer 1 extends from 0-1.5m depth with the resistivity of 52Ωm. In contrast with borehole, this layer comprises of sandy soil. The thickness of the second layer is from 1.5m to 9.1m with the resistivity of 160Ωm. According to borehole, this layer comprises of sand. The third layer has the resistivity of 13Ωm and thickness of 39.4m. It ranges from 9.1m to 48.6m depth. Comparison of the third layer with borehole exposes that it mainly comprises of sand with small-intercalated layers of clay. The second and the third layer have almost the same lithology with a huge difference in resistivity values. This may be due to the poor quality water content in the lower layer, which is below the water table (10 to 15 m) in the study area.

The last layer shows very low resistivity (4Ωm), whereas, the borehole data indicates this layer is mostly comprised of clay.

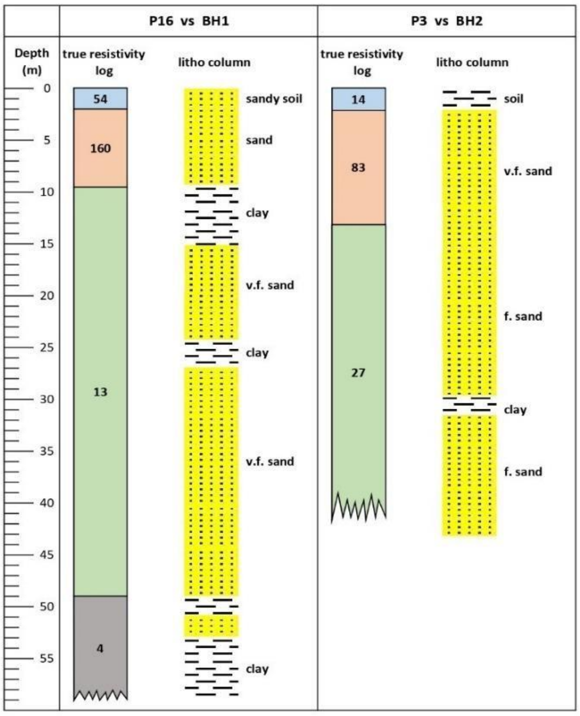


Fig. 6 Correlation of VES P16 vs BH1 and VES P3 vs BH2.

Comparison of Borehole (BH2) with VES point (P3)

The borehole BH2 lies in the western edge of the study area and VES P3 is a resistivity point closest to the BH2 (Fig 1). Correlation is shown in the Fig 6. The range of AB/2 for P3 was 50m. VES (P3) indicates three layers until the depth of 40m to 45m. The first layer ranges from surface to 2.4m depth having resistivity of 14Ωm. Comparison of first layer with borehole indicates the soil. The second layer has the thickness of 11m and is ranging from the depth of 2.4m to 13.2m with the resistivity value of 83Ωm that in comparison with the borehole data indicates the sand layer. Layer 3 has the 27Ωm resistivity and ranges from 13.2m onward. Layer 2 and 3 have almost the same strata but difference in resistivity values is observed. This is due to the presence of water in the lower resistivity layer.

Comparison of Borehole (BH3) with VES point (P29)

BH3 is situated in the north of central part of the study area and lies near the VES point P29 (Fig 1). Correlation of P29 and BH3 is given in the Figure 7. Because of limited space for resistivity spread expansion, the value of AB/2 for P29 is 40m only. Layer model of P29 shows three distinctive layers. First layer have the resistivity of 8Ωm with the depth of 3.9m from the ground surface. First resistivity layer represents the silty and clayey soil. Layer 2 thickness ranges from depth of 3.9m to 9.1m with the very low resistivity of 2Ωm. This layer completely comprises of clay. The third layer comprises of sand with the resistivity of 48Ωm. Depth is ranging from 9.1m onward.

Comparison of Borehole (BH4) with VES point (P42)

BH4 is located in southeastern part of the study area and P24 is almost 20m away from the borehole. Value of AB/2 for VES point is 50m. Comparison of P42 and BH4 is shown in the Figure 7. Layer model of P24 reveals three layers. Layer 1 has 18Ωm resistivity and ranges from ground surface to 6.5m depth. In contrast with borehole, it comprises of sandy soil. The second layer is 21.7m thick ranging from 6.5m to 28m. It has 7Ωm resistivity. By comparing with borehole log, it shows the clay deposits. The third layer has resistivity of 31Ωm. The major part of the layer comprised of sands.

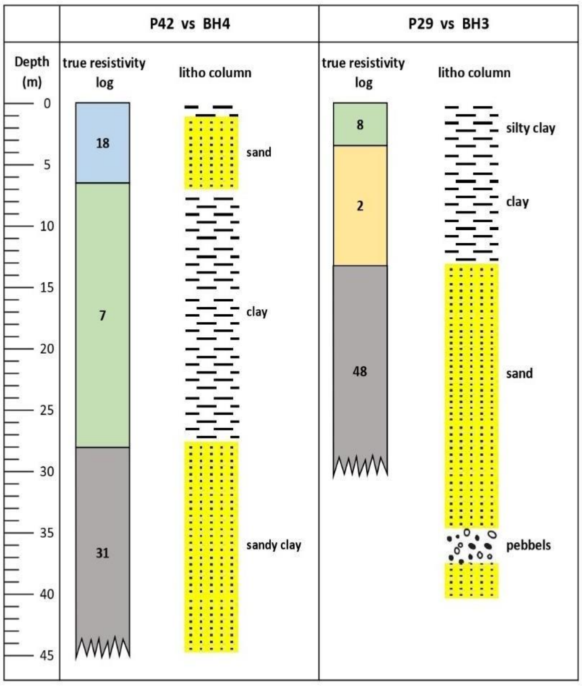
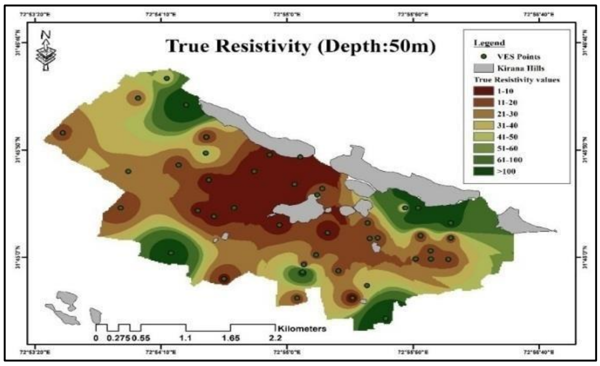


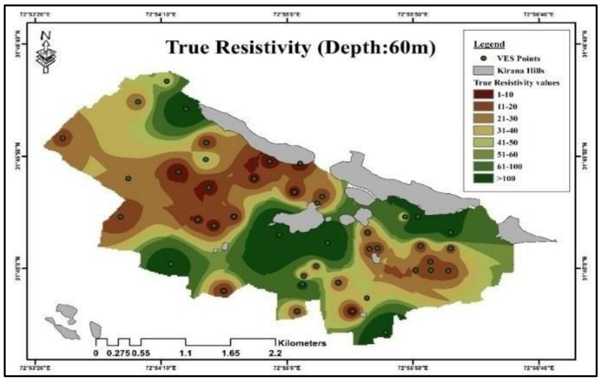
Fig. 7 Correlation of P42 vs BH4 and P29 vs BH3.

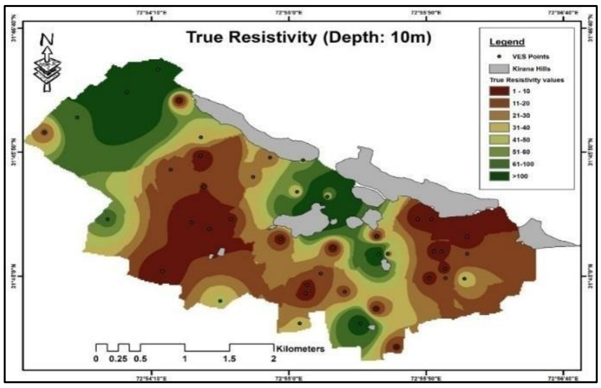
True-Resistivity Maps

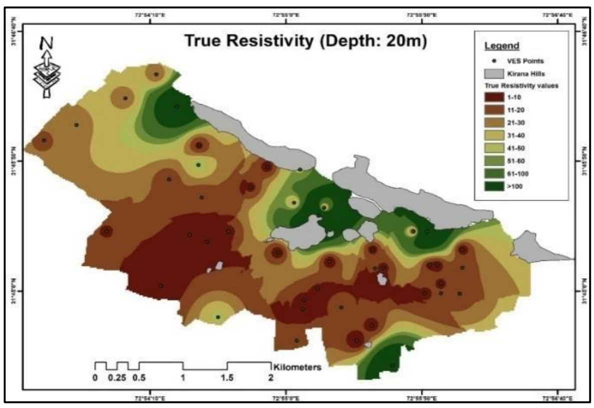
True resistivity map shows the variation of subsurface resistivity values. These maps provide the information about lateral and horizontal variations of subsurface resistivity and provide aid for studying and understanding of subsurface lithological changes. True resistivity maps have been prepared by using the Arc GIS software for the depths of 10m, 20m, 30m, 40m, and 60m.

Map of 10m depth shows the concentration of low resistivity values that ranges between 1Ωm to 30Ωm in the central and eastern parts while the western parts have high resistivity contours with the values of greater the 60Ωm (Fig. 8). Some points of the central area that lies-in between the Kirana Hills exposures have relatively high resistivity. True resistivity values decrease in the study area as depth increases (Fig. 9), except few points, which lie in vicinity of these hills, other all points have low to very low resistivity contours less than 30Ωm. Conditions of resistivity distribution at the 40m depth (Fig. 11) are almost same as 30m except the eastern part, which is most promising beacause greater than 100Ωm resistivity values.









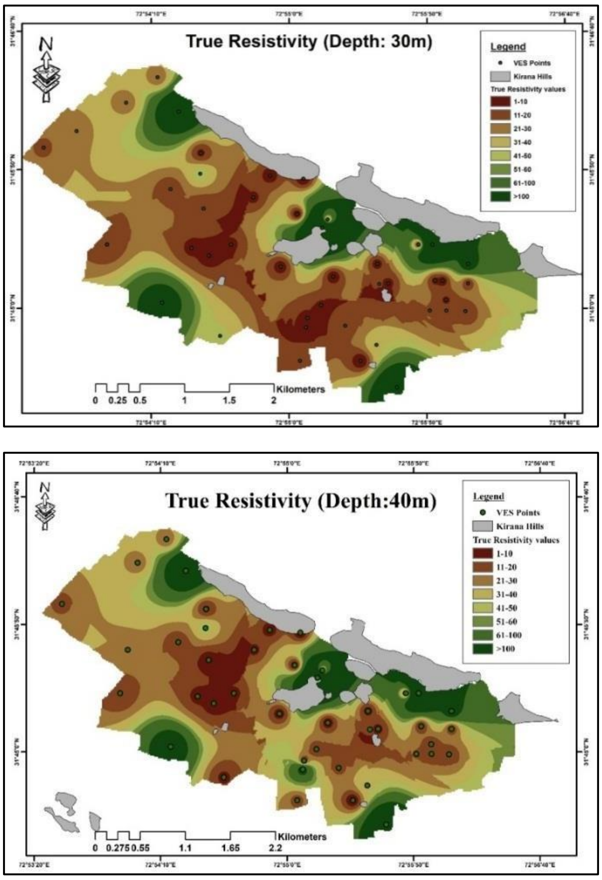


Fig. 8 True resistivity maps at depth of (a) 10m (b) 20m (c) 30m (d) 40m (e) 50m (f) 60m.

The 60m depth map shows increase in resistivity near the exposure, which is in the center of the study area. Very high resistivity values greater than 100Ωm indicate presence of basement rocks. The low resistivity values less than 10Ωm indicate presence of clay with saline water (Fig.12).

Pseudo Sections

Four true resistivity pseudo sections were created in different part of the area (Fig. 9). Pseudo section profile A is in the western part of the area, which comprised of VES points P33, P32, P3, and P20 from north east to south west. The value of resistivity is in the same range. True resistivity ranges from 80 Ωm to 150Ωm. At the depth of 65m the resistivity is relatively low which is in the range of 25 to 35Ωm. The profile B is directed in NNW-SSE direction. This profile is comprised of points P15, P29, P30, P1, P4 and P8. The resistivity values are extremely low in the northern part of the area until point P4 (less than 15 Ωm). In the southern part of the profile, resistivity values gradually increase. The profile C is east-west trending and comprises of points P31, P34, P5 and P18. Resistivity value is high in the center part of the profile and relatively low in the east and western parts of the profile. The profile D is in the southern part of the area and comprised of points P37, P40, P41 and P24. All profiles indicate very low resistivity in the area close to the Kirana Hills.

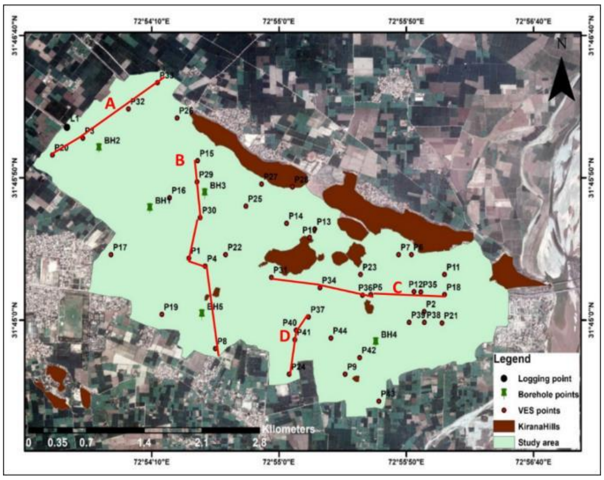


Fig. 9 Location map showing aquired VES and location of pseudo resistivity sections.

The average values of EC, TDS, hardness, Ca, Cl, andSO_4 were extremely high in water samples of the area close to the Kirana Hills (Ahmad et al., 2016). The low resistivity values close to the Kirana Hills are due to poor water quality and fine sediments. As we move away from the Kirana Hills the water quality gets relatively better (Fig. 14).

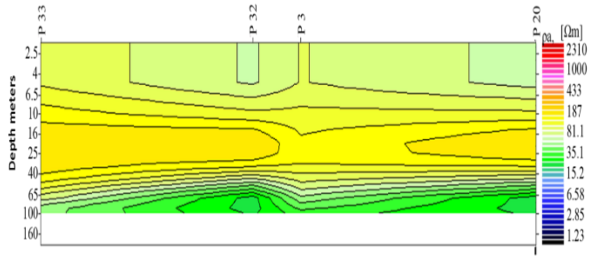


Fig. 10 Pseudo resistivity section along line, as shown in Figure 9.

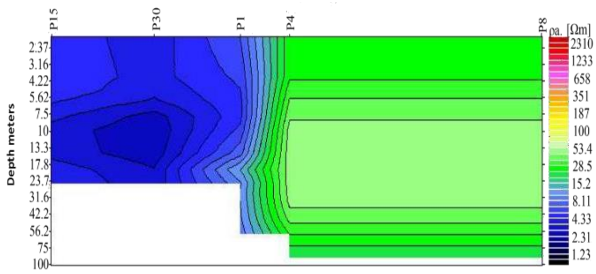


Fig. 11 Pseudo resistivity section along line B shown in Figure 9.

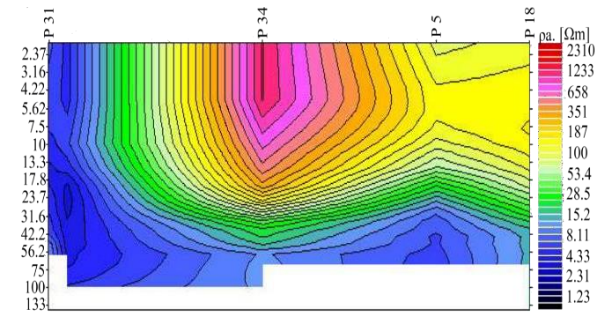


Fig. 12 Pseudo resistivity section along line C shown in Figure 9.

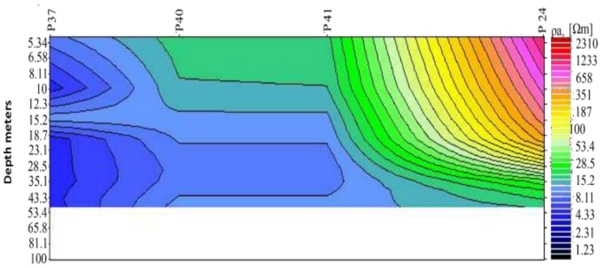


Fig. 13 Pseudo resistivity section along line D shown in Figure 9.

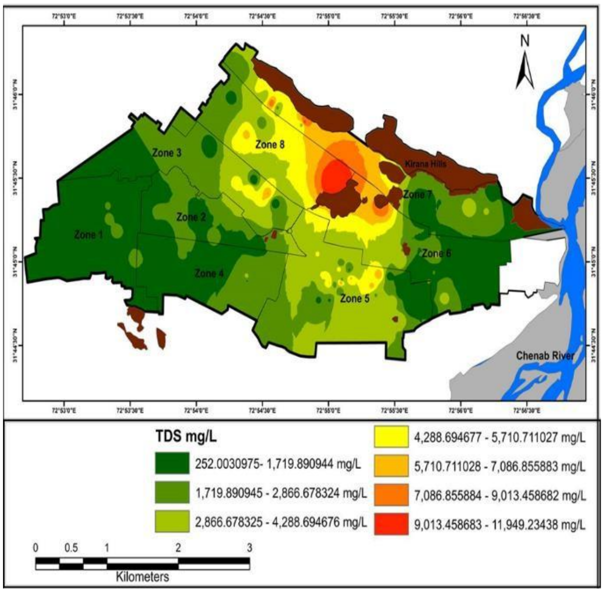


Fig. 14 TDS variation in the study area after (Ahmad et al., 2016).

Conclusion

Vertical electrical sounding (VES) technique has identified groundwater aquifers distribution of different alluvial sediments. The comparison of borehole data and resistivity profile indicates that upper dry layer has resistivity in the range of 160 to 83 Ωm. The clay below water table has extremely low resistivity of less than 10 Ωm. Resistivity within sand layers is relatively greater in the range of 13 to 70 Ωm. This variation in resistivity values within sand is due to variation in grain size and water quality. High resistivity values correspond to the low TDS water in coarse grain sand.

True resistivity maps at various depths show high values (greater than 100Ωm) near Kirana Hills exposure. Beyond 40m depth, resistivity values in the eastern and central part of the area are greater than 100Ωm. High values indicate shallow basement and, pseudo sections of resistivity profiles show relatively high values in a western profile of the area. Rest of the pseudo sections indicate low resistivity values of shallow layers (up to 40 m) in the northern part. Resistivity values increase as we move southward.

Low resistivity values in shallow alluvial sediments are due to poor quality water.

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