# The study of aquifers potential and contamination based on geoelectric technique and chemical analysis in Mirpur Azad Jammu and Kashmir, Pakistan

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## Abstract

In the study area thirty three Vertical Electrical Soundings (VES) were randomly surveyed using the Schlumberger configuration to delineate the aquifer system of Mirpur area in Azad Jammu and Kashmir (AJ&K) Pakistan. The VES curves were interpreted using IPI2WIN software to determine the depth, thickness and true resistivity of the subsurface strata. The subsurface geological model and fence diagrams have been computed by using the rockworks GIS based software. The present study suggested that the aquifers are mostly comprise of boulder gravel and sand in the different areas with variable thickness. The output of the geo-electric data shows a close agreement with boreholes data of the area. The water samples have been collected from different locations and also analyzed to correlate the contamination with the dump sites, foam and automobiles industries waste in the area. The results of the water samples collected near the dump sites are not found satisfactory for the drinking purpose due to high level of TDS and hardness of water. In the study area missing stream link is also demarcated by using the geoelectrical data which is the source of groundwater in the area. The productive groundwater zones are delineated in the north eastern and central part of the study area, whereas aquifer overburden protection capacity in the south eastern part of the area is rated as poor to weak.

*Keywords:* Groundwater, Vertical Electrical Sounding (VES), Lithological modeling, Hydrology, Geographical Information System (GIS), Contamination.

## 1. Introduction

Mirpur city is located at the latitude N 33°05′ to N 33°07′ and E 73°37′ to E 73°45′ and is one of the most densely populated city of Azad Jammu and Kashmir (AJ&K) Pakistan. This area is industrial state of the country. The AJ&K is tax free area which attracts the investor for the investment in the development of industries. The industrial waste fluid directly makes its way into Nalas and stream in the form of contaminants. The Mangla electric transformer repairing workshop is also working in the area and disposing waste in the form of oil into the stream waters. In this area most of its population depends upon the ground water for domestic use. The aquifers are the important source of groundwater in arid areas of Pakistan and this resource yielding water in drought conditions, has not yet fully investigated. The global climate change and the drought condition forced the farmer to use the ground water for irrigation which can supply sufficient quantity of water (Ahmad et al., 2007). In the study area ground water use are becoming increasing day by day with the population and more demand for water supplies and increasing pollution. It’s the need for sustain yield of aquifers.

There are some tube wells in the area drilled by the Irrigation department of AJ&K. The aquifer properties and vulnerability mapping have been carried out in south-east Bhimber District AJ&K of the study area. (Niaz et al., 2016).However, no detailed work has been carried out on the aquifer properties of the Mirpur area. The present study was first of its kind to study the groundwater potential, depth and thickness of aquifer as well as the vulnerability risk using Schlumberger configuration.

The surface geo-electrical methods, especially the VES method is relatively cheap and gives the better results as compared to other geophysical method for the exploration of groundwater. The quantitative evaluation technique used to locate the exploration sites as well as depth of groundwater. This method is suitable for the determination of underlying geology of the area (Stampolidis et al., 2005; Soupios et al., 2007; Kalisperi et al., 2009). The GIS tool provides the suitable management of complex data (Saraf and Choudhury, 1997). In the study area rapid analysis of the spatial data and integration of different layers is possible in GIS software. The GIS tool is thus used to develop numerical modeling of groundwater, presentation and integration of the image processing, and modeling results.

Geoelectric method is repeatedly used in determination of thickness, depth, and boundary of an aquifer (Omosuyi et al, 2007, Bernstone et al., 2000; Asfahani, 2006). Electrical resistivity techniqueis the most preferred method in the determination of groundwater potential (Ako and Olorunfemi, 1989; Madan et al., 2008; Awni, 2010). The Vertical alterations of the resistivity of the subsurface layers are measured by VES (Anomohanran, 2013; Adeoti et al., 2012). This method has been proven to be more efficient for hydro geological investigation of sedimentary basin as well as groundwater contamination.

The inverse and forward modeling is used to model the variation of resistivity with depth. Geophysical investigation with electrical resistivity involves the investigation of the nature and status of groundwater contamination (Hamza et al., 2006). The Schlumberger configuration has a greater depth penetration than Wenner. In resistivity method, Wenner configuration measures the alteration of lateral variation of the rocks while the Schlumberger technique is used for the deeper sounding ((Omosuyi et al., 2007). The missing stream link is established between Markanda River and Vedic Saraswati River based on the geoelectric data (Kshetrimayum and Bajpai, 2011). In the present study Paleochannel is delineated based on resistivity variations. The depth, extension and the contamination level of the aquifer in the study area is delineated by using goelectrical method. The contamination is also verified by chemical analysis near the dump sites and industrial area.

## 2. Geological setting of the study area

The study area is located in north eastern part of Pakistan, while in the southern part of the State of Azad Jammu and Kashmir. It lies within the extensive Potwar basin which is extending almost throughout the Punjab province of Pakistan. It is an active sedimentary basin. The Himalayan molasse deposits of recent sediments underlie the area. The geological formations in the area are Chinji, Nagri Dhok Pathan, Soan

Formations of Siwalik Group and Mirpur Formation. Siwalik Group as a whole consists of sediments of clastic origin and alternating beds of sandstone and argillaceous material (Shah, 1977; 2009). Chinji Formation lies at the base of this group and consists of red clays with subordinate sandstone. Thickness of Chinji Formation is highly variable and varies from 300 m to 1800 m. It is overlain by Nagri Formation which consists predominantly of thick sandstone with minor clays. Thickness of this formation is also very inconstant ranging from 300 m to 2000 m. The Dhok Pathan Formation overlies the Nagri Formation in the area which shows cyclic deposition of sandstone and clays. The average thickness of Dhok Pathan Formation in the study area is reported to be approximately 1820 m. The youngest formation of this group is Soan Formation which consists of conglomeratic sandstone and clays sequence. Its thickness varies from 120-450m in the Potwar area. In the study area Mirpur Formation also exists which consist of conglomeratic unit with some mudstone and sandstone.

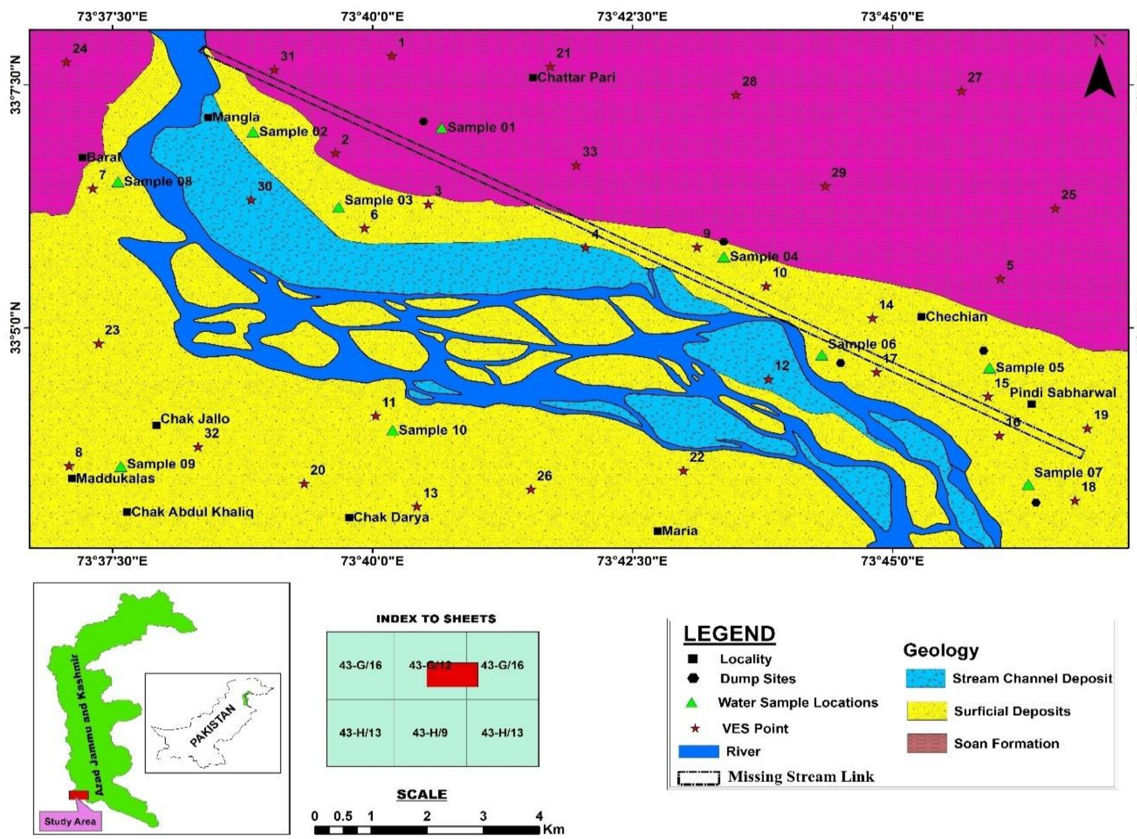


Fig. 1. Geological and location map of the Vertical electrical sounding points of the study area (after GSP, 2004).

## 3. Hydrogeology of the study area

The climate of the area is ranges between arid to semi-arid and seasonal variation in temperature and rainfall. The monthly temperature shows the hot period from April to October with mean temperature exceeding 31 °C. In the winter average temperature drops down to 11 °C in December and January. Rainfall is low and seasonal with the annual precipitation of approximately 837 mm (PWP, 2013). The maximum rainfall occurs in the months of June, July and August ranges between 77mm to 85mm. The main drainage in the area is River Jhelum. Many seasonal nallas join the secondary tributaries which flow into the river. Mangla water reservoir built on River Jhelum is the major source of recharge in the area.

## 4. Materials and methods

The electrical resistivity method was used for the study. The apparatus used for the study is the ABEM terrameter SAS 4000 Sweden with accessories. The characteristic features of the instrument include the calculation of the geometric factor and it displays the resistivity value on the screen.

In the study area 33Schlumberger configurations have been carried out. The location and distribution of the sounding stations is shown in the figure 1. The maximum current-electrode spacing was kept upto 400m. Six sounding points were taken near the borehole sites for the comparison of resistivity values with the geology. The geological section of the boreholes developed by irrigation department was used to get the information of subsurface geology. Lithological and structural conditions determine the spatial distribution of the aquifers in the area. The lithology and subsurface strata were studied using litho-logs of the boreholes. The field data was subjected to the computer iteration software IPI2WIN. The field curves were interpreted using the partial curve matching technique. True resistivity, thickness and depths of each layer were calculated. The hydro-resistivity map such as aquifer thickness, longitudinal conductance, and anisotropy were prepared. The different profile sections were plotted using the litho-blend technique of the Rockworks 2006 software. The water sample were also collected from the different locations of the study area (Fig. 1) in distilled bottles and then transported within four hours in the Pakistan council of research in water resources (PCRWR) lab Islamabad for chemical analysis. All the tests were performed by the PCRWR lab.

## 5. Results and discussion

IPIWIN2 software was used to iterate resistivity curves of VES 1-33. True resistivity, thicknesses and depths were calculated by using partial curve matching technique. The true resistivity and thickness of different layers in the study area are presented in the Table 2. The subsurface lithological models and cross sections were also developed by using rockworks software based on the true resistivity and well data. Overall depth of the wells in the area ranges between 90 to 200 m. The figure 2 is showing the 3D model of the subsurface lithology of the area. The lithology is dominated by boulders and gravels with clay matrix with variable thickness of sand. The compact sandstone is also present which shows high resistivity values. The unconsolidated deposits are the part of Himalayan molasse which after transportation from the Higher, Lesser and Sub-Himalayas is deposited in this area. The top layer is the clay with variable thickness. Underneath the first layer there are boulders of the Mirpur Formation having clayey matrix. The gravel deposits are dominant in the south western part while in south eastern part sand deposits are found with gravel. Compact sandstone is found in the area with high resistivity and it tends to decrease in southward direction. Gravel clay is reported in this area in some wells. The extension of the sandstone in the south eastern part of the study area is terminated by clay gravel and sand (Fig. 2). Figure 3 shows the resistivity models of the different profiles.

The cross section A-A´ (Fig. 4) represents the correlation between the borehole data and the resistivity data interpretation. The sounding data were correlated with the nearest well data and found close agreement with geology. Well-04 and VES-13, well-01 and VES-06 and well-05 and VES-07were correlated with each other. It also represents the deposition of sand in northwestern and southeastern part of the study area, but it’s missing in the central part. This missing in the deposition is probably due to the diversion of river course from the central portion. Whereas, gravel deposits extend from north to southward with the average thickness of 20 m to 70m showing the paleochannel course in this area as shown previously in the figure 1. These deposits are linked with the stream and provide the suitable water production in the area as reported by the well data.

The figure 5 shows the resistivity cross section of the subsurface lithology. In this cross section the green color with the resistivity values ranges between 104 ohm-m to 149 ohm-m is interpreted as gravel deposits of the missing stream link and are almost extended in the whole area. The high resistivity values in the northwestern and southeastern part with red color indicates the compact sandstone as indicated earlier in the 3D model (Fig.2) given above.

The figure 6 and figure 7 present the fence diagram of the lithology in different profile directions showing the best match of the extension and thickness of subsurface lithology. The both the figures showing the extension and varying thicknesses of the subsurface strata along different directions of the study area.

The profile sections shown in the figure6 presents the geology of the study area. The subsurface geology is dominated by the clay with the layering of gravels and varying thickness sand. The gravel deposits are dominant in the northwestern part where stream channel deposits are found. Sand deposits with minor layering of clay are prominent in the northeastern part where surficial deposits and Soan formation of the Siwalik Group is abundant.

### *5.1. Aquifer thickness map*

The figure 8 shows the aquifer thickness map used for ranking lithology because aquifer thickness is the function of volume of water from each sounding station.

In the study area “good” to “moderate” potential zones of ground water have been identified. The research reveals that “good” potential occurs at the southwestern portion as well as northeastern part of the study area with thickness values of 45 to 85 m. The “moderate” ground water potential zone has an aquifer thickness of 20 to 35 m and lies in the central and southeastern part of the study area.

### *5.2. Longitudinal conductance*

The ratio of different layers to their respective resistivities is known as longitudinal conductance. The properties of the conducting layers is determined interms of the longitudinal conductance and resistive layer by transverse resistance (Yungul, 1996; Nwanko et al., 2011; Slater, 2007). Figure 9 presents the total longitudinal conductance map. The values of conductance ranges from 0 to 3.8 Siemen. The Conductance increase in the northwestern and southeastern part of the area. The increases in conductance values hence, reduces resistivity of the aquifer indicates the groundwater potential (Gowd, 2004; Joseph, 2012).

The conductance values in the present study range from 0.02 to 3.8 Siemens. The northeastern and western part of the study area shows high conductance values. The clay overburden conductance can also be delineated by using unit longitudinal conductance values. (Table 1; Parasnis, 1979). The map of vulnerability risk is also prepared by the unit longitudinal conductance (Fig. 9) delineates the distribution of overburden protection capacity of the aquifers in the area. These values are useful for assessing vulnerability risk of the aquifer as the earth is a natural filter to percolating fluids (Mogaji et al., 2007; Niaz et al., 2016).

The hydraulic conductivity of the aquifer directly proportional to protective capacity of an overburden. Thick layer of clay obstruct movement of fluid is characterized by low hydraulic conductivities and low unit longitudinal conductance (Henriet, 1976). The generalized protective capacity values are presented in table 1.

The rating values are helpful for the delineation of different zones of protective capacity of the area under investigation and are rated as “poor”, “weak”, “moderate” and “good” zones. The study areas rated as “weak” and “poor” are more susceptible for contamination. The overburden moderate protection capacity in the northeastern part of the area ranges between 0.4 to0.8 Siemen, while good protective cover delineated with conductance values 0.8 to 3.2 Siemen. The central and southeastern part of the map has “weak” protective capacity zone with 0.02 to 0.4 Siemen and is susceptible to infiltration of polluted fluids from waste dumps.

*5.3. Anisotropy*

Figure10presents the coefficient of the anisotropy of study area. The coefficient of anisotropy values ranges from 0.8 to 3.1. The “high” values are observed in the southeastern as well as northwestern part of the study area while the remaining part of the area has “low” value of the anisotropy. This relatively high values of coefficient of anisotropy in northwestern and southeastern portion suggests that these are due to the near surface inhomogeneity and also due to the variation in structural features like faults, joints and fractures and is relevant to the groundwater development in the area (Bayewu et al., 2014). The rest of the area is characterized by the low values of the anisotropy (0.8 to 1.2).

*5.4. Chemical analysis*

The results of the chemical analysis were presented into the table 3. The water sample collected from the tube wells near the dump sites and industrial area were found unsatisfactory for drinking. These samples have high TDS and hardness values than the permissible limit of World health organization (WHO)/ PSQCA standard. And also the amount of chloride and nitrate were much higher than permissible limit. So the water of these areas is not a suitable for drinking. It was determined that the water samples from southeastern and central portion of the study area which is rated as “weak” protective overburden capacity is not fit for drinking.

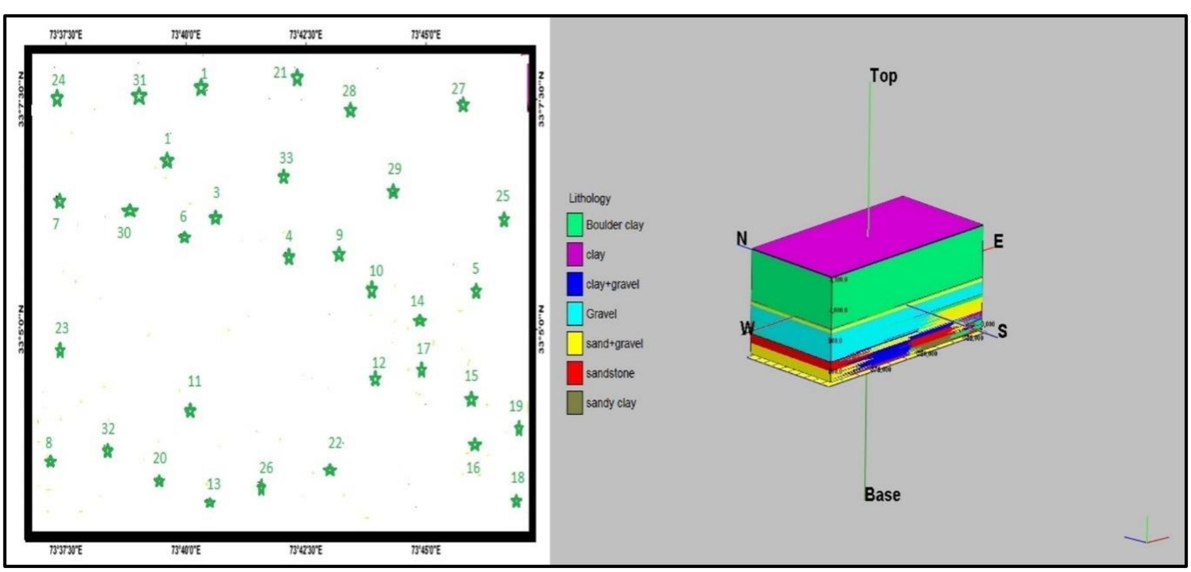

Fig.2 Three-Dimensional model of subsurface lithology.

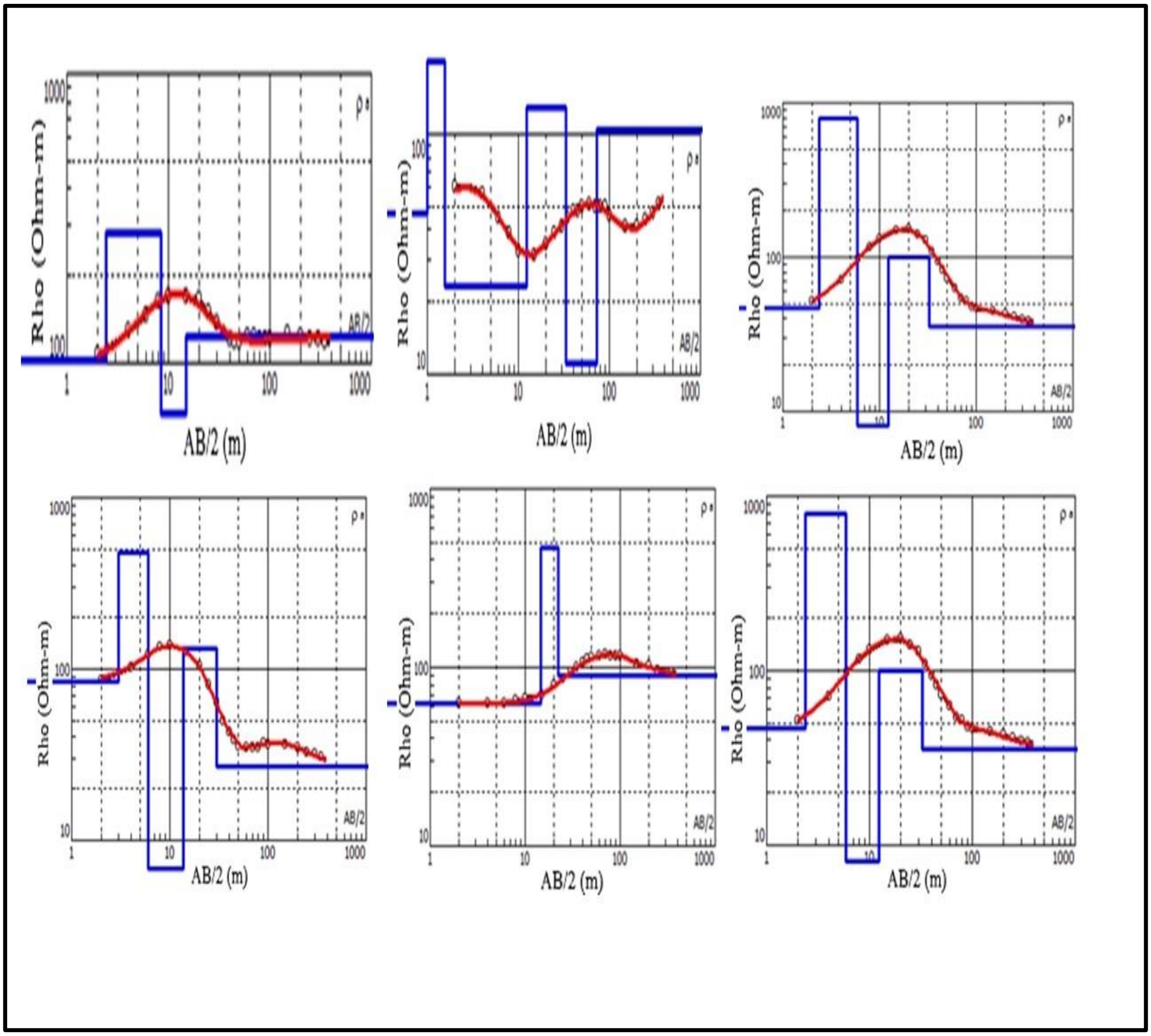


Fig. 3. Resistivity models of the study area.

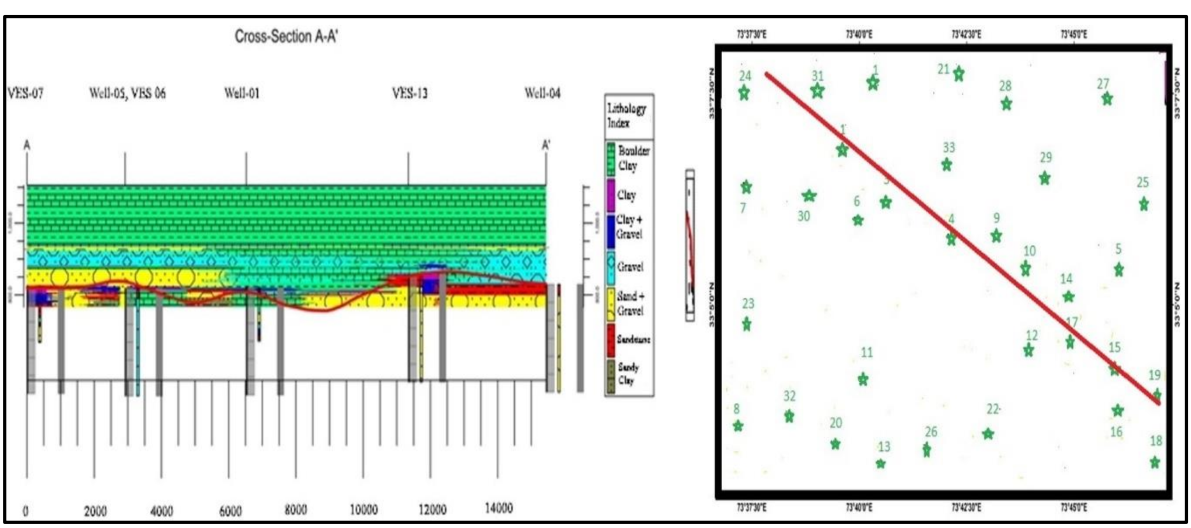


Fig. 4. Correlation of VES data and Well data.

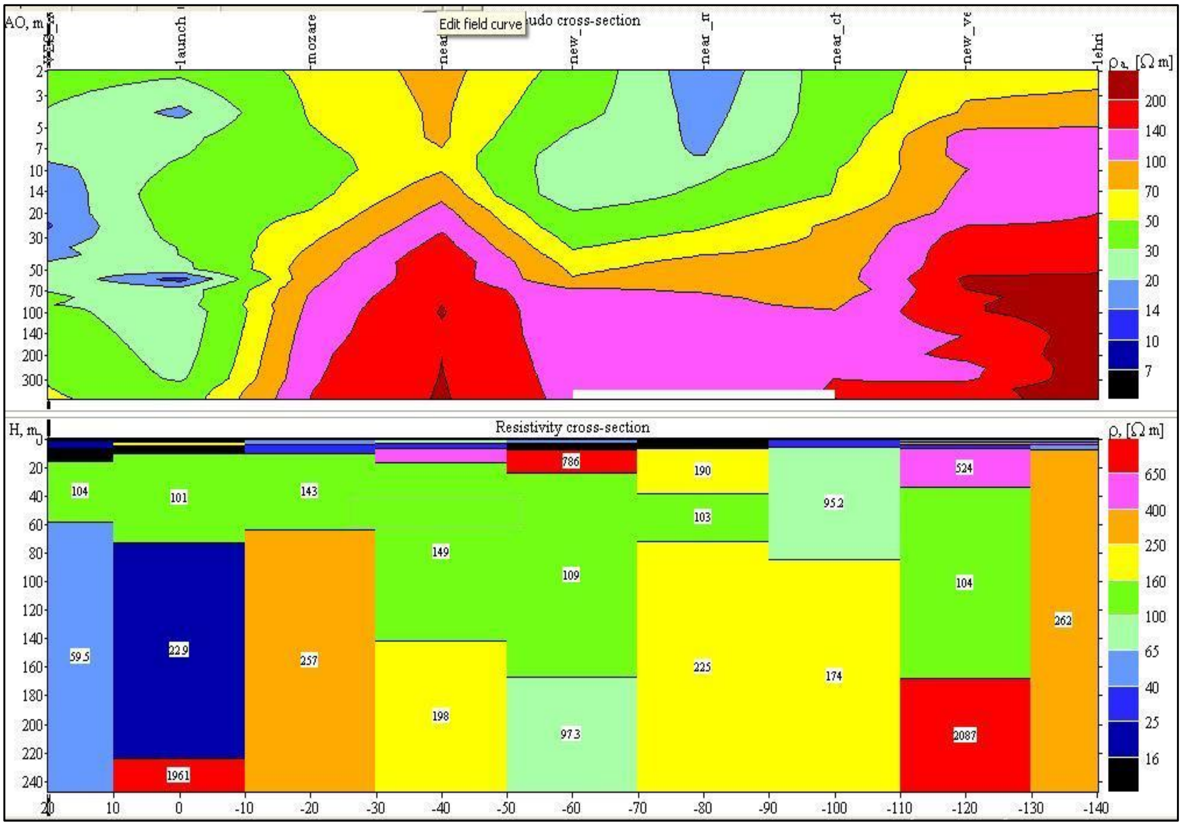


Fig. 5. Resistivity and Pseudo-section of the study area.

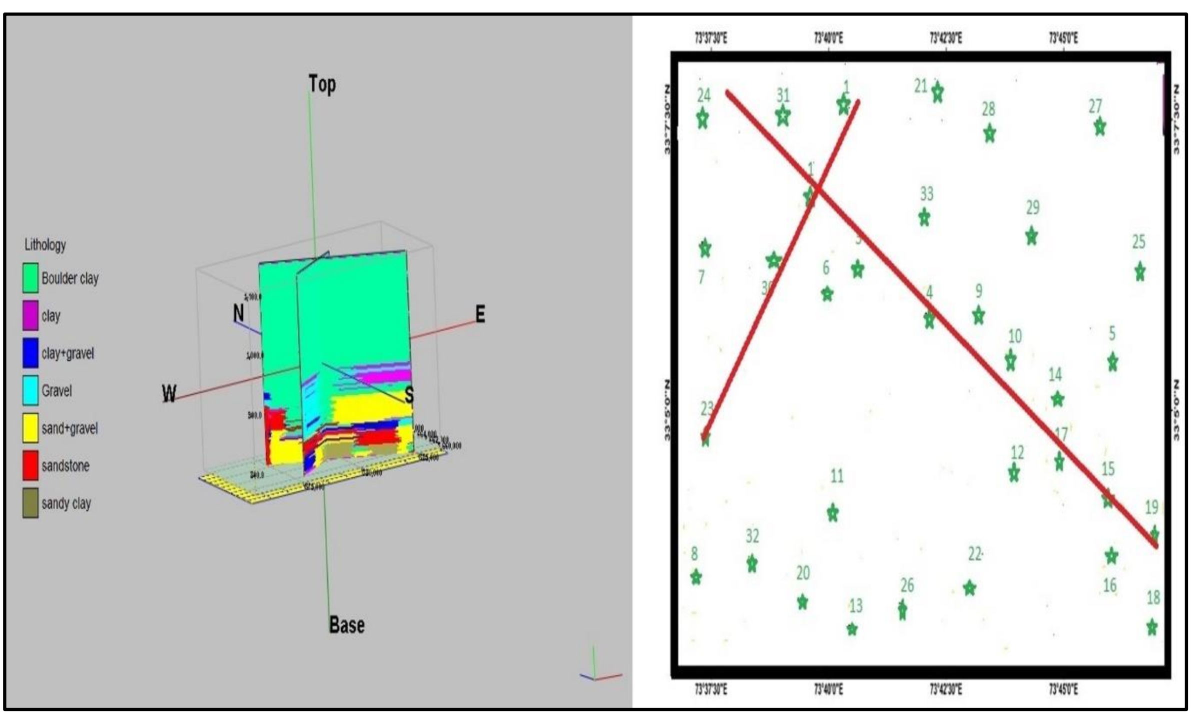


Fig. 6. Fence diagram of the study area showing subsurface lithology.

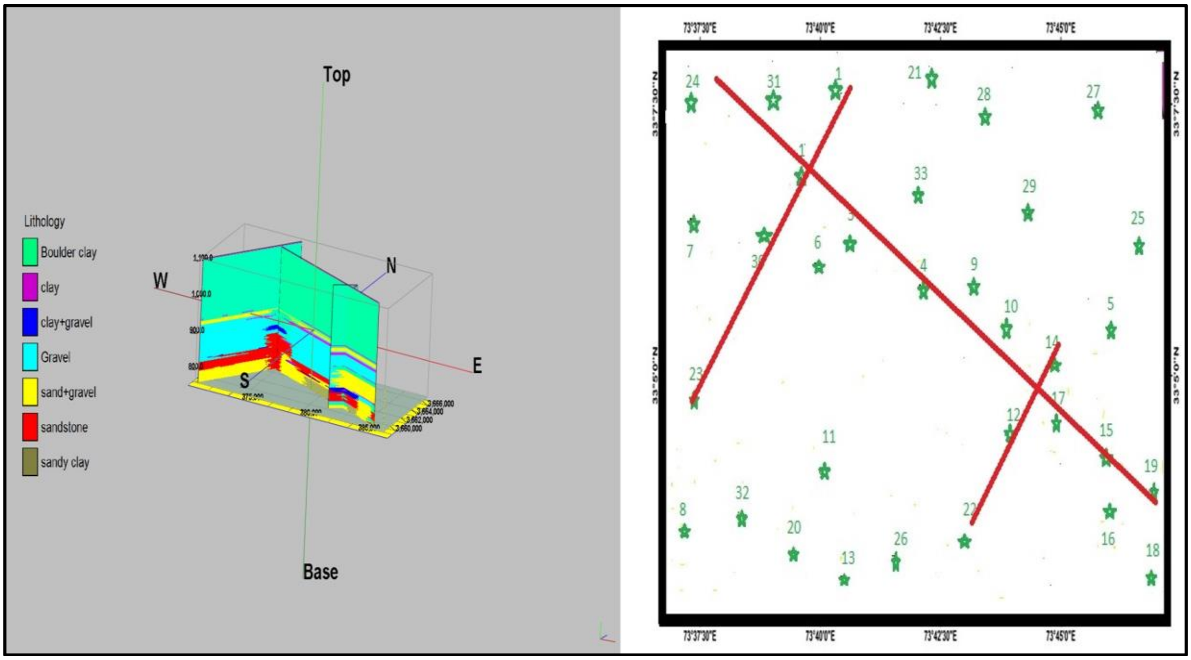


Fig. 7. Fence diagram of the subsurface lithology.

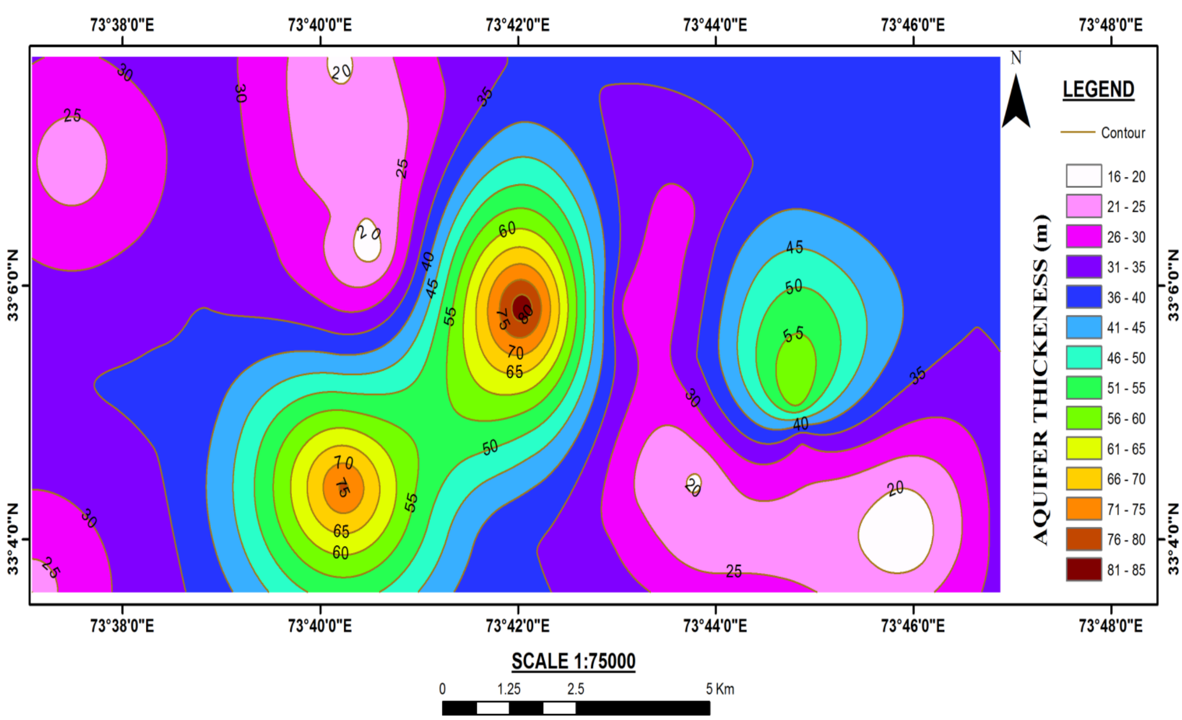


Fig. 8. Aquifer thickness Map of the study area.

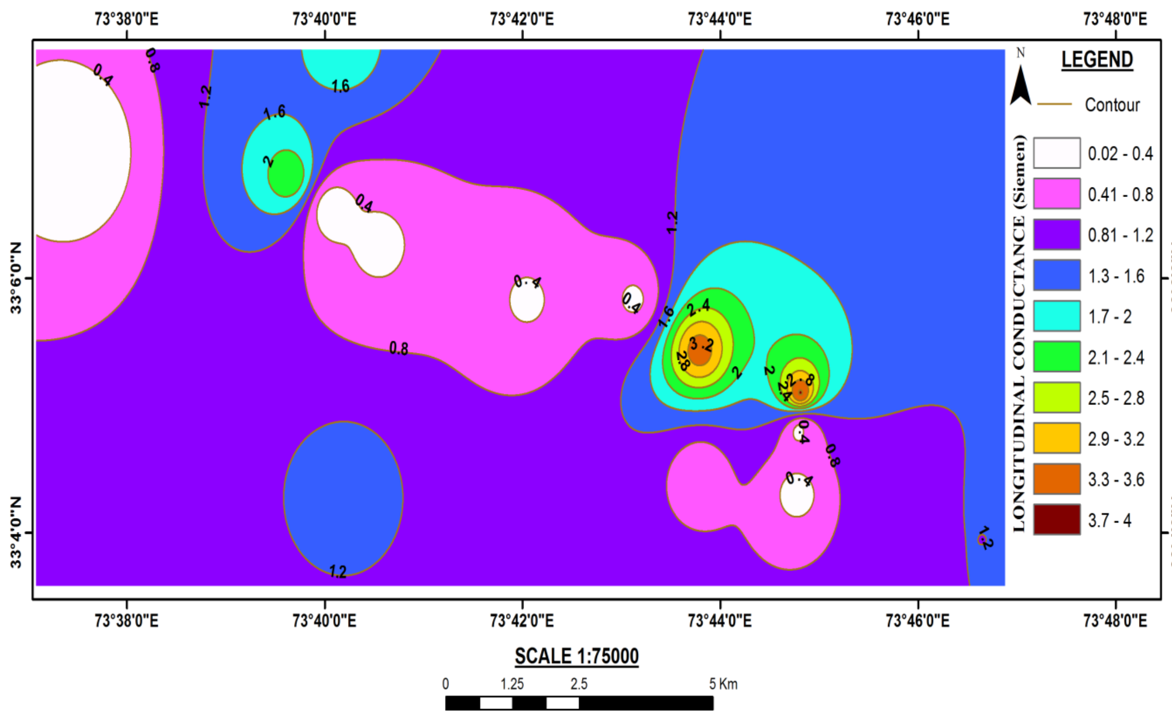


Fig. 9. Conductance map of the study area.

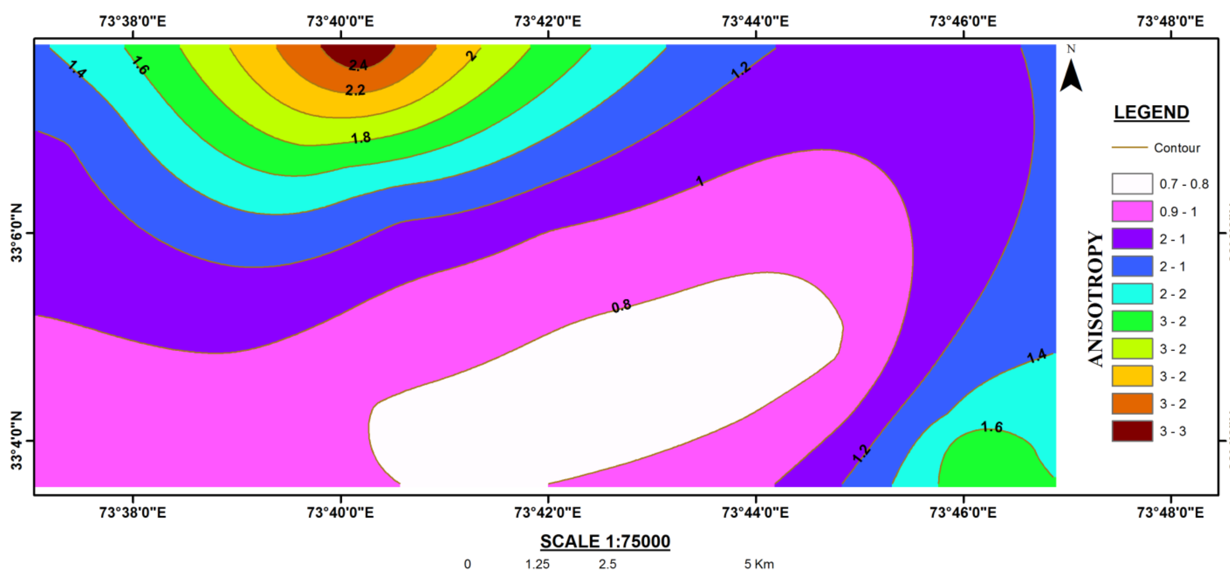


Fig. 10. Anisotropy map of the study area.

Table 1. Longitudinal conductance rating/ protective capacity rating (after Henriet, 1976)

| **Longitudinal conductance (mhos)** | **Protective capacity rating** |
|---|---|
| >10 | Excellent |
| 5 – 10 | Very good |
| 0.7 - 4.9 | Good |
| 0.2 - 0.69 | Moderate |
| 0.1 - 0.19 | Weak |
| <0.1 | Poor |

Table 2. Results of vertical electrical soundings interpretation.

| VES No | Latitude | Longitude | ρ1 | h1 | ρ2 | h2 | ρ3 | h3 | ρ4 | Depth (H) | Aquifer thickness | Longitudinal conductance | Anisotropy |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| VES1 | 73°40.187 | 33°07.799 | 56.34 | 1.769 | 151 | 4.57 | 3.22 | .7 | 28 | 12 | 10.24 | 1.82 | 3.106 |
| VES2 | 73°39.644 | 33°06.801 | 162 | 12.5 | 10.2 | 22.8 | 2388 | - | -- | 35.3 | 22.8 | 2.31 | 2.095 |
| VES3 | 73°40.538 | 33°06.273 | 66.3 | 3.52 | 25.4 | 5.14 | 163 | - | -- | 8.66 | 5.14 | 0.26 | 0.82 |
| VES4 | 73°42.050 | 33°05.829 | 142 | 1.92 | 1091 | 1.31 | 346 | 14 | 123 | 117 | 114 | 0.34 | 0.815 |
| VES5 | 73°44.808 | 33°04.795 | 63.7 | 2.47 | 252 | 28 | 97.6 | - | -- | 30.5 | 28 | 0.15 | 0.882 |
| VES6 | 73°40.067 | 33°06.543 | 61.1 | 3.19 | 756 | 31.5 | 245 | - | -- | 34.7 | 31.5 | 0.09 | 0.936 |
| VES7 | 73°37.484 | 33°06.979 | 220 | 1.36 | 1034 | 13.9 | 57 | - | -- | 15.3 | 13.9 | 0.02 | 0.818 |
| VES8 | 73°37.084 | 33°03.585 | 61.5 | 1.52 | 28.9 | 5.06 | 11 | 0 | 89 | 16.7 | 15.7 | 1.12 | 0.705 |
| VES9 | 73°43.123 | 33°05.833 | 67.3 | 1 | 256 | 7.9 | 47.4 | 4 | 283 | 22.5 | 13.6 | 0.33 | 0.898 |
| VES10 | 73°43.787 | 33°05.432 | 65.2 | 5.85 | 32.9 | 6.44 | 10.28 | 2 | 13 | 44.5 | 38.64 | 3.42 | 0.798 |
| VES11 | 73°40.232 | 33°04.413 | 21.4 | 4.74 | 85.3 | 97.8 | 9069 | - | -- | 103 | 97.8 | 1.37 | 0.849 |
| VES12 | 73°43.808 | 33°04.476 | 68.2 | 2.87 | 23.1 | 9.76 | 186 | - | -- | 12.6 | 9.76 | 0.46 | 0.813 |
| VES13 | 73°44.868 | 33°04.795 | 14.5 | 1.85 | 21.9 | 11.2 | 208 | - | -- | 13.1 | 11.2 | 0.64 | 0.81 |
| VES14 | 73°44.808 | 33°05.102 | 36.5 | 5.56 | 26.4 | 91.9 | 0.561 | - | -- | 97.5 | 91.9 | 3.63 | 0.803 |
| VEs15 | 73°45.868 | 33°04.234 | 31.5 | 2.98 | 10.2 | 11.2 | 122 | - | -- | 14.2 | 11.2 | 1.19 | 0.817 |
| VES16 | 73°46.028 | 33°03.896 | 39.5 | 1.01 | 14.8 | 11.1 | 474 | 5 | 1.4 | 27.2 | 15.1 | 0.81 | 4.014 |
| VES17 | 73°44.776 | 33°04.320 | 137 | 14 | 389 | 25 | 1.81 | - | -- | 39 | 25 | 0.17 | 0.937 |
| VES18 | 73°46.654 | 33°03.946 | 40.8 | 1 | 18.7 | 20.2 | 278 | 3 | 2.7 | 44.5 | 23.3 | 1.19 | 2.07 |
| VES19 | 73°46.875 | 33°03.969 | 148 | 3.77 | 23.9 | 37.5 | 420 | - | -- | 41.3 | 37.5 | 1.59 | 0.981 |
| VES20 | 73º 47‘ 33 | 33º 3‘ 59.4‘ | 31.3 | 13.1 | 7.89 | 67.1 | 15.3 | - | -- | 80.2 | 67.1 | 18.434 | 0.597192 |
| VES21 | 73º 47‘53.4‘ | 33º 4‘ 26.4‘ | 100 | 2.16 | 3.22 | 1.59 | 13.5 | 34.75 | 48.4 | 137.5 | 134.75 | 13.186 | 0.55988 |
| VES22 | 73º 48‘ 25.2‘ | 33º 3‘ 57.6‘ | 39.2 | 2.64 | 346 | 3.02 | 24.2 | 03 | 14.8 | 108.66 | 103 | 5.2296 | 2.508195 |
| VES23 | 73º 49‘ 39‘ | 33º 3‘ 17.4‘ | 32.5 | 17.2 | 68.6 | 12.8 | 2.68 | 7.6 | 79.2 | 65.8 | 27.6 | 25.082 | 0.667987 |
| VES24 | 73º 50‘ 50.4‘ | 33º 3‘ 30.6‘ | 52.2 | 26.4 | 20.5 | 260 | 7.07 | -- | -- | 286.4 | 260 | 21.716 | 0.539291 |
| VES25 | 73º 50‘ 49.8‘ | 33º 3‘ 0‘ | 60.1 | 1 | 641 | 0.901 | 27.3 | 1 | 72.4 | 42.0901 | 28 | 28.227 | 0.725438 |
| VES26 | 73º 47‘ 58.8‘ | 33º 2‘ 50.4‘ | 33 | 1 | 76.9 | 1.49 | 26.1 | 3 | 405 | 15.49 | 13 | 63.716 | 1.993992 |
| VES27 | 73º 49‘ 24.6‘ | 33º 2‘ 45‘ | 112 | 1.24 | 38.8 | 6.81 | 57.3 | 42 | 188 | 381 | 342 | 56.871 | 0.502312 |
| VES28 | 73º 51‘ 51‘ | 33º 2‘ 7.2‘ | 195 | 2.49 | 299 | 3.71 | 60.6 | 2.6 | 26.7 | 37.13 | 32.6 | 68.9 | 0.667779 |
| VES29 | 73º 53‘ 51.6‘ | 33º 1‘ 55.2‘ | 279 | 1.25 | 723 | 1.58 | 82.2 | .88 | 4.08 | 11.2 | 8.88 | 12.609 | 3.107892 |
| VES30 | 73º 53‘ 52.8‘ | 33º 0‘ 45‘ | 122 | 2.33 | 36.8 | 18.3 | 8.35 | 0.5 | 42.9 | 30.11 | 29 | 17.549 | 0.956764 |
| VES31 | 73º 56‘ 6‘ | 33º 1‘ 48‘ | 143 | 2.56 | 13.3 | 3.6 | 234 | .79 | 22 | 9.14 | 8 | 35.431 | 1.978 |
| VES32 | 73º 57‘ 15.6‘ | 33º 1‘ 7.8‘ | 54.6 | 2.16 | 104 | 27.9 | 48.9 | -- | -- | 30.6 | 27.9 | 97.651 | 0.514331 |
| VES33 | 73º 57‘ 9‘ | 33º 0‘ 37.2‘ | 89.6 | 5.33 | 259 | 7.91 | 13.7 | 6.9 | 112 | 29.6 | 17 | 228.02 | 0.541235 |

Table 3. Results of the chemical analysis of water samples.

| Parameters | Sample # 1 | Sample # 2 | Sample # 3 | Sample # 4 | Sample # 5 | Sample # 6 | Sample # 7 | Sample# 8 | Sample # 9 | Sample #10 | WHO/PSQCA Limit |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Color | Color less | Color less | Color less | Color less | Color less | Color less | Color less | color less | Color less | Color less | Colorless |
| E.C µs/cm | 1089 | 755 | 1307 | 1710 | 3120 | 3242 | 1677 | 1235 | 978 | 1120 | NGVS |
| pH | 6.6 | 7.96 | 7.32 | 7.67 | 7.77 | 7.33 | 7.22 | 7.14 | 7.51 | 7.11 | 6.5-8.5 |
| Turbidity (NTU) | 3.33 | 3.14 | 3.28 | 4.66 | 2.19 | BDL | 0.82 | 3.82 | 4.79 | 4.38 | Less than 5NTU |
| Alkalinity (mg/L) | 366 | 282 | 302 | 352 | 358 | 308 | 413 | 387 | 257 | 273 | NGVS |
| Bicarbonate | 378 | 282 | 302 | 353 | 302 | 302 | 492 | 365 | 271 | 321 | NGVS |
| Calcium | 132 | 111 | 121 | 161 | 221 | 111 | 121 | 102 | 123 | 117 | NGVS |
| Carbonate | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | NGVS |
| Choloride | 402 | 400 | 72 | 120 | 109 | 111 | 135 | 74 | 47 | 89 | 250ppm |
| Hardness | 1602 | 1614 | 552 | 421 | 1602 | 1603 | 542 | 432 | 417 | 509 | 500ppm |
| Magnesium | 41 | 21 | 61 | 58 | 194 | 198 | 70 | 33 | 53 | 37 | NGVS |
| Nitrate | 120 | 6 | 133 | 25 | 9 | 7 | 5 | 8 | 7 | 9 | 10ppm |
| Potasium | 0.4 | 0.7 | 3.6 | 1 | 1.4 | 1.6 | 1.2 | 0.6 | 3.7 | 0.8 | 0.4ppm |
| Sodium | 32 | 14 | 57 | 110 | 78 | 57 | 165 | 44 | 23 | 55 | NGVS |
| Sulphate | 150 | 52 | 223 | 273 | 400 | 300 | 190 | 47 | 73 | 42 | NGVS |
| TDS | 2215 | 415 | 1103 | 1026 | 976 | 823 | 711 | 713 | 531 | 713 | 1000ppm |
| Lead | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | 50ppb |
| Arsenic | 0.44 | 0.37 | 1.10 | 0.83 | 3.19 | 0.24 | 0.13 | 0.23 | BDL | BDL | 50ppb |

**NGVS:** no Guideline value set, **WHO:** World Health Organization, **PSQSA**: Pakistan standard quality control authority, **BDL**: Below detection limit, **ppm:** Parts per million.

## 6. Conclusion

The geo electrical method is a cost effective technique for the study of the ground water. To enhance the hydraulic parameter calculation this method is a good alternative. The ground water zones were marked on the bases of geo-electrical data interpretation. The good potential zones are found in the north eastern and central region of the study area. A missing stream link is established in cross section extending from North-west to South-east direction. It is composed of gravel deposits and are recharging by the Jehlum River. Buried gravel deposits are the main source of the water supply in the area because these deposits are linked to the Mangla reservoirs outlet stream. The Geo-electric parameters derived from the sounding data are used for generation of hydro-resistivity maps, such as longitudinal conductance map anisotropy map and aquifer thickness map. The lithological models also reflect the extension and thickness of various geological units. The compact sandstone is also reported in the area with high resistivity. Aquifer overburden protection capacity in the south eastern and central region of the area is rated as weak to poor. In these areas aquifers are highly vulnerable to leaching fluids and contamination waste dumps or leaking of underground storage. The chemical analysis of the tube wells water samples study area showed that the water sample collected from the tube well of central and south eastern part, near the dump sites and industrial area were found unsatisfactory for drinking purpose, while the rest of the water sample were found good for drinking. The contamination is also reported by the chemical analysis in the central and southeastern part of the study area due to less overburden thickness. This indicates that the bad management of the domestic and industrial fluids is a serious threat to the inhabitants of the area which increases the contamination level in the groundwater.

The current study will be helpful for the borehole scheme installation and can provide guidance to waste management, ground water development projects of the area.

The tube well installation are recommended in north eastern as well as central part of the study area. The presence of thick aquiferious zone assures the area of adequate water resource.


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***Authors' contribution***

*Abrar Niaz initiated Ideology of the project, technical writing, data processing and interpretation. M. Rustam Khan did Supervision of the project and provide financial support through institute of geology UAJ&K for field work also helped in data interpretation. Umair Bin Nisar involved in field planning and data acquisition. Sarfraz Khan reviewed the manuscript. Sohail Mustafa helped in field data acquisition and geological field, Fahad Hameed in GIS map productions, Saleem Mughal in field data processing and geological literature, Muhammad Farooq in technical writing and M. Rizwan in field data acquisition and geological field.*

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