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Geoelectrical resistivity measurements for mapping groundwater seepage zones

Birendra Pratap[1*] and Rajan Kumar[2]
[1]Department of Geophysics, Institute of Science, Banaras Hindu University, Varanasi-221005, India
[2]Geophysics Division, Geological Survey of India, Central Region, Nagpur-440006, India
bpratap@bhu.ac.in

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Abstract

Groundwater anomalously seeping into the basements of shops and houses in Jodhpur, Rajasthan, is eroding the foundations and shortening the lifespan of the structures. A geoelectrical resistivity approach was utilised to identify the groundwater-bearing fractured zones that sustain the groundwater seepage in the research area in order to map the spatial distribution of seepage zones. Seven vertical and five horizontal geoelectrical cross-sections were prepared to delineate the groundwater-bearing fractured zones in the study area. The information obtained from the geoelectrical cross-sections provides insights into highly weathered, semi-fractured, and groundwater-saturated fractured zones that are characterised from surface to deeper depths in the area. Weathered formations frequently come into contact with the surface soil layer directly beneath, which rises to greater depths. In order to determine the range of resistivity of the formations in the research area, the layer characteristics of geoelectrical soundings are correlated with the closest accessible borehole lithology.

Keywords: Seepage, Spatial distribution, Layer parameters, Geoelectrical cross-sections.

Introduction

A state like Rajasthan in India, especially western Rajasthan, is prone to recurring droughts due to poor monsoon rainfall. Jodhpur, popularly known as Sun City, is the second-largest city of the Rajasthan, founded by Rao Jhodhaji in 1459 A.D. The city has historically relied on traditional water management systems, including step wells (Baories), ponds, Jhalaras, and open wells, to store and manage water. Mainly, Kailana-Takht Sagar, Ummed Sagar, and Bal Samand are essential surface water bodies surrounding the city to store water. Takht Sagar and Kailana Lake have excellent connections. The elevation of these water bodies is higher than that of the urban regions. As the city has grown rapidly over the years due to population growth and urbanization, the demand for water supply has increased significantly. The existing groundwater and surface water resources are insufficient to meet this demand, leading to the need for additional water supply schemes. Kailana-Takht Sagar was further connected with the Rajiv Gandhi Lift Canal (RGLC) to continuously supply water to the reservoir and meet the city's water requirements. To fulfil the increasing demand of the population of Jodhpur city during the last decade, it needs to store more water in these reservoirs. However, due to unforeseen conditions, certain parts of the city, particularly the old city area, are facing issues such as seepage and the accumulation of groundwater in the basements of shops and houses in busy markets. This seepage is weakening the foundations of buildings and causing dampness and erosion in walls, leading to reduced building lifespan[1]. Hydrogeological, hydrochemical, and isotopic studies have indicated that the primary cause of water seepage in the city is the increased storage capacity and maintenance of the enhanced of water level of Kailana Lake-Takht Sagar[2-6].

In Western Rajasthan, groundwater potential zones are located and separated into potable and saline groundwater potential zones using vertical electrical sounding (VES)[7,8]. In order to identify groundwater zones that are suitable for irrigation and residential use, Chandrasekharan commenced geoelectrical Investigations in the Bandi catchment, a sub-catchment of the Luni basin, in the Siwan region of western Rajasthan[9]. Chandrasekharan and Ram[10] used vertical electrical sounding in a closed grid pattern to locate groundwater potential zones in the Siwan region in western Rajasthan. Some case studies on geoelectrical investigations for groundwater in the Thar Desert, Western Rajasthan were given by Chandrasekharan[11]. Shukla and Pandey[12] used geoelectrical sounding near Jodhpur to select a suitable site for constructing a sub-surface dyke for recharging the area. In the Jhanwar area of the Jodhpur district, Rajasthan, Yadav et al.[13] employed geoelectrical sounding to identify the presence of fresh groundwater zones and their potential. The self-potential and DC resistivity methods were conducted for monitoring of an evolving plume in partially saturated fractured basalt at the Columbia River[14].

A geoelectrical resistivity method was employed in the current study to designate groundwater carrying fractured zones, which sustain the groundwater seepage in the study area, in order to map the spatial distribution of seepage zones.

The study area: The study area, which covers 172 km^2 and coincides with the survey of India Top sheet Nos. 45F/3, 45F/4, 45B/15, and 45B/16 are located in the westernmost part of Rajasthan between latitudes $26^0$13'N and $26^0$20'N and longitudes $72^0$56'E to $73^0$04'E. Jodhpur City is located on plains created by the weathering of rhyolites and sandstone, part of which runs down the foot of hills. The piedmont region contains the bulk of the old city. The hills border the city to the north and west. Rhyolites Hills, a prominent feature near Kailana Lake in the western section of the city, rise to a height of 395 metres above mean sea level (MSL). The topography decreases towards the plain region and reaches a height of 180m above MSL in the city southeast. There is no perennial drainage in the investigated region. An ephemeral stream in the region, the Jojari River, flows in response to monsoon rains. The research area has an arid and semi-arid climate, which is marked by significant evaporation, temperature extremes, and sporadic, unreliable rainfall. Outside of Jodhpur, the intensity of the rain decreases as one moves from east to west. .

The main part of the study area falls under the Luni and Mandor Blocks of Jodhpur district. Jodhpur district is bounded in the north by Bikaner, in the north-west by Jaisalmer, in the east by Nagaur and Pali, in the south by Pali and Barmer, and in the west by Jaisalmer districts. The area stretches towards the north, up to the outcrop of stone quarries near Bal Samand and Ravati. An outcrop of rhyolite, which is being quarried for roads and building materials, extends up to the southern limit of the study area in the close vicinity of the Jhalamand area. The eastern limit of the study area covers Ummed Bhavan, whereas the western side extends up to Chopasni and Tilwariya villages. The entire study area is approachable by road.

Geology and Hydrogeology: Any region's geology and hydrogeology must be thoroughly understood and studied in order to locate its groundwater resources. The geological configuration of the Jodhpur district is characterized by the presence of the Trans-Aravalli (Marwar super group), the Malani suite, and the Vindhyan supergroups[15-18]. Paliwal[19] reported that the Malani bed consists of felsite and quartziferous porphyries. The main geological formation of the study area comprises of sedimentary rocks, i.e., limestone, sandstone and shale, and some other areas are engaged by the rhyolite suite[19,20]. Due to tectonic activity in the city, the geological strata have undergone significant deformation. The research area consists of a number of sandstone and rhyolite hills with flat tops that are oriented in a NE-SW direction.

The geological formations of the city, like Jodhpur sandstone and Malani rhyolite, are interlayered with shales. Malani rhyolite is highly faulted, folded, weathered, and fractured due to tectonic activity in the city and the main reservoir, viz. Kailana Lake-Takht Sager is also positioned on such type of rock formation. The Jodhpur group of rocks, including sandstone and shale, cover the majority of the ancient city. Neotectonic activity in the region has severely distorted these rock formations, which covers the majority of the old city. Rhyolite, shale, and sandstone strata in the city of Jodhpur have generated several parallel faults and joints as a result of this activity, which are trending in the NW-SE, E-W, and NE-SW directions. The Jodhpur city and adjoining area comprise rocks of Upper Proterozoic to Lower Paleozoic age, i.e., the Malani suite of igneous rocks and the Jodhpur group of sedimentary rocks.

Groundwater in Malani rhyolites occurs under water table conditions and its movement along the joints and fractures. It forms a poor aquifer due to the absence of porosity and permeability. However, at some places, it is highly weathered, fractured and jointed which have a good quantity of groundwater. In the central, northern, and western regions of the research area, aquifers are formed by jodhpur sandstone. It is hard, compact, and medium to fine-grained. It typically forms when shale is intercalated, which lowers the water potential. In the south, south-east, and south-western portions of the research region, Quaternary deposits serve as an aquifer. It comprises older alluvium containing sand, silt, clay with kankar, transported material of sandstone and rhyolite (gravel and pebbles etc.) rock fragments. The south-west part of the alluvium (hydrogeological formation) directly follows the grey and pink granites.

Materials and Methods

The geoelectrical sounding data was carried out using the Terrameter SAS-300, manufactured by M/s. ABEM Sweden. The Schlumberger configuration with two sets of current electrode separations was used to obtain geoelectrical sounding data. A total of 71 geoelectrical soundings were collected, including new and old soundings. When doing fieldwork in areas where sounding was not possible due to a lack of suitable space, previous sounding data was gathered from the Ground Water Department in Jodhpur.

Figure-1 depicts the location of these geoelectrical soundings and geoelectrical cross-sections. The field curves were interpreted in two steps: first, the layer parameters were determined using curve matching methods using master curves of Rijkswaterstaat[21] and associated auxiliary point charts[22]; second, the data were interpreted using the computer programme 'AIMRESI', or Automatic Iterative Method of Resistivity Sounding Interpretation[23]. This interpretation provides data on the resistivity and thickness of each layer. The layer parameters of geoelectrical soundings were correlated with the nearest available borehole lithology in the study area.

Based on the interpreted results of geoelectrical sounding data and available borehole lithology, vertical geoelectrical cross-sections were prepared in the x-z plane and horizontal cross-sections at different depth levels in the x-y plane. In the vertical geoelectrical cross-section, the positions of sounding locations are marked on the x-plane and the depth of individual layers is marked in the z-plane. Lithological information available through boreholes (BH) has been incorporated along the section so that the validity of the geoelectrical section may be verified. For the sake of clarity, resistivity values are written in their respective positions in the geoelectrical layers. The bedrock is demarcated by continuous lines below the sounding locations where the bedrock has been mapped by the array. The broken lines indicate the bedrock for the sounding location was not mapped by the array, for which the depth has been approximated by evaluating the minimum possible value of total longitudinal conductance[24].

Results and Discussion

Correlation of layer parameters with lithology: The interpreted results of geoelectrical sounding data gives information about the resistivity and thickness of the individual layer. These parameters are correlated with existing borehole lithology to identify the range of resistivity of the formations in the study area. The layer parameters of the geoelectrical soundings were correlated with the nearest available borehole lithology in the study area. For the simplicity correlation of the layer parameters with lithology for the two locations are presented in Figure-2 and 3.

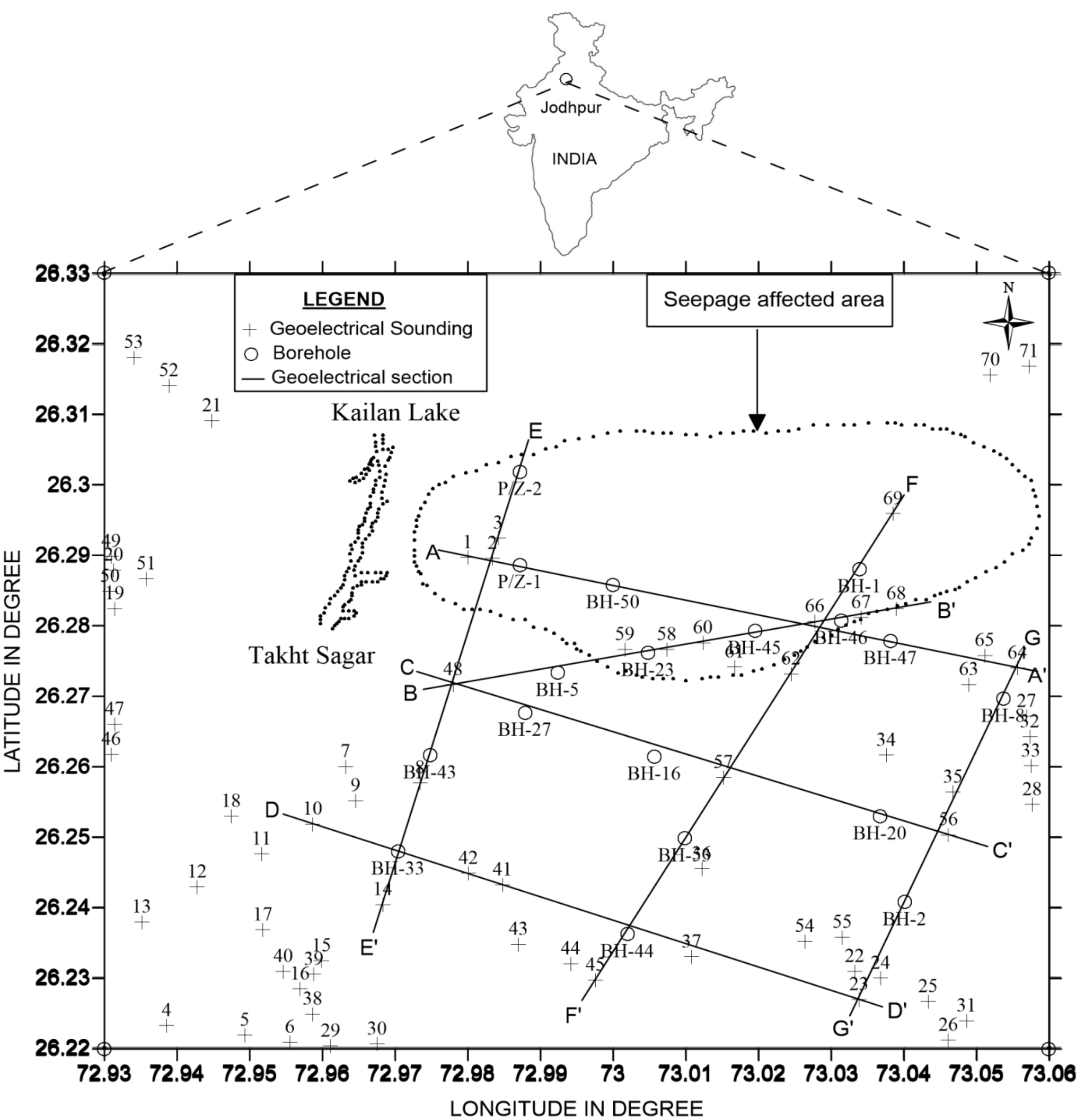
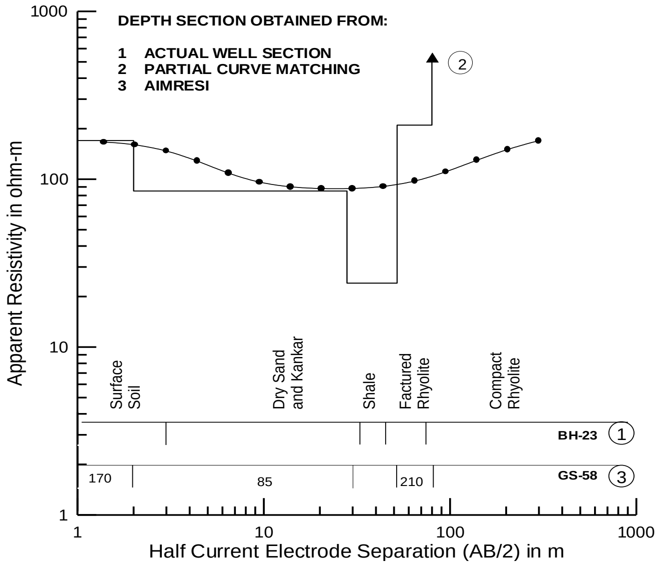
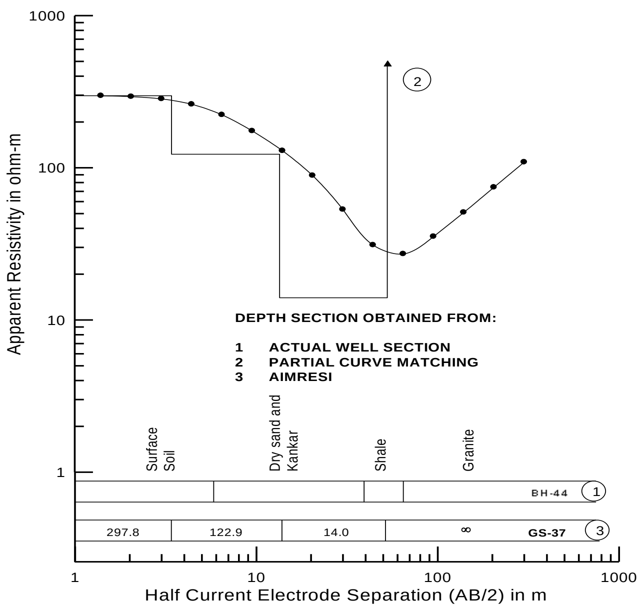


Figure-1: Location map of the study area.



Figuer-2: Interpretation by partial curve matching and AIMRESI computed values and their correlation with GS-58 and actual well-data BH-23.



Figuer-3: Interpretation by partial curve matching and AIMRESI computed values and their correlation with GS-37 and actual well-data BH-44.

Figure-2 shows the correlation of layer parameters obtained at GS-58 location with the nearest available borehole BH-23. The fractured rhyolite is almost correlated with the layer parameters obtained through the geoelectrical sounding interpretation having a resistivity value of 210 ohm-m. The shale bed observed as a third layer in the lithologs is correlated with the resistivity value of 24 ohm-m. The thickness of these layers is not matched with the lithologs data. However, the depth of occurrence of these layers is varying because a distance of about 450m separates them. The upper portion of the geoelectrical sounding results show one more layer between the surface layer and fractured rhyolite due to variation in moisture content but the litholog shows only one layer of alluvium having different grades of soil, sand and kankar. Similarly, Figure-3 shows the correlation between the results of GS- 37 and lithology data of BH-44. In this correlation, the boundary of the formations is not coinciding due to the distance between these locations. However, a shale layer having a resistivity of the order of 14 ohm-m is present below the surface soil and alluvium cover. Based on the study of the correlations of sounding results with lithologs, the resistivity range of individual lithological units was identified and presented in Table-1.

Table-1: Range of resistivities for different lithological units

Lithological units	Range of resistivities in (ohm-m)
Surface soil	50-500
Dry sand and kankar	50-250
Shale	10-50
Fractured sandstone	50-150
Sandstone	150-350
Fractured rhyolite	50-250
Semi-fractured rhyolite	250-500
Compact rhyolite/ granite	> 500

Vertical geoelectrical cross-sections: Seven vertical geoelectrical cross-sections were made in the research area to demonstrate the subsurface distribution of fractured zones and its vertical extent. The geoelectrical cross-sections help to define the potential seepage zone and give a comprehensive image of the subsurface geological formations. The careful analysis of the geoelectrical cross-sections reveals a number of geological formations, as well as distinct weathered and fractured zones, that occurred at various depths in the research area. It is merely presented for simplicity that the geoelectrical portions cover the majority of the seepage region in Jodhpur city.

Geoelectrical cross-section A-A': This geoelectrical cross-section is approximately 8km long and is oriented roughly in the WNW to ESE direction as seen in Figure-4. With the exception of GS-65, where the section has five layers, the covered part of the section shows 4-layer stratification. The section's western end runs through an area with seepage zones. The uppermost layer, which has resistivity readings ranging from 50 ohm-m to 395 ohm-m, is thought to be made up of sand and wind-blown soil. Due to the diverse surface soil types and varying levels of dryness and moisture, the resistivity values of the surface soil vary from location to location.

This layer ranges in thickness from 1 to 3 metres. The entire section reflects several lithological/geological units below the top layer. From top to bottom, the lithological sequence of semi-fractured rhyolite (resistivity's 203-248 ohm-m), fractured rhyolite (resistivity 50-110 ohm-m), and compact rhyolite (resistivity 516-994 ohm-m) is present on the western side of the section, whereas the eastern side of the section is composed of different lithological units. The section shows how these layers' thicknesses vary greatly from location to location. Rhyolite may be seen in the section as being close to the surface on the western side and occurring at a depth of 40 to 100 metres on the eastern side. At geoelectrical sounding locations GS-1, GS-2/3, and GS-65, the groundwater is located in the fractured zone close to the bedrock with a resistivity range of 50 ohm-m to 127 ohm-m. The segment, with the exception of GS-64, has a high likelihood of groundwater seepage since the top part of the western side is covered by semi-fractured to fractured rhyolite. In this part of the segment, it is impossible to completely rule out the possibility of groundwater flowing both horizontally and vertically.

Geoelectrical cross-section B-B': The second geoelectrical cross-section, which likewise travels through the seepage region, is roughly oriented in the WSW-ENE direction. As illustrated in Fig. 5, the section was created using the data of six geoelectrical soundings, GS-48, GS-59, GS-58, GS-66, GS-67, and GS-68. A total length of around 6.6 km is covered by the geoelectrical cross-section. For the correlation of the hydrogeological formation, the lithological data from four boreholes (BH-5, BH-23, BH-45, and BH-46) has been taken into consideration.

The surface layer's resistivity ranges from 42 ohm-m to 170 ohm-m, primarily due to variations in moisture content or various surface soil types. The surface layer's thickness ranges from 1 to 4 metres. Sand and kankar make up the second layer in the area where the resistivity ranges from 40 ohm-m to 120 ohm-m. The layer's thickness varies according to location. On the western side of the section, different lithological units such as shale (resistivity 20-25 ohm-m), sandstone (resistivity 150 ohm-m), and rhyolite (highly resistive) are present from top to bottom. The segment squeezes out the sedimentary strata that are located on the eastern side above the rhyolite. The section shows how these layers' thicknesses vary greatly from location to location. The higher portion of the bedrock (Malani rhyolite) has a semi-fractured to fractured zone where there is groundwater. There is a good chance that groundwater will seep through this zone because the higher part of the western half is covered in sand with kankar up to fractured rhyolite. Along the lineament in the shale/sandstone portion above the rhyolite (bedrock), sedimentary formations may have small cracks on one side of the section. In this part of the area, it is also possible for groundwater to move both horizontally and vertically.

Geoelectrical cross-section C-C': At a distance of roughly 2 km to the south, this portion runs roughly parallel to the cross-section A-A' in the WNW-ESE direction. This portion is 7.6 kilometres long in total. The three geoelectrical sounding interpreted findings, GS-48, GS-57, and GS-56, as well as the three litholog of the boreholes, BH-27, BH-16, and BH-20, were used to produce the geoelectrical cross-section, as shown in Fig. 6. Except for BH-16, where five strata have been discovered, the section shows four layers of stratification. The surface soil is found in the top layer, which ranges in thickness from 1.5 meters to 5 meters and in resistivity from 110 ohms to 260 ohms. A portion of dry sand mixed with kankar that has resistivity ranging from 40ohm-m to 90 ohm-m makes up the second geoelectric layer. This layer has a thickness that ranges from 2 to 10 meters. The section's Jodhpur sandstone, which has a resistivity range of 26 to 36ohm-m, makes up the third geoelectric layer. This layer's thickness varies as well, from 20 to 40 meters. Just above the Malani rhyolite, a further thin layer of shale can be discovered beneath the BH-16. Finally, the rhyolite that is semi-fractured to fracture is represented by the last layer, which ranges in resistivity from 500 ohm-m to 250 ohm-m (from left to right). The semi-fractured zone of rhyolite is where the groundwater is found in boreholes BH-27 and BH-16 with resistivities ranging from 250 to 500 ohm-m, and the fractured rhyolite is where the groundwater is found in borehole BH-20 with resistivity ranging from 125 to 180 ohm-m above the bedrock (Malani rhyolite). There is a good chance that groundwater will infiltrate via pore spaces in these formations since the upper part of the segment is either made up of sandstone or fractured rhyolite.

Geoelectrical cross-section E-E': As shown in Figure-7, the geoelectrical cross-section was created using the findings of four geoelectrical soundings, GS-2/3, GS-48, GS-8, and GS-14. Utilised lithological data from boreholes BH-43, BH-33, and piezometer P/z-2 for the hydrogeology correlation. This portion is 4 kilometres to the east of the Kailana-Takht Sagar and runs parallel to it. The entire geoelectrical cross-section displays four-layer stratification. The soil surface layer covered by the segments E-E' has a resistivity ranging from 110 ohm-m to 395 ohm-m. The presence of different types of soil and moisture content are the main causes of the difference in the resistivity values of surface soil. This layer ranges in thickness from 1 to 5 metres. The second layer, which has a resistivity of 203 ohm-m, is made up of semi-fractured rhyolite on its northern side, with a resistivity range of 40 to 111 ohm-m, and dry sand and kankar on its southern side. The third geoelectrical layer in this series is made up of fractured rhyolite with a resistivity of 110–125 ohm–m on the northern side and a thick layer of shale with a resistivity range of 10-29 ohm–m on the southern side, present between BH–43 and GS–14. Both sections of both formations are almost completely squeezed out. On the northern side of the section, the last layer symbolises the resistant substratum, or bedrock, while the remaining portion denotes the presence of a semi-fractured zone. It may not be possible to rule out groundwater seepage in this semi-fractured zone.

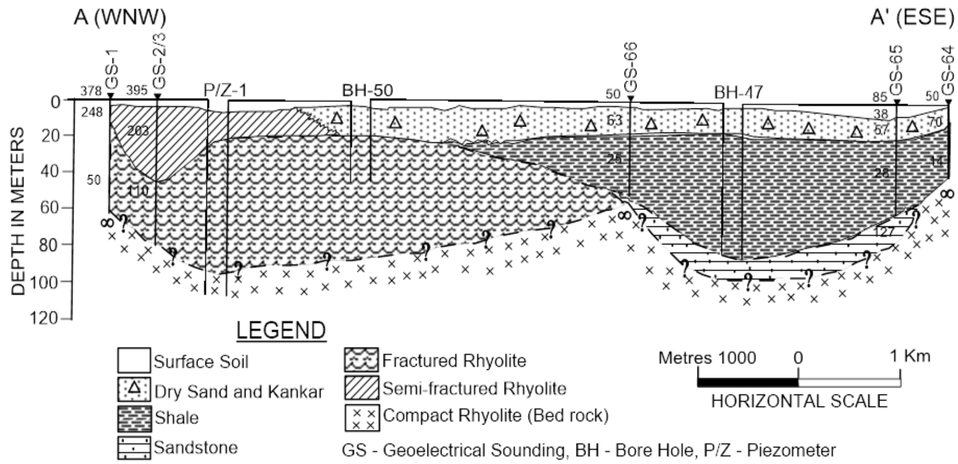


Figure-4: Geoelectrical cross section A-A'.

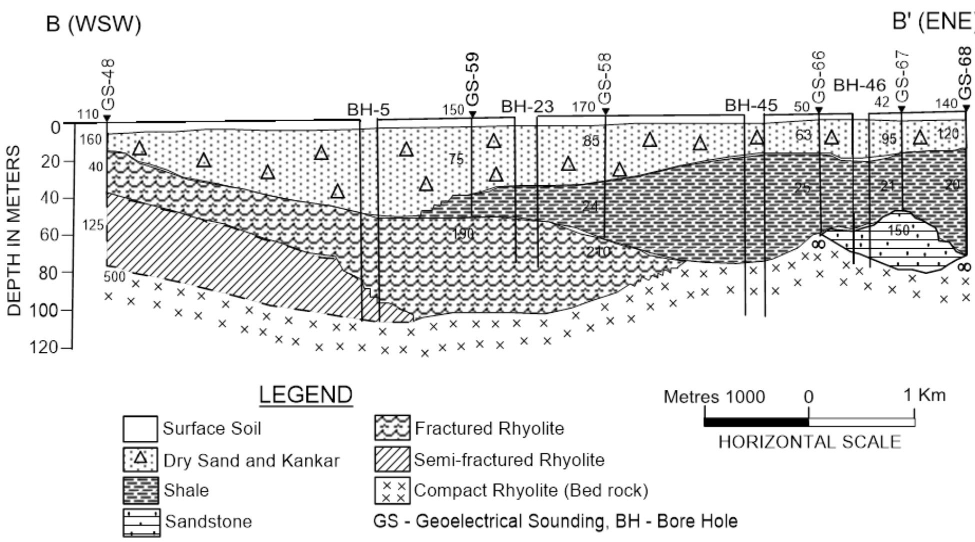


Figure-5: Geoelectrical cross section B-B'.

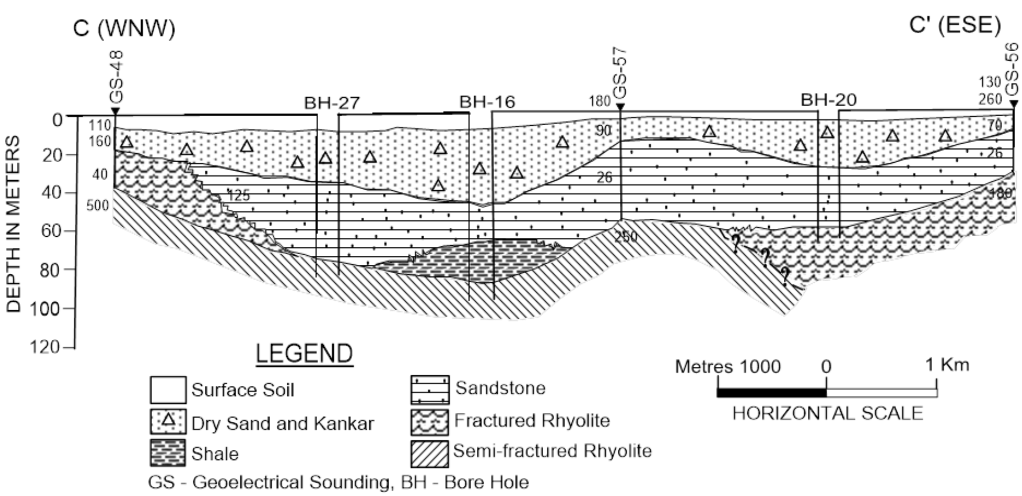


Figure-6: Geoelectrical cross section C-C'.

Geoelectrical cross-section F-F': Most of the seepage area is also covered in this section. As shown in Fig. 8, the cross-section F-F' integrates the findings from five geoelectrical soundings, namely GS-69, GS-66, GS-62, GS-57, and GS-45, and runs roughly in the NE-SW direction. Along the segment, there is information on the lithology that was gleaned from the three available boreholes, BH-1, BH-53, and BH-44. This geoelectrical cross-section measures roughly 8.8 kilometres in length overall. Four-layer stratification is seen over the whole geoelectric cross-section.

The section consists of the top layer of surface soil, which varies in thickness from 1 to 6 metres and has a resistance ranging from 40 ohms to 180 ohms. The second layer in this sequence is made up of dry sand and kankar, with varied thicknesses throughout the segment, and has a resistance range of 34 ohm-m to 93 ohm-m. This stratum ranges in thickness from 8 to 32 metres. Shale is present throughout the section with the exception of the middle area, where sandstone is found, according to the third geoelectrical layer, which has resistivity variations between 10 ohm-m and 26 ohm-m. This stratum has a thickness that ranges from 32 to 48 metres. Rhyolite that is compact on the northern side, semi-fractured in the middle, and granite on the southern side make up the final stratum. Sand, sandstone, and/or shale sedimentary strata, which may have minor fissures along the lineament above the bedrock, cover the upper part of the section. These fractures and fissures could provide support for groundwater seepage in both horizontal and vertical directions.

Horizontal geoelectrical cross-sections: The only subsurface distribution of lithology and fractured zone along a line, including the sparse findings of geoelectrical soundings and borehole lithologs, is shown in the vertical geoelectrical cross-section. The horizontal geoelectrical cross-section can indicate the overall lithology and spatial distribution of fractured zones at various depth levels in the studied area. With the aid of interpreted layer characteristics from geoelectrical sounding and lithological data obtained by boreholes in the x-y plane, the five horizontal geoelectrical cross-sections at chosen depth levels of 10, 20, 30, 45, and 60 m were created. The fractured and partially fractured zones that support groundwater seepage into the subsurface are clearly visible in the horizontal cross-sections. The next section provides a description of each unique cross-section.

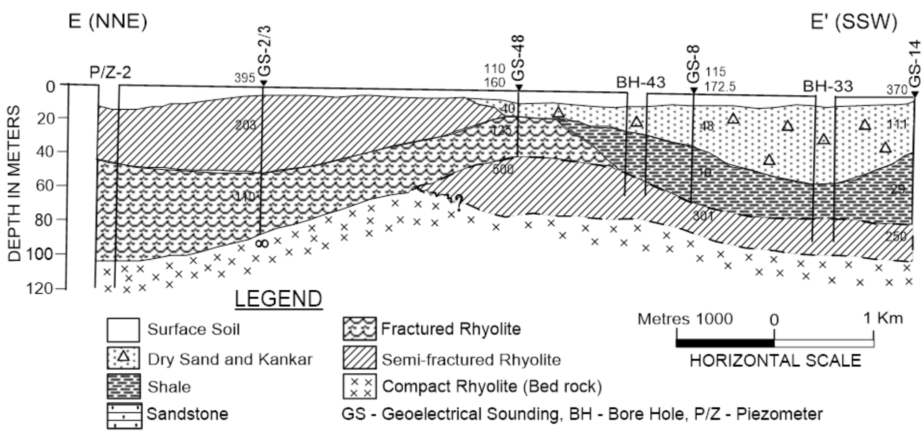


Figure-7: Geoelectrical cross section E-E'.

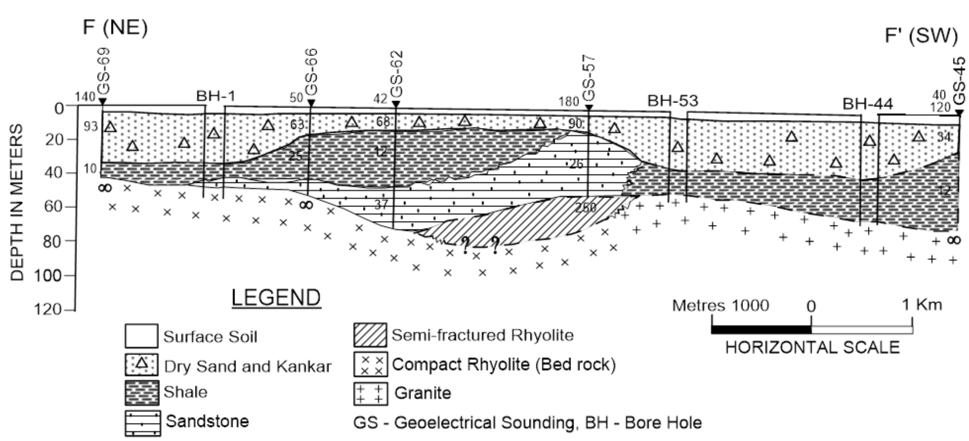


Figure-8: Geoelectrical cross section F-F'.

Horizontal cross-section at 10 m depth: To show the areal distribution of lithology near the surface layer, a horizontal cross-section at 10m depth was prepared. The cross-section shows similar characteristics observed at the ground surface with a few exceptions, as shown in Figure-9. An isolated patch of semi-fractured rhyolite is exposed in the east of Kailana Lake - Takht Sagar and almost parallel to it. In the south-east corner, a strip of shale is present in the section. Two more patches of similar nature are seen near the eastern boundary of the study area. The remaining part of the area is covered by dry sand and kankar. The hard rock patch of rhyolite is not seen at this depth level throughout the area.

Horizontal cross-section at 20m depth: The second horizontal geoelectrical cross-section was prepared to show the areal extent of the formations at a depth of 20m, as shown in Figure-10. On the basis of the resistivity contour at this depth, the entire area gets divided into five types of lithological units. A thick strip of dry sand and kankar is seen in the central part of the section, which extends from the SW to the NE direction. Two more small patches of the same formation are also seen near the eastern boundary. Two isolated patches of small sandstone are also present in the section. As compared to the previous section, a patch of semi-fractured to fractured rhyolite (near Kailana Lake-Takht Sagar) is seen at the same location with a higher areal extension of fractured rhyolite. The seepage of groundwater through this fractured zone cannot be ruled out.

Horizontal cross-section at 30m depth: Figure-11 shows the horizontal geoelectrical cross-section at a depth of 30m. The section clearly indicates that a strip of dry sand and kankar is present in the central part of the area, extending from the south-west corner towards the north-east direction. One small patch of the same nature is seen in the south-east corner. In the south-east, one-fourth of the area is covered by shale except for a few patches of sandstone, and dry sand and kankar. Two more small patches of shale are seen on the south-west side of the section. A thick strip of sandstone is encountered at this depth level, which is extends from the middle to the eastern boundary, covering a small patch of compact rhyolite. As compared to the previous section, a patch of semi-fractured and fractured rhyolite is seen at the same location, i.e., the north-west side. The presence of fractures in this portion of the area provides an easy pathway for the seepage of groundwater towards the city area.

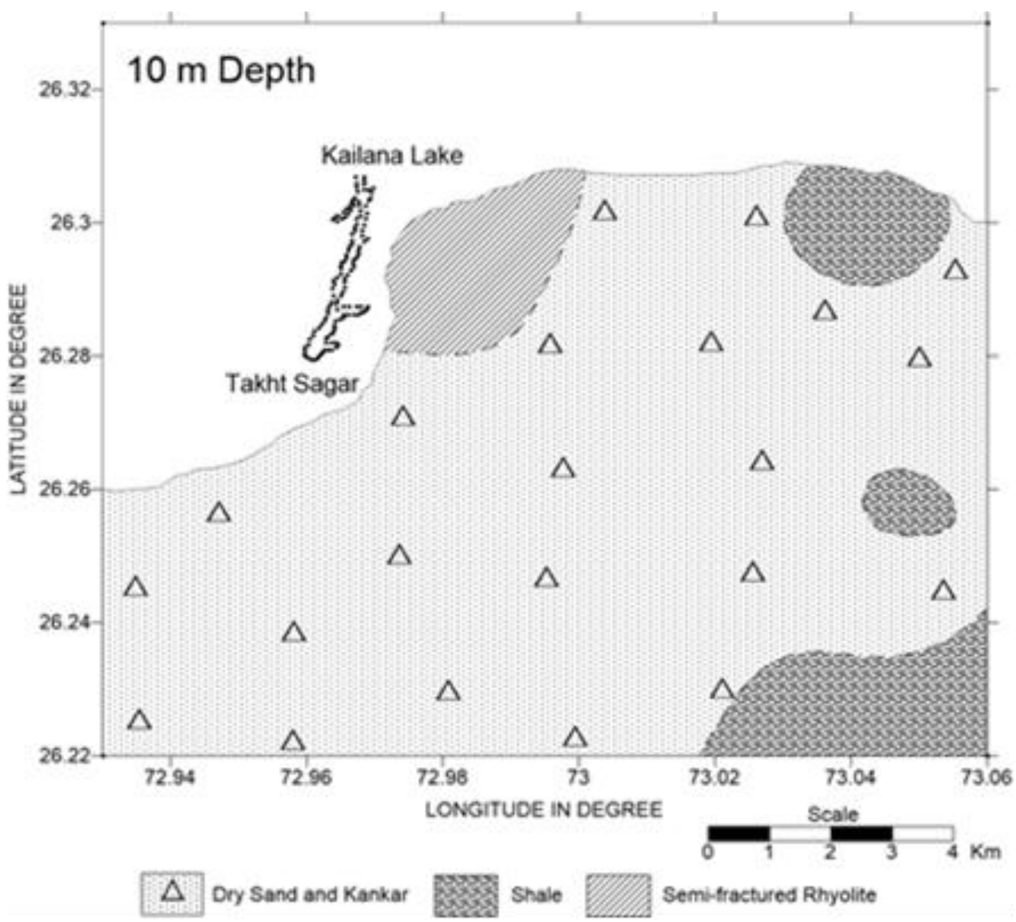


Figure-9: Horizontal geoelectrical cross-section at 10 m depth.

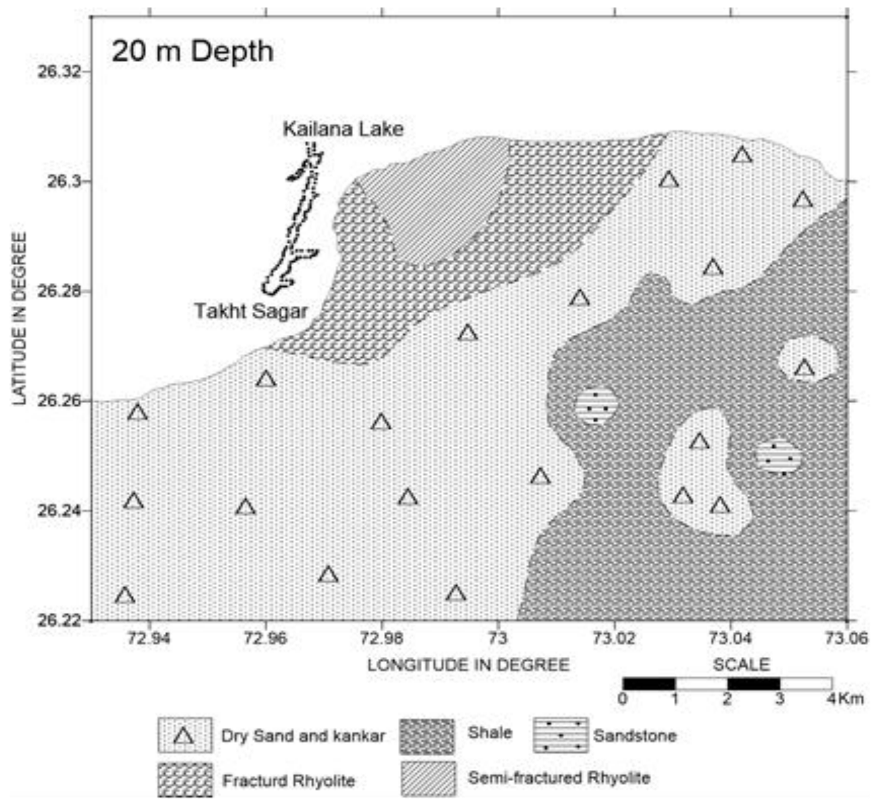


Figure-10: Horizontal geoelectrical cross-section at 20 m depth.

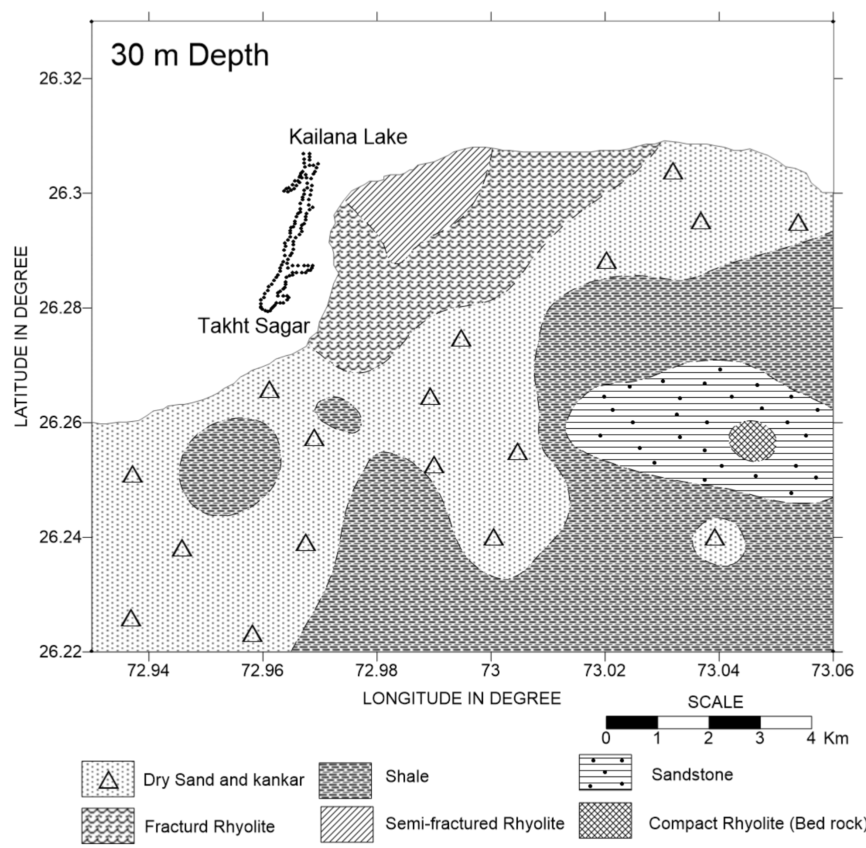


Figure-11: Horizontal geoelectrical cross-section at 30 m depth.

Horizontal cross-section at 45m depth: The section clearly shows that the semi fractured and fractured rhyolite is dominant at 45m depth having more extension near Kailana Lake-Takht Sagar. One more patch of fractured is seen near the eastern boundary. The possibility of seepage of groundwater cannot be denied through these zones. The formation changes from place to place due to the complex geology of the study area. The 50 per cent of the area is occupied by shale that is extended from the south-west corner towards the north-east direction. A narrow long strip of sandstone is present and extended approximately in the NW-SE direction. As compared to the previous section the strip of sandstone is shifted from the eastern boundary towards the western side of the study area as shown in Figure-12. The areal extent of compact rhyolite present in the earlier section is increased at this depth.

Horizontal cross-section at 60 m depth: The last horizontal geoelectrical cross-section was prepared at a depth level of 60 m as shown in Figure-13. The figure clearly indicates that more than 50 per cent of the area is occupied by fractured to semi-fractured rhyolite and sandstones at this depth level. The section also shows the presence of deeply fractured zones parallel to Kailana Lake -Takht Sagar above the compact Malani rhyolites (bedrock) in the area. A thick patch of shale is encountered in the south-west corner of the area. This section indicates that the dimension of hard rock is increased in the south-east and north-east corner of the area.

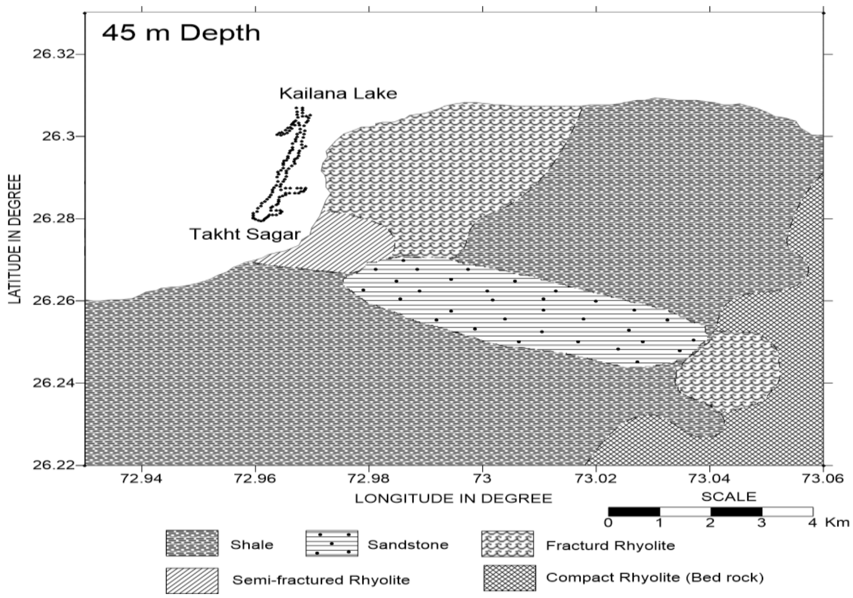


Figure-12: Horizontal geoelectrical cross-section at 45 m depth.

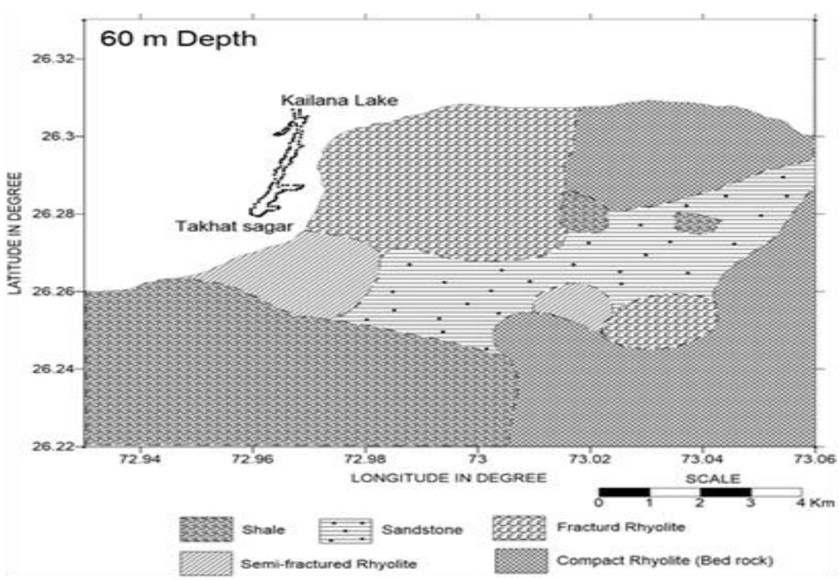


Figure-13: Horizontal geoelectrical cross-section at 60 m depth.

Conclusion

The geoelectrical resistivity measurement was successfully performed in the mapping of the spatial distribution of groundwater bearing fractured zones, which support groundwater seepage in the study area. Highly weathered, partially fractured, and groundwater saturated fractured zones are found in the research region from the surface to greater depths, according to the vertical geoelectrical cross-sections. In many locations, the soil layer that extends up to further depths meets the weathered formation right below the surface. To determine the range of resistivity of the formations in the research area, the geoelectrical sounding layer parameters are connected with the closest known borehole lithology.

The horizontal geoelectrical cross-section shows an isolated patch of semi-fractured rhyolite exposed in the east of Kailana Lake-Takht Sagar at 10m depth. A similar path of semi-fractured to fractured rhyolite is seen at the same location, with higher areal extension at 20m depth. Also, a similar patch of semi-fractured and fractured rhyolite is present at the same location, i.e., on the north-west side at 30m depth. The semi fractured and fractured rhyolite is dominant at 45m depth, having more extension near Kailana Lake-Takht Sagar. The horizontal geoelectrical cross-section at a depth level of 60m clearly indicates that more than fifty percent of the area is occupied by fractured to semi-fractured rhyolite and sandstones. The section also shows the presence of deeply fractured zones parallel to Kailana Lake-Takht Sagar above the compact Malani rhyolites (bedrock). It is inferred from the study that many weathered, semi-fractured and fractured zones are present in the area and contribute to groundwater seepage in the city area.

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