

Composite Electrical Geophysical Techniques for Ground Water Exploration in the Hard Rock Area of Bundelkhand, Uttar Pradesh, India

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Abstract: Hard rock terrains of Bundelkhand region are well known for a serious shortage of groundwater, particularly in the summer season. Groundwater occurs in limited areal extent in secondary porosity within hard rock formations commonly developed due to fracturing, weathering, jointing, faulting, etc. In present study Gradient profiling (GP) followed by vertical electrical sounding (VES) has been successfully utilized to locate the water saturated fractures in hard rock areas of Kabrai Block, Mahoba District of Uttar Pradesh India. To begin with, the GP survey was conducted with fixed current electrodes separation of 600 m and the potential electrodes separations of 10 m for all the points lying between the central region of the profile (about 33% of the total spread) at a station interval of 5m. The response of GP analysis set the sound base for the VES sounding survey, further the VES sounding survey carried out at three different stations where relatively low resistivity observed at the profile and hence the promising position for groundwater occurrence. The interpretation of VES results shows the presence of fractured to the highly-fractured zone at the low resistivity observed on GP profile. A test borehole drilled at the optimistic and final location, which yields a continuous groundwater discharge of 300 LPM, a good yield in water scarce area and boon for the local people. The present study demonstrated that composite 1D (GP and VES) resistivity techniques and its encouraging advantage in locating groundwater in hard rock areas.

Keywords: Hard rock, Gradient Profiling, Groundwater, Secondary porosity and Fracture

1. Introduction

Basically, rocks and minerals are nearly insulators in nature, but the fluid presents in between voids let the rocks to proceed with the current.

Consequently, the variation of currents in the Lithology and rock prominently affected by the presence of water in pores and its movement. This is the primary principal utilized by the passive geoelectrical methods. From the available all geophysical methods viz shallow seismic, gravity, microtremor, and electrical survey. Generally, an electrical survey of the various sort is employed for the search of groundwater by delineating water-bearing zones. Amongst geoelectrical surveys are conducted either to find out lateral changes of resistivity from place to place up(resistivity profiling) or to find out resistivity variation with depth (resistivity sounding). The profiling is done only qualitative evaluation whereas sounding is conducted for one-dimensional quantitative evaluation of thickness and resistivity different at a specific location. If the objective of the survey is to find out the depth and extent of water-bearing layers in the thick alluvial covered areas then resistivity sounding alone is sufficient to provide the required information. However, in thin soil covered hard rock areas where groundwater occurs in secondary porosity with limited extent, developed due to weathering, fracturing, joints, etc., geoelectrical sounding alone may not result productive alone. Hence, there is a need for integrated resistivity surveys to identify the presence of fracture zones in the hard rock geological settings.

Unlike alluvium planes of enormous groundwater availability, the water in hard rock's terrains found diversified both laterally and vertically. The potential groundwater resources in hard-rock terrain are geologically associated with fractured and fissured zones. The subsurface water is contributed by the surface weathering, connected with faults, joints, and fractures. The thickness of the weathered and fractured section signifies the potential groundwater availability and quantum of groundwater. The resistivity of fractured rocks and unweathered hard rock bring marginal resistivity contrast in the absence of saturated zones. But when the fractured rock is saturated with water the significant resistivity contrast will be there. That can be demarcated on the resistivity profile graph with kink. The fractured zone shows lower resistivity than hard rock's¹. The VES geoelectrical sounding in alluvium plain is most productive with finding aquifer zones. But groundwater trap in fractures and faults are territorially⁶ diversified and geologically random in nature. Hence, groundwater exploration becomes a challenging task in the hard rock terrains. As a consequence manifold, geoelectrical soundings fails in these type of geological setting and it costs huge to the organizations and government.

Currently, combined geophysical surveys have been carried out for groundwater exploration in different hard rock terrains, experimented by Bernard and Valla², Rønning et al.³, Kaikkonen and Sharma⁴, Ramteke et al.⁵, Krishnamurthy et al.⁶, Yadav and Singh⁷. Correlations between electrical resistivity and geotechnical parameters also investigated by Devi et al.⁸. To resolve the equivalence problem the composite geophysical techniques have been applied by the mentioned researchers. This integrated approach and its practical application have been talked about by Yadav and Singh⁷, effectively employed a GP survey followed by geoelectrical sounding for delineation of water-saturated fracture zones in Gurudev Nagar, Mirzapur district, Uttar Pradesh, India.

2. Study Area and Hydrogeological Settings

The present study has been carried out in Kabrai block 34 km from the Mahoba district headquarter of Uttar Pradesh. The Region lies in the Bundelkhand area of Uttar Pradesh state of India (Figure.1). The area is facing water scarcity, particularly in the pre-monsoon season. The study area lies on the 80.000879 Northing and 25.413951 Easting with an elevation of 153 msl. Three ridges are clearly shown through visualization including their respective elevation. Additionally, a large water body as a pond is also present in the proximity of the survey profile figure. 3 (A & B). Due to geological and geomorphological settings of the region, the study point signifies the low groundwater potential zone of the district as shown in figure.2

Through surface geomorphological and geological observation and soil type analysis it is clear that area covered with upper fills weathered soil, and exposed granitic boulders. Surface weathering, vertical joints, and faults are clearly observable in figure 4 (A & B). The average annual rainfall of the area is 864 mm. The climate is typical subtropical stressed by long and intense summer. About 87% of the annual rainfall is received from the south-west monsoon. May is the hottest month with temperature shooting up to 47.50C. The major source for recharging the area is rainfall during the monsoon season.

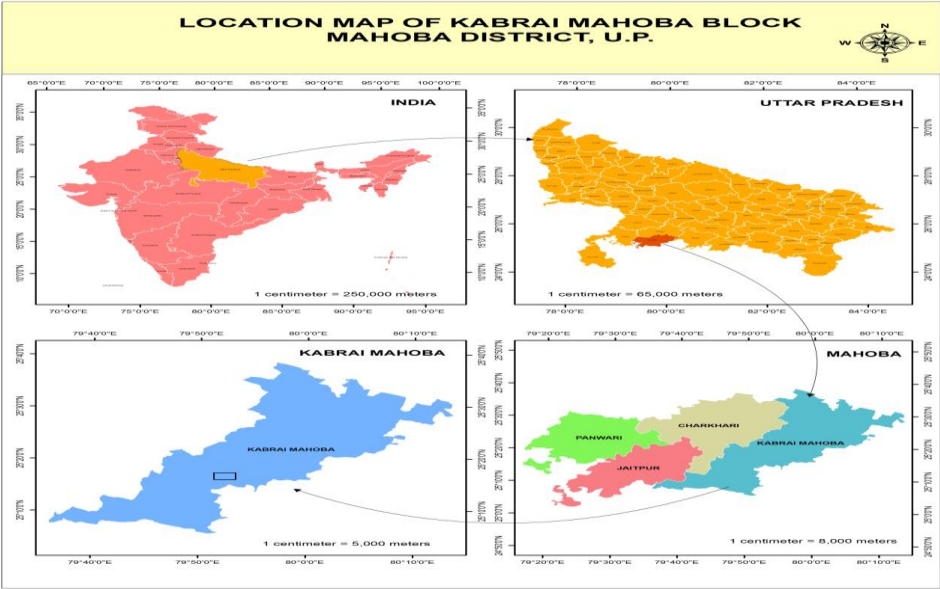


Figure 1. the Study area lies in the Kabrai block of the Mahoba district of Uttar Pradesh. The study the area is part of Bundelkhand region stretched in Uttar Pradesh state, India.

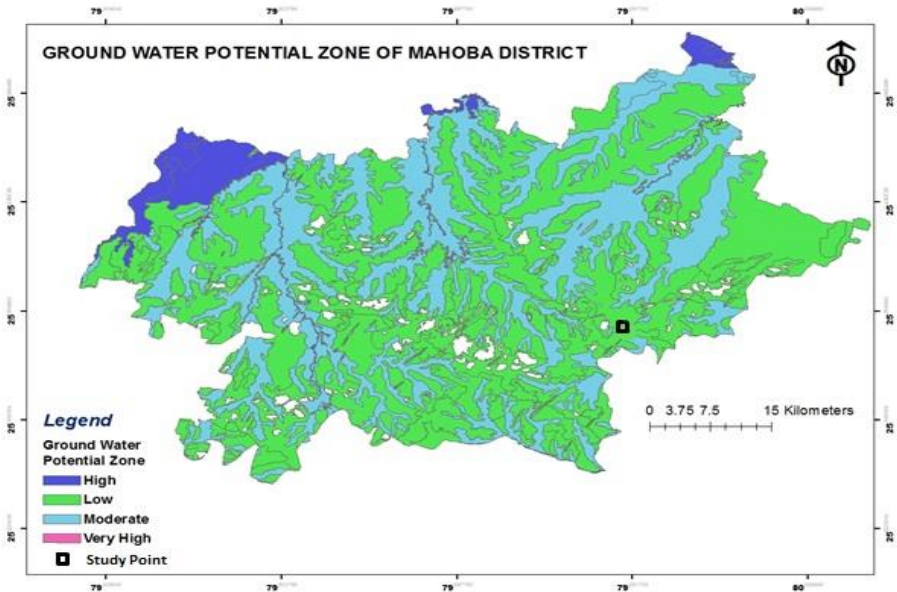


Figure 2. Groundwater potential zone of the Mahoba district comprising study area.

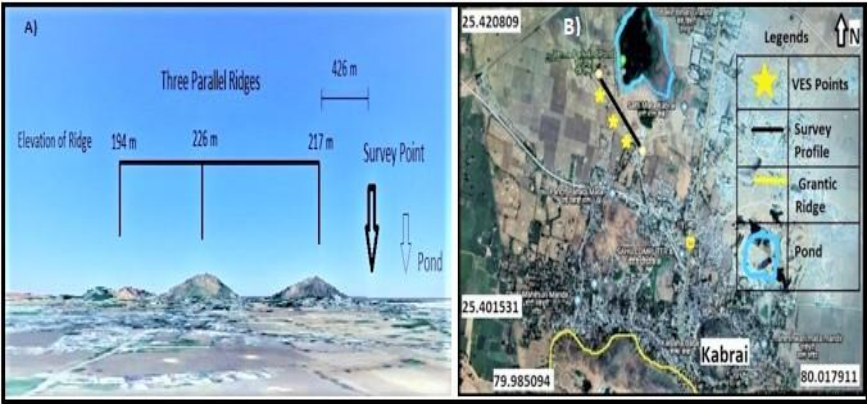


Figure 3. A and B, The satellite image of the study area observed that survey point lies between the pond and one of three parallel ridges. The profiling is much closer to the large water body. (Image via Google Earth Pro)

The area unconformably is overlain by Quaternary alluvium consisting of gravel, sand, and clay. The thickness of these materials known as overburden varies from 7.00 m to 35.00m. The sand content is less than the clay. The area mainly comprises of hard rock formation of Bundelkhand massif granite, gneiss, and schist dolerite and quartz reef. The rainfall does not percolate and stores subsurface since the rocks are of massive & compact nature. The vertical, as well as horizontal joints, are encountered in the granites in different parts of the area. Consequently, secondary porosity in the form of joints and fissures allow some water to percolate. That available surface water percolated down and stored as groundwater.

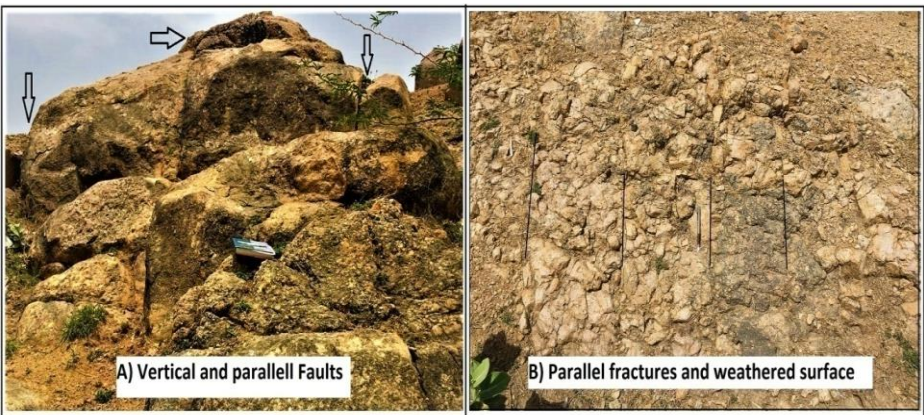


Figure 4. A) The vertical and parallel faults and B) fractures as appeared on the weathered surface. These fractures and faults are perpendicular adjacent to the profiling line.

The district lies in Yamuna Drainage Basin area aquifers boundary in finding at the intersection of Banda plain and Rocky surface. Aquifer characteristics are as porosity is pours, the yield is medium and water quality is potable. In the region, the groundwater occurs in two forms

- (i) Shallow zone, the phreatic conditions is only limited to the overburden the depth of which is maximum up to 35-40 m.
- (ii) Deeper fracture zones, the groundwater occurs in fractures and joints, the potential fractures are encountered from around 35 m to 96 m in some places. Being the hilly and rugged terrain the occurrence of groundwater in this terrain is highly uncertain. (CGWB Brochure, Mahoba District).

3. Methodology and Survey Design

In three dimensions the Laplace equation is equivalent to the inverse square law of gravitational or electrical attraction (in source-free regions; in regions with sources, it becomes Poisson's equation). Examples of potential fields include the field of the gravity potential, static electric and magnetic fields.

A potential field is any physical field that obeys Laplace's equation, this equation is stated below $\Delta^2\phi = 0$ or $\Delta\phi = 0$. Geoelectrical survey technique is the potential field governed non-destructive geophysical technique. In which potential field is governed by the unified contribution of distance between the source and measuring point of electric potential. But this field is also contributed by effectual formation material resistivities. The potential field changes due to the distance between the source and measuring point, together with formation resistivity of the material down to the traced depth.

Commonly, geoelectrical surveys are conducted either to determine the lateral or vertical resistivity variations. For lateral variations, Gradient Resistivity Survey is employed while for vertical (Vertical electrical Sounding) VES. The profiling looks for qualitative evaluation whereas sounding is carried out for quantitative assessment of thickness and resistivity of various subsurface layers.

Various works in this regard has been contributed by these researchers, Kearey and Brooks ⁹, and Telford et al. ¹⁰ where comprehensive details with respect to resistivity survey and geometries of a gradient array have been provided. In respect to resistivity and chargeability for gradient array over resistive and conductive veins theoretically provide by Furness ^{11,12}.

Yadav and Singh ⁷ discussed the application of gradient array with a mobile pair of a potential dipole for evaluating lateral ground variations.

GP Array: The array of gradient profiling (GP) consists of two fixed current electrodes separated by a large distance and two current electrodes serving as a potential dipole with relatively smaller electrode separation. The resistivity is measured in the central region of the potential dipole, whereas current electrode remained fixed. The potential dipole measures the one-third section of the whole current electrode line profile. i.e. 33% segment between the of broadly separated current electrodes along the profile line. In the case of homogeneous unvarying subsurface layers; the potential field remains constant as a consequence of uniformly generated horizontal electric field. However, with confronting any sort of inhomogeneity between current and potential electrode regions yields variation. This resistivity variation contributed by minerals, rocks and pore fluid (if any) collectively is measured and plotted with the profile. The two-dimension resistivity variation graph is marked with several high and low points. The further vertical resistivity sounding survey point and its recommendation depend on these precise low points.

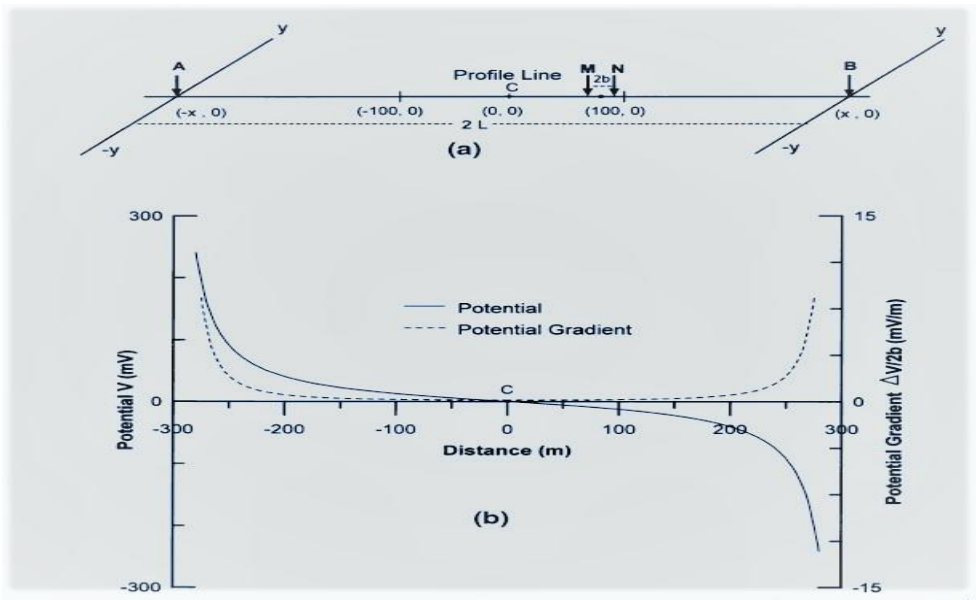


Figure 5. (a) General layout of gradient measurement of the potential field where A and B are current electrodes, and M and N are potential electrodes and (b) distribution of potential and gradient of potential along the line at the surface of homogeneous earth.

For a fixed current electrode separation $AB=600$ m over homogenous subsurface, the corresponding theoretical aftermath of potential (mV) and potential gradient (mV/m) has been plotted. It demonstrates that the curve for potential gradient value is nearly constant in the central one-third region. However, considerable changes in the potential gradient external to the determined one-third section can be noticed. Hence, the array is specific to calculate the potential gradient within the certain designed limit as $L \geq 3x \geq 0$. It is emphasized that the field strength and depth of investigation would be nearly constant in the central region bounded by $x = L/3$ in the case of the homogeneous earth.

The mainstream layout of the gradient array has been shown in figure 5, together with homogenous earth the predicted theoretical deviation of potential and potential gradient along with a profile between the current electrodes. The mathematical expressions for finding the variation in apparent resistivity variations can be drawn from figure 5 as,

$$(3.1) \quad \rho(a) = \frac{2\pi}{\left(\frac{1}{(L+x-b)} - \frac{1}{(L-x+b)} - \frac{1}{(L+x+b)} + \frac{1}{(L-x-b)} \right)} \frac{\Delta V}{I},$$

where $2L$ and $2b$ are the distances between the current electrodes and the potential electrodes, While x is the distance between the centers of the current and potential electrodes, ΔV is the observed potential difference, and 'I' is the input current. The computation of potential and potential gradient is done keeping $(I\rho/2\pi) = 5,000$ ($I=1,000$ mA, $\rho=31.4$ ohm-m).

In figure (Figure-5),

- i. A couple of current electrodes A and B are fixed at a distance of 600 m and this position can also be switched from B to A.
- ii. The task is to scan the fixed central one-third segment of the profile line between the current electrodes (-100 & $+100$ m both sides from center C). The selected patch is scanned at regular station intervals of 5 m to achieve the smallest possible spacing of potential electrodes.
- iii. The condition to select the particular spacing of potential electrodes may be taken as 10 or 20 m with $(L-x) \gg 5b$ condition satisfied, where L is the half of separation between two current electrodes; b is the half of the separation between two potential electrodes; and x is the distance between the center of the current electrodes and potential electrodes, to calculate the potential gradient ¹⁰.

- iv. The whole array layout can be planned and carried out as per the research interest and available space on filed.
- v. For the qualitative interpretation of the GP survey, the apparent resistivity ' ρ ' plotted against the surface profiling to obtain the cumulative effect of the geoelectrical layer. The outcomes of this method can be used for preparing an iso-apparent surface electric resistivity map and pinpoint the VES survey location.

VES Array: Vertical Electrical Sounding (VES) in precise called sounding is a competent electrical method to determine the 1-dimensional subsurface layer parameter. The VES array consists of four collinear metallic electrodes. The outer two electrodes are current (source) electrodes while the inner two electrodes are potential (receiver) electrodes. This method is used to find the aquifer thickness and fracture depth. However, its combination of gradient profiling (GP) is an optimistic fusion and exploration approach to locating groundwater in hard rock areas. Because, in thin soil cover hard rock terrains the chances of groundwater restricted to secondary porosity with limited extent, developed as a result of surface weathering, fracturing, joints, etc., so vertical electrical sounding may not synthesize productive results alone. This type of survey plan and execution will lead to improper site selection that may result to fail dry drilling. Hence, there is a need for integrated resistivity surveys to identify the presence of fracture zones in hard rock areas. The VES array geometry satisfies the condition $AB \geq 5MN$ and $x=0$.

The mathematical expression for apparent resistivity $\rho(a)$ in vertical electric sounding is given by.

$$(3.2) \quad \rho(a) = \frac{\pi}{2} \frac{(L^2 - x^2)}{x} \frac{\Delta V}{I},$$

where L is the distance between the center and current electrodes, X is the distance between the center and potential electrodes, ΔV is the observed potential difference, and ' I ' is the input current.

Layout Plan:

- i. The potential electrodes are fixed at the center O of the electrode array with relatively a small separation MN , typically less than one-fifth of the separation of the current electrodes AB as shown in figure.6

- ii. The current electrodes are extended to a greater separation with the designed mathematical pattern along the fixed center point AB.
- iii. The potential electrodes remain in the same position as far as the observed voltage becomes too small to measure, then these two also forwarded along the designed profile length.
- iv. The bulk average resistivity of all rock-forming minerals, depositional layers, and rock affect the current flow. Average resistance of these rocks obtained by dividing the measured potential difference by the input current then this resistance is multiplied by an array-specific geometric factor.
- v. For quantitative interpretation layer parameters as true resistivity ' ρ ' and layer thickness, ' h ' of a geoelectrical layer is obtained. The results of this method are represented can be represented by the 1-dimensional subsurface model.

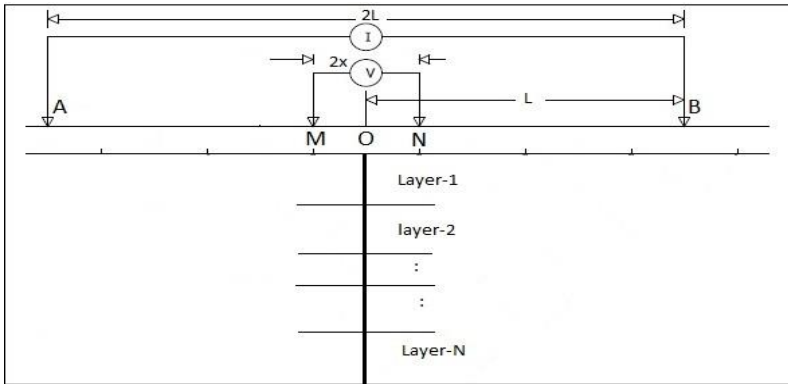


Figure.6 The survey layout of the Vertical Electrical Sounding and one-dimensional findings at center points as layers.

4. Results and Discussion

By observing the area on the given top sheet (number 63C/3), through surface indicators like weathered zone, fractures and orientation of lineaments. Along with the depression of the undulated surface and available nearby drainage. The GP gradient profiling has been conducted in the optimistic interested depressed zone. That is lying parallel to the roadside and in between the first ridge and much closer to the large water body. The direction of the profile was North-South, parallel to the ridge, approximately. The current electrode has been fixed with available separation of 600 m in a straight line. And, potential electrode dipole separation was taken as 10 m with a close station interval of 5 m along a

profile, to examine the 200 m section in between the central interested region, precisely; i.e. one-third of the profile.

Along with the given profile, the apparent resistivity measured with a movable potential dipole from the center at (-100 to +100). For qualitative interpretation of profiling resistivity variation data (apparent resistivity versus distance) plotted on linear scales. With distance displayed on the horizontal scale and while the apparent resistivity on the vertical scale as shown in figure-7. Conceptually, the asymmetric 'low' with 'high' apparent resistivity variations on either side is the recurring response of the background resistivity of subsurface features. However, the gradient profiling analysis limited to the qualitative interpretation of anomaly, rather than quantitative. It becomes complicated by means of structure or shape of the subsurface body that don't influence the gradient measurements considerably due to equivalence problems (Schluz¹³). The qualitative interpretation of structural fractures, Faults or dipping bodies are portrayed in the form of these asymmetrical curvatures. This suggests the prominent low observed along each profile indicates the presence of a low resistive body (probably fractured rocks) and vice versa.

The apparent resistivity (ohm m) variations in the magnitude observed throughout the 200 m section. The total variation fluctuates in the midst of 208.5-ohm m as a minimum to 521.5-ohm m maximum. The three geoelectrical soundings viz. VES-1, VES-2, VES-3 were conducted at position (P-1, at -78m), (P-2, at +30m), (P-3, at +75m) as shown in figure-7 along with the profile, respectively. Distinguished minima obtained at three stations at these VES points viz P-1, P-2, and P-3 along with the profile. These indicate the decent fractured zone of 14 m (at P-1) width, and 2 m (at P-2) and 7 m (at P-3) width.

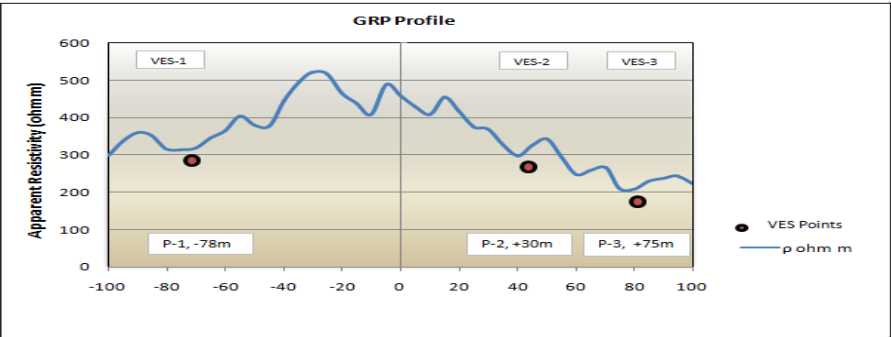


Figure.7 The layout of gradient apparent resistivity profiling in linear scale. The VES (Vertical Electrical Sound) position is denoted by VES-1, VES-2, VES-3 as P-1, P-2 and P-3 respectively at their location mark along with the profile.

All three points correspond to the relative local resistivity minima obtained, analytically. The corresponding layer parameters are obtained through the Interpex 1 Dimensional software package. The respective layer parameter of individual VES points is clearly shown along with the lithology in figure-8. The layer parameters were initially obtained using a partial curve matching technique (Koefoed ¹⁴) with the help of three-layer master curves and auxiliary point charts.

It is significant to remark that the geoelectrical sounding site selection is based on the lowest encountered apparent resistivity observed along with the GP profile (Yadav and Singh⁷). For the promising water prospecting spot, the surfaces fractured zones revealed along with these profiles as shown in figure 4, are qualitatively merged with the relatively low resistivity surface domains derived through GP analysis. Then analytically three interesting points (viz. VES-1, VES-2, and VES-3) were recommended for the further geoelectrical sounding and test drilling.

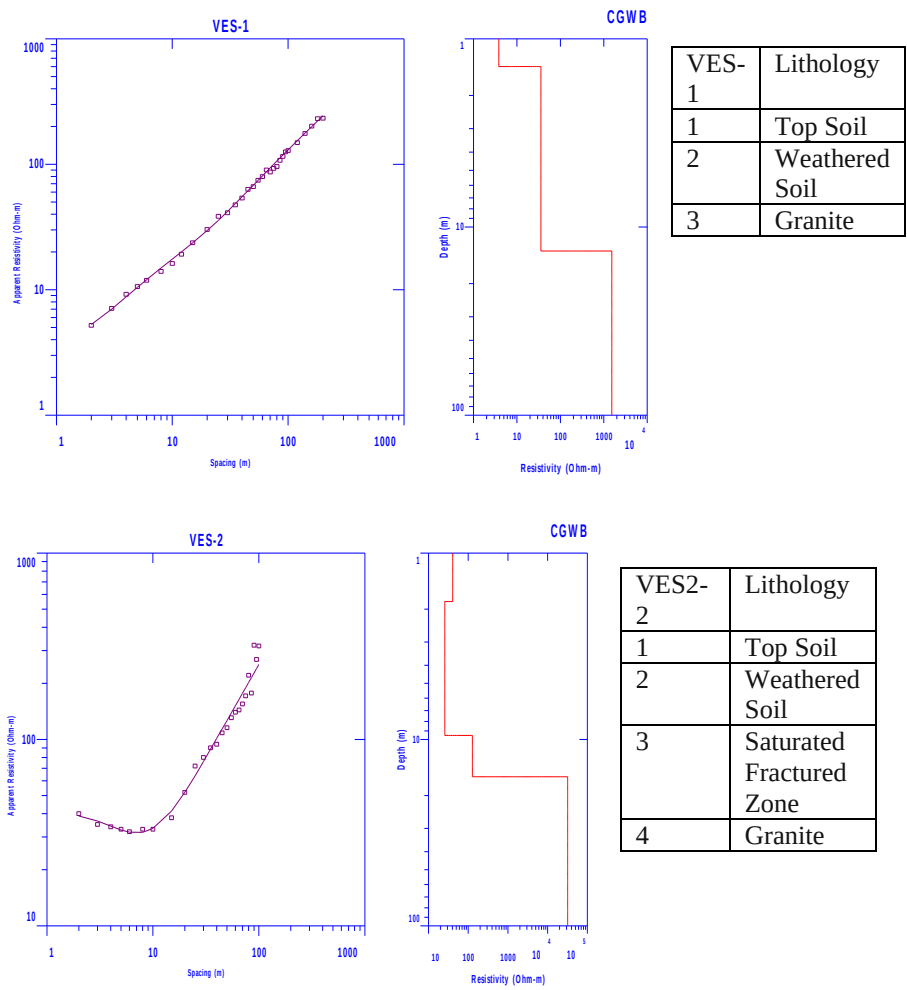
Table.1 Findings of three VES analysis and recommended point VES-3 for drilling.

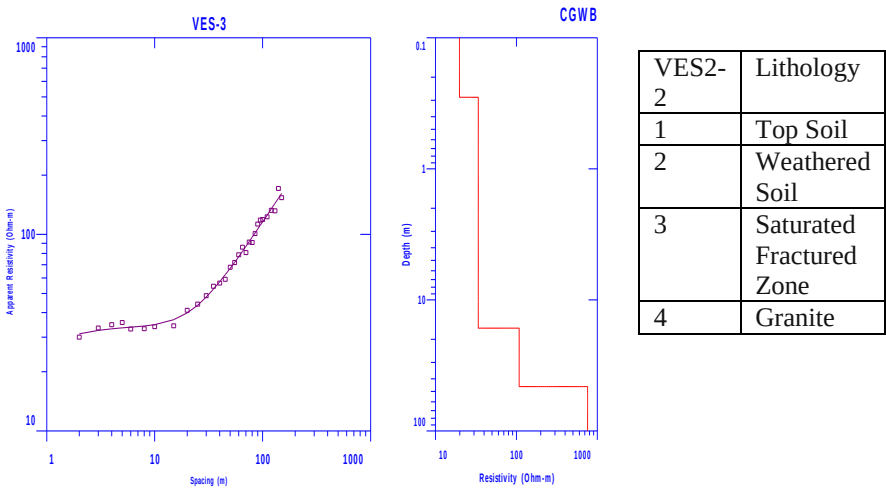
VES Point	Fractured and Saturated Zone	Thickness	Recommendation for Drilling
VES-1	Absent	Nil	-
granite VES-2	Present over massive	6.34	-
VES-3	Present over fractured granite	29.50	Recommended

Observing the quantitative and qualitative assessment of the layer parameters of all three VES points. It is observed through studying layer parameters in the computed section of individual VES data processing (VES Graphs Figure.8), fractured water-saturated rock is absent in VES-1 while moving towards VES-2 the water fractured saturated zone of thickness 6.34 m is directly lying the massive hard rock. And finally, at VES-3, the water-saturated fractured zone has an impressive thickness of 29.50 m and with 108.20 ohm.m resistivity also the underlying hard rock is fractured too. Hence the third site is recommended for the drilling.

The recommended third layer has a true resistivity (108.20-ohm m) and thickness 29.50 m. A test borehole was drilled exactly over the spot at the location. The test drill was conducted by the state unit of Jal Nigam (State Government) over CGWB (Central Ground Water Board) recommendation ¹⁵. The derived layer parameters out of VES sounding data demonstrate righteous correlation relative to borehole Lithology. The lithological units

determined and precisely assigned based on the resistivity value. The interpreted results at the location P-3 at VES-3 reveal the four subsurface layers; having a total depth of 51.40m. The final Lithology portrayed in figure.9 with the first layer as Topsoil, second fractured zone (Not containing water), third layer fractured zone with water and fourth as hard rock slightly water-saturated. The quantitative evaluation has been shown precisely in the Figure as (VES-1, VES-2, and VES-3 respectively).





Figures.8 shows VES-1, VES-2, and VES-3. The respective interpretation of VES-1,2, & 3 data (the square box is the field data and the smooth line is the computed curve) along with model layer parameters and resistivity vs. depth model on right.

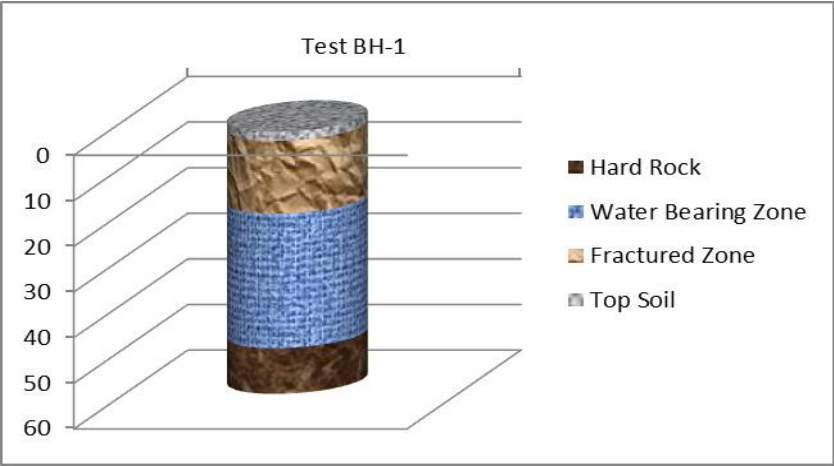


Figure. 9 Lithology of test borehole drilled on the recommended VES-3 delineates the water-bearing zone as the third layer.

5. Conclusion

Instead of performing an unguided sightless electrical survey in the hard rock terrains, it is better to approach to take advantage of joint VES and GP electrical methods. The association of GP qualitatively and VES electrical survey quantitatively is promising joint attempt for hard rock

geological settings. The present combined geophysical and hydrogeological study gainfully employed in the water scarcity area of Kabrai of Bundelkhand region of Uttar Pradesh. The drilling executed after 3 days of geophysical survey promisingly confirms the availability of groundwater. The water encountered at 29-meter depth within hard rock's which yields a continuous groundwater discharge of 300 LPM. Water proposed to supply to local government to meet the need for the area. So joint geophysical technique provides the gainful promising prospects for groundwater in the hard rock terrains. That can further be applied to a similar type of hydrogeological settings.

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