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EFFECT OF SOIL THICKNESS OVER THE HARD ROCKS ON THE RESPONSE OF APPARENT RESISTIVITY OBTAINED FROM GRADIENT PROFILING SURVEY FOR DETECTION OF GROUNDWATER SATURATED FRACTURES

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ABSTRACT

The gradient profiling is done in the presence of horizontal electric field which is one of the techniques to locate the low resistivity response within the hard rock formations. This low is obtained due to the presence of fractures, cracks, joints, fissures or even due to presence of shale which may create confusion for detecting the presence of groundwater. The thickness of soil cover may also play major role in the fluctuations of apparent resistivity response of gradient profiling. The paper deals to show the effect of soil thickness over hard rocks in the selected area where 5 gradient profiling and 7 geoelectrical sounding have been carried out. The presence of thick surface soil/clay at some locations clearly indicates its effect on the apparent resistivity response in terms of its magnitude and fluctuations as well. The prominent "low" on the apparent resistivity response has been observed along each gradient profile, but only more than 50% locations show the presence of fractured sandstone saturated with groundwater which is confirmed by the sounding results for that location. Only these locations, as indicated by the results of sounding, have sufficient fractured in a sandstone formation with good saturation of groundwater that has been verified from the nearby existing borehole drilled by the farmers. At few locations, groundwater may not be available due to presence of shale. It is inferred from the above study that, neither geoelectrical sounding alone, nor gradient profiling alone can provide sufficient information about the presence of a saturated fracture - zone for groundwater exploration.

KEYWORDS: Gradient Profiling, Geoelectrical Sounding, Groundwater Exploration, Hard Rocks & Fractured Sandstone

INTRODUCTION

Groundwater is an important natural resource with high economic value and sociological significance. Fortunately, this water has been gifted by the nature in bounteous proportion, with its quality of transformation through a perennial hydrological cycle of evaporation, condensation and precipitation. With the ever increasing demand for water supply and the inadequate surface water, especially in the hard rock areas, attention is turned to groundwater resources, mainly because, it is replenishable by natural hydrological processes and could be even perennial provided, caution is exercised to maintain a proper balance between the need and the supply.

The choice, for the use of the geophysical methods, is based on the geological conditions, accessibility and targets of exploration in soft and hard rock areas where preliminary information is available through remote sensing. There are many ways to conduct geoelectrical surveys for groundwater exploration, which are described in the standard books and journals, such as Al`pin (1950); Keller and Frischknecht (1966); Bhattacharya and Patra (1968); Koefoed (1979); and Yadav (1988). Generally, geoelectrical surveys are conducted either to find out lateral changes of resistivity from place to place up to a targeted depth called ‘resistivity profiling’ or to find out the resistivity variation with depth called ‘resistivity sounding’. The profiling is done only for qualitative evaluation where as sounding is conducted for quantitative evaluation of thickness and resistivity of different layers at a specific location. If the aim of the survey is to find out the depth of the aquifer in the thick alluvial covered area, then resistivity sounding alone is sufficient to provide required information. However, in the thin soil covered hard rock area where the possibility of occurrence of groundwater is limited, then in many places, sounding alone may not give fruitful results due to improper and random selection of its location. This may be due to the fact that in hard rock areas, groundwater occurs due to the presence of secondary porosity which generally developed due to weathering, fracturing, joints etc.

A surface geophysical survey for the exploration of groundwater resources is a continuously evolving science, which either adopts different techniques or combination of techniques to standardize the approach. So, there may not be a set of field technique, procedure or approach to obtain maximum information about the objective especially in hard rock areas. Since, the basis for geophysical application is the contrast between the physical properties of the target and the surrounding environs, more the contrast or anomaly, better could be the geophysical response and hence identification, and accordingly the techniques are selected. For effective delineation it is essential to design an approach of alternative techniques or combination of techniques which are sensitive to different physical properties of the target and the surrounding. More than half of the global expenditure on the groundwater geophysics is through the application of geoelectrical resistivity survey and there are numerous case studies to enlighten its success.

The Gradient Profiling (GP) survey method has been developed by Yadav and Singh (2007, 2008) and Yadav (2015) followed by Geoelectrical Sounding (GS), using Schlumberger configuration to delineate the saturated fracture in the hard rock’s area. The combination of these types of survey has already been conducted and tested in different parts of hard rock areas of Mirzapur and Sonebhadra districts of the U. P for groundwater exploration. Keeping this in view, the present investigation is proposed to study the effect of soil cover above the hard rock on the apparent resistivity response, obtained from gradient profiling array, during groundwater exploration followed by Geoelectrical Sounding.

HYDROGEOLOGY OF THE AREA

The location map of the survey area is presented in Figure (1). The area lies towards the south side about 10 km from the Chunar, Mirzapur district, U. P. The location of Gradient Profiling and Geoelectrical Sounding is marked on the location map. In this area, groundwater occurs in secondary porosity developed due to weathering, fracturing, jointing, faulting etc., that is highly variable and varies within very short distances and contributing to near surface inhomogeneity. The bed rock present in these areas is highly jointed and has developed fractures and cracks which permits the percolation of copious amount of water to great depths. Sometimes meticulously fractured hard rock contains good quality of water provided the underlying rocks are impervious. Moreover, the high cost of drilling for deep wells also limits water exploration from the hard rock formations.

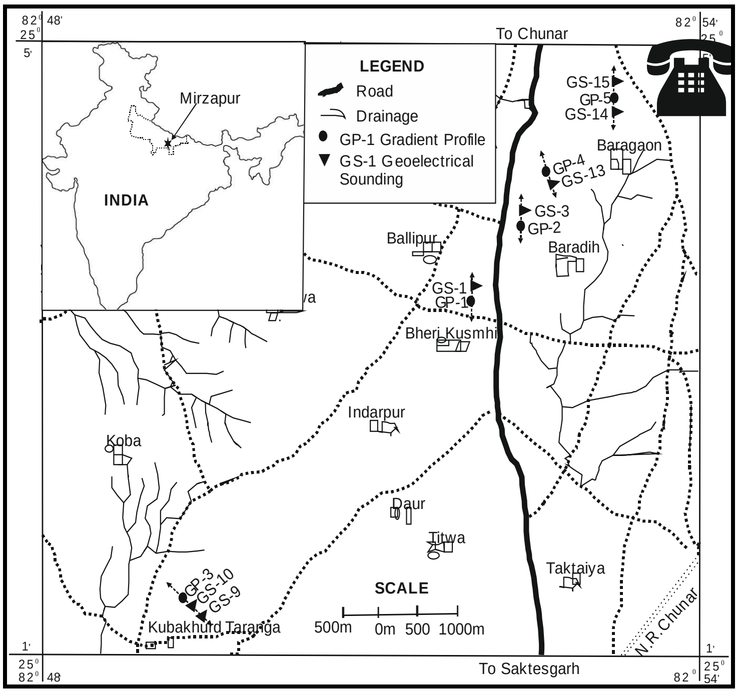

Figure 1: Location Map of the Area under Investigation.

However, it is very difficult to proclaim the correct lithology of the field area unless and until the lithologs are available from the existing boreholes, which are scanty in the area. The area recharges due to rainfall in the monsoon season. The annual rainfall in the area is about 1050 mm out of which, about 90% is received in the rainy season, i.e. from June to September and 10% is received, during the remaining months of the year. The average maximum temperature in the day-time rises to about 45^0C in summer.

MATERIALS AND METHODOLOGY

One of the cheapest and fast methods in geophysics in groundwater exploration is geoelectrical method. The collection of data can be done by profiling and sounding which are discussed in the following sections.

Gradient Profiling (GP)

Although the concept of gradient profiling has already been developed and published by the author in his referred papers, but some of the salient points is discussed in this paper. It is already established that the GP requires stationary and uniform horizontal electric field in the one third central region between the widely separated current electrodes. The potential electrode separation is taken as infinitely small, so that the observed quantity approximates to the measurement of electric field or potential gradient.

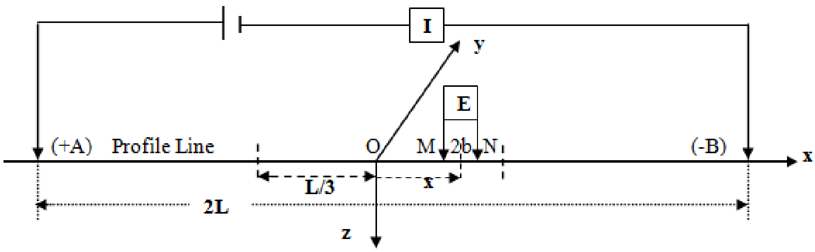

Figure 2: Field Lay-Out of Gradient Profiling Where A, B = Current Electrodes with 2L Distance and M, N = Potential Electrodes with 2b Distance, I = Current Supplied in the Earth and E, the Measured Electric Field = ΔV/2b

The field layout of the GP is shown in Figure (2); the separation of current electrodes is fixed at 600 m. It can be increased or decreased depending on the availability of the accessible space. The central 1/3rd region between the current electrodes is scanned at regular station interval of 5 m using the potential electrodes spacing of 10 m or 20 m or both which is the minimum separation to measure the potential gradient. The formula used for calculation of apparent resistivity is given as

$$\rho_a = \mathrm{K}\frac{\Delta V}{I} \tag{1}$$

Where, K is the geometrical factor and can be written using the notations of Figure 2 as,

$$\mathrm{K} = \frac{2\pi}{\left(\frac{1}{(L+x-b)} - \frac{1}{(L-x+b)} - \frac{1}{(L+x+b)} + \frac{1}{(L-x-b)}\right)}$$

Where 2L & 2b are the respective distances between the current electrodes and the potential electrodes, □ I the input current, ΔV is the observed potential, x is the distance between the centers of the current electrodes and the potential electrodes which may fulfill the condition, i.e., $x \le L/3$.

The same principle may be extended for further survey along the same profile line. In case, the zone of interest exceeds the 1/3rd central space or to increase the coverage area, the entire GP array is shifted 200 m along the same line at one side with same current electrodes spacing of 600 m so that the new portion of the region could be covered. In this way, it is possible to locate a favorable site for conducting the Geoelectrical Sounding (GS), through the Schlumberger array. The selection of GS location is made based on the lowest peak of the apparent resistivity observed along the profile line.

Geoelectrical Sounding (Gs)

If we put x = 0 in the Figure (2) of gradient profiling and the current electrodes A, B are kept as dynamic and potential electrodes M and N are kept as fixed for a series of measurements then array becomes a Schlumberger array as shown in Figure (3).

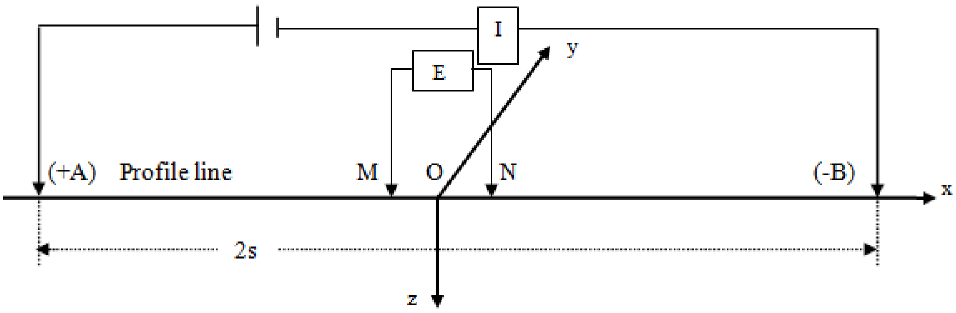

Figure 3: Lay-Out of Schlumberger Configuration.

Similarly, we can write the expression for potential difference in the case of Schlumberger array and simplified it for the computation of field apparent resistivity is given as

$$\rho_{aS} = \pi(s^2 - b^2)\frac{\Delta V}{2b.I} \qquad (2)$$

If b (s/5, we can put (s^2 –b^2) of equation (2) equal to s^2 with an error less than 4%. This assumption is made for the computation of theoretical apparent resistivity for the case of Schlumberger arrangement which can be given as

$$\rho_{aS} = \pi s^2 \frac{\Delta V}{2b}\frac{1}{I} = \pi s^2 \frac{E}{I} \qquad (3)$$

Where E = ΔV/2b is (approximately) the electric field intensity at the central point O.

RESULTS AND DISCUSSIONS

The entire area is covered by the surface soil/clay with varying thickness. As the area under study is lying in the close vicinity of the Vindhyan exposures, the bedrock (Vindhyan group of rocks) is expected below the surface soil/clay cover. Groundwater may occur in the weathered and fractured sandstone provided the zone is connected with recharging sources. These fractures may be present even below the thin bed of semi-consolidated sandstone.

Gradient Profiling (GP)

Five gradient profiles (GP) were conducted using fixed current electrodes separation of 600 m with the help of microprocessor based deep resistivity meter manufactured by IGIS, Hyderabad, India. The potential electrode separation was taken as 10 m or 20 m or both along the same profile line with an observation interval of 5 m to cover 100 m of length in one side of the central region of the profile for AB/2 = 300 m. A similar procedure is adopted to obtain the data for 100 m on the other side also. The length covered by each profile is varied depending upon the availability of assessable space. The apparent resistivity has been computed for each GP using equation (1). The apparent resistivity versus distance has been plotted on a linear graph which indicates the “low” resistive peak on each of the profiles. The profiles showing the variation of apparent resistivity with distance are presented in Figures (4a, b, c, d & e). The positions of GS have been marked where “low” peak with sharp gradient was observed on each profiles.

The comparative studies of two curves observed for MN = 10 m and MN = 20 m where ever measured show similar characteristics except the variation in their smoothness. More smooth curve for MN=20 m is obtained due to averaging effect of the material come across the measurement compared to the response of MN=10 m. This happens because of the percentage of new columns of material is less compared to previous observation so little amount of change in apparent resistivity value is seen.

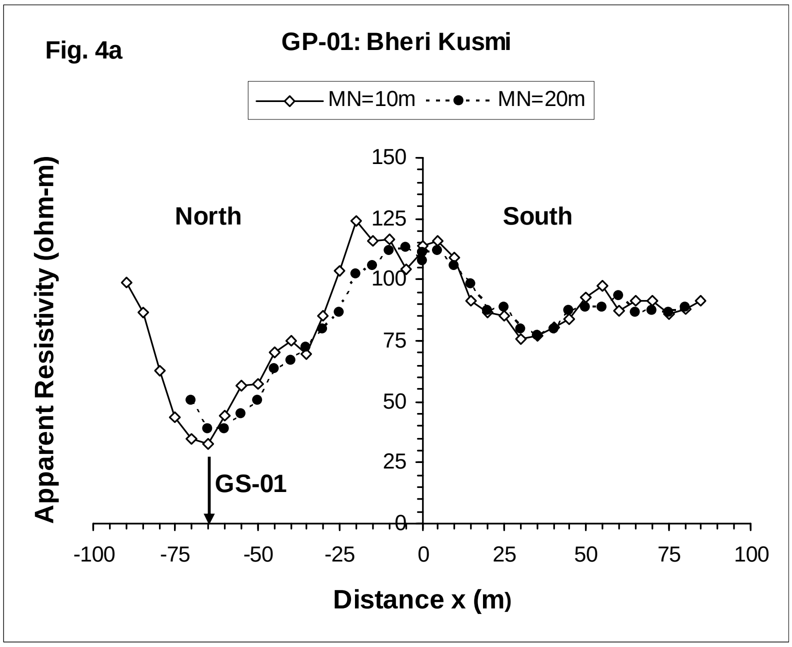

Figure 4(a): Showing the Apparent Resistivity Response along Profile GP-01 (Bheri Kusmi) Covering 200 M Length for MN=10 M and 20 M and Position of One Selected Location GS-01 on the Profile

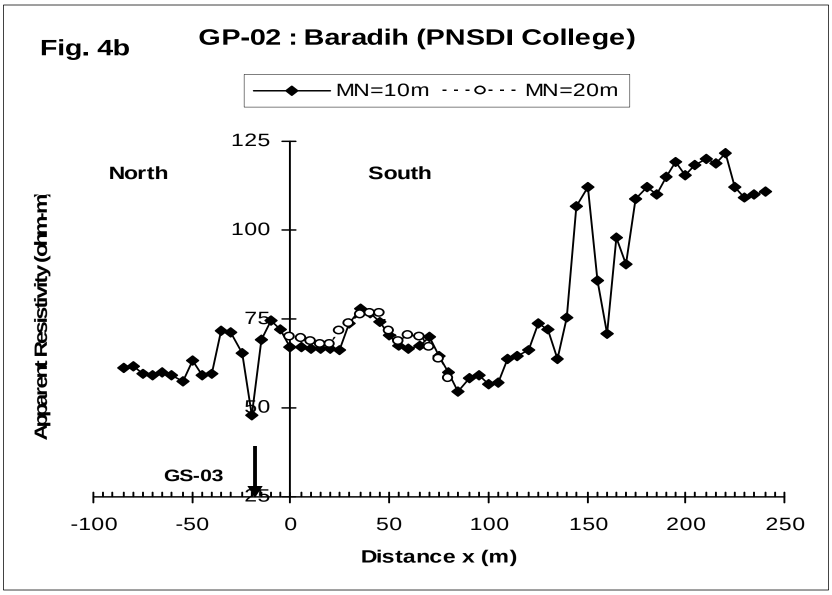

Figure 4B: Showing the Apparent Resistivity Response along Profile GP-02 (Baradih –PNSDI College) Covering 350 M Length for MN=10 M and 20 M and Position of One Selected Location GS-03 on the Profile

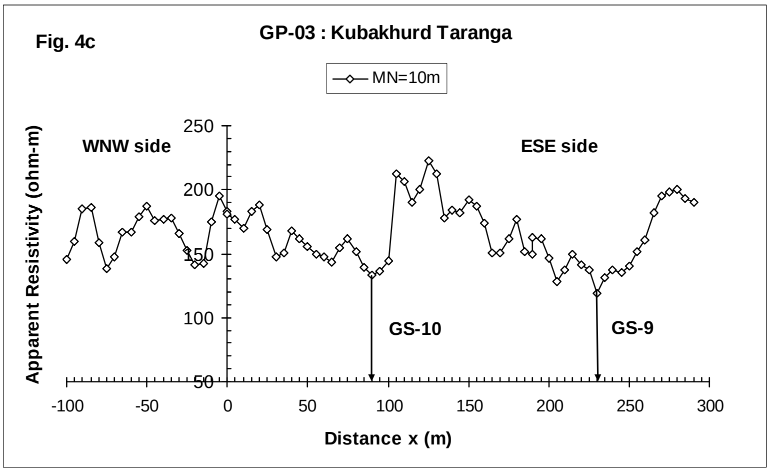

Figure 4C: Showing the Apparent Resistivity Response Along Profile GP-03 (Kubakhurd Taranga) Covering 400 M Length for MN=10 M and Position of Two Selected Locations GS-09 and GS-10 on the Profile

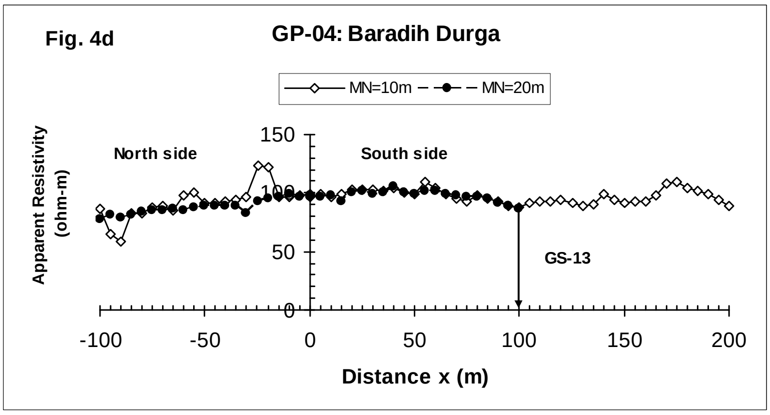

Figure 4D: Showing the Apparent Resistivity Response along Profile GP-04 (Baradih Durga) Covering 300 M Length for MN=10 M and MN=20 M and Position of One Selected Location GS-13 on the Profile

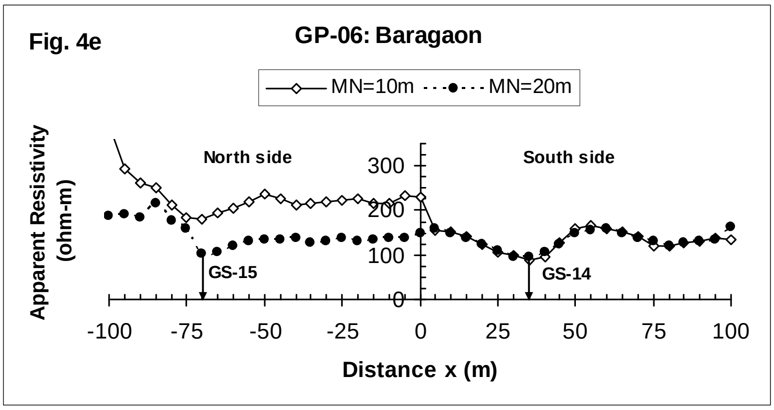

Figure 4E: Showing the Apparent Resistivity Response along Profile GP-06 (Baragaon) Covering 200 M Length for MN=10 M and MN=20 M and Position of Two Selected Locations GS-14 and GS-15 on the Profile

From the study of entire curve, one prominent low is observed in the north side of the profile at a distance of 65 m for conducting geoelectrical sounding GS-01, as shown in Figure (4A). Geoelectrical sounding is necessary to study the depth wise variation of apparent resistivity. The only one prominent low is observed in the north side of the profile GP-02 at a distance of 20 m from the centre towards the south side which is selected to conduct geoelectrical sounding GS-03, as shown in Figure (4B). Total length covered by GP-03 profile is 400 m having two centers, one at zero and other at 200 m as shown in Figure (4C). Two prominent low is observed on the ESE side of the profile, at a distance of 90 m and 230 m from the centre which are selected to conduct geoelectrical sounding GS-10 and GS-09, respectively, as shown in Figure (4C).

Total length covered by GP-04 profile is 300 m having two centers one at zero distance and another at 100 m towards the ESE side as shown in Figure (4D). This figure clearly shows very small fluctuation in the apparent resistivity response which is most probably due to the presence of thick soil/clay cover above the hard rock. Due to this reason the magnitude of apparent resistivity is very low, i.e. within the range of 100 ohm-m only. The only one low is observed on the profile at a distance of 100 m towards the south side from the centre which is selected to conduct geoelectrical sounding GS-13 as marked on the Figure (4D). Similarly, the total length covered by GP-06 profile is 200 m having 100 m coverage towards both sides as shown in Figure (4E). Figure clearly shows very small fluctuation in the apparent resistivity response which is most probably due to the presence of thick soil/clay cover above the hard rock. Due to this reason the magnitude of apparent resistivity is also very low, i.e. within the range of approximately 150 ohm-m only. Two prominent low are identified one towards the south side at a distance of 35 m and another at 70 m towards the north side of the profile. These points are selected to conduct geoelectrical sounding GS-14 and GS-15 respectively, as shown in Figure (4E).

Geo-electrical Sounding (Gs)

Based on the results of 5 gradient profiling 7 geoelectrical soundings (GS), using Schlumberger configuration were carried out for a maximum current electrode spacing of 600 m except GS-13 with the help of same resistivity meter. The data is obtained in the field at each sounding location comprised of records of values of resistance as well as computed apparent resistivity for the given current and potential electrode spacing. As a precautionary measure, eight stacks were used to take the readings for each current electrode separation. The entire data are processed using equation (2) by the instrument itself. The nature of apparent resistivity curves is presented in Figure (5).

In the first step of interpretation, the layer parameters were initially obtained using the partial curve matching technique with the help of three layer master curves (Rijkswaterstaat, 1969) and auxiliary point charts (Ebert, 1943). These parameters were used as an initial model, for computer assisted interpretation program AIMRESI viz. Automatic Interactive Method of Resistivity Sounding Interpretation (Yadav, 1995). Finally, these layer parameters have been further refined using 1X1D computer software of INTERPREX. The layer parameters obtained in this way is not a unique solution because of the ambiguity of the method which exists due to the principle of equivalence and suppression problems in geoelectrical sounding interpretation. However, the estimated depth/thickness may be differed from the actual, within the given RMS error limit.

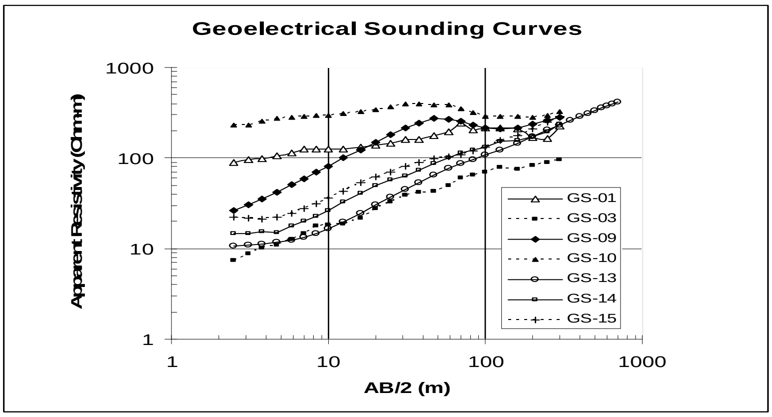

Figure (5): Showing the Apparent Resistivity Response of Geoelectrical Soundings Obtained at Various Locations with Varying Current Electrode Separation, AB/2

As the interpretation of the geoelectrical sounding curve is accomplished in terms of the layer parameters, the problem arises about their interpretation in terms of lithological units. At this stage, it is necessary to have a correct idea about the actual resistivity values of various formations to arrive at the best possible interpretation of the geophysical results in terms of different lithological units in the existing geological setups. Based on the geophysical data and its interpretation, the derived layer parameters and corresponding lithological units/formation are presented in Table (1).

Table 1: Interpreted Layer Parameters and Its Lithology with RMS Error

GS-01 Bheri Kusmi I RMS Error = 5.23 %				
Layer	**Resistivity (ohm-m)**	**Thickness (m)**	**Depth (m)**	**Lithology**
1	68.0	1.1	1.1	Surface soil
2	133.5	22.6	23.7	Weathered rock
3	781.0	19.0	42.7	Semi compact sandstone
4	29.7	40.4	83.1	Shale
5	6359.0			Hard Compact sandstone
GS-03 Baradih (PNSDI Collage) RMS Error = 4.17 %				
1	5.6	1.2	1.2	Moist surface Clay
2	24.4	5.5	6.7	Dry Silty Clay
3	158.4	37.2	43.9	Weathered saturated sandstone
4	41.3	61.6	105.5	Shale
5	1095.1			Compact sandstone
GS-09 Kubakhurd Taranga I RMS Error = 5.21 %				
1	20.6	2.1	2.1	Surface soil
2	259.6	1.5	3.6	Weathered rock
3	1963.4	7.3	10.9	Semi compact sandstone
4	36.2	41.3	52.2	Shale
5	2770.2			Compact sandstone
GS-10 Kubakhurd Taranga II RMS Error = 2.24 %				
1	189.4	1.1	1.1	Surface soil
2	304.7	12.6	13.7	Weathered sandstone
3	1216.4	9.4	23.1	Semi compact sandstone
4	97.9	24.1	47.2	Weathered saturated sandstone
5	379.3			Weathered sandstone
GS-13 Baradih Durga RMS Error = 1.63 %				
1	10.5	6.0	6.0	Surface Clay
2	132.3	3.2	9.2	Dry weathered rock
3	246.1	128.3	137.5	Weathered saturated sandstone
4	1004.3			Hard Compact sandstone

Table 1: Contd.,				
GS-14 Baragaon I RMS Error = 3.48 %				
1	13.7	3.7	3.7	Dry Surface Clay
2	15.7	1.0	4.7	Silty Clay
3	194.4	183.9	188.4	Fractured saturated sandstone
4	1074.1			Hard Compact sandstone
GS-15 Baragaon II RMS Error = 2.8 %				
1	21.5	2.2	2.2	Dry Surface Clay
2	5.4	0.6	2.8	Clay
3	141.9	97.4	100.2	Fractured saturated sandstone
4	16996.4			Hard Compact sandstone

The effect of thick surface soil/clay on the apparent resistivity response at some locations clearly indicates its effect as evidenced from the above results. This can be established from the GP-04 and GP-06 profiles (Figure 4d, Figure 4e) and the results of corresponding GS-13, GS-14 and GS-15 soundings (Table 1). However, the presence of groundwater is delineated from the sounding results which can be seen through GS-03 having resistivity 158.4 ohm-m with 37.2 m thickness; GS-10 having resistivity 97.9 ohm-m with 24.1 m thickness; GS-14 having resistivity 194.4 ohm-m with 183.9 m thickness; and GS-15 having resistivity 141.9 ohm-m with 97.4 m thickness. Only these layers as indicated above have adequate fractured sandstone with good saturation of groundwater that has been verified from the nearby existing borehole drilled by the farmers. The correlation of these results could not be confirmed due to non availability of actual drilling data. However, some amount of groundwater may be tapped at GS-13 location having resistivity 246.1 ohm-m with 128.3 m thickness. No groundwater will be found at other locations, namely GS-01 having resistivity 29.7 ohm-m with 40.4 m thickness and GS-09 having resistivity 36.2 ohm-m with 41.3 m thickness due to presence of shale formation.

CONCLUSIONS

The presence of thick surface soil/clay at some locations clearly indicates its effect on the apparent resistivity response of gradient profiling as evidenced from the above results. The region covered with thick soil/alluvial cover has reduced the overall response of apparent resistivity. The prominent "low" on the apparent resistivity response has been observed along each gradient profile, but only more than 50% locations show the presence of fractured sandstone saturated with groundwater which is confirmed by the sounding results for that location. Only these locations, as indicated by the results of sounding, have a sufficient fracture in a sandstone formation with good saturation of groundwater that has been confirmed from the owners of the nearby existing borehole. Exploitable groundwater may not be found in few locations due to presence of shale as derived from the sounding results. It is inferred from the above study that neither geoelectrical sounding alone, nor gradient profiling alone can provide sufficient information about the presence of saturated fracture for groundwater exploration.

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REFERENCES

1. Al’pin, L. M., 1950. The theory of dipole sounding; Gostoptekhizdat, Moscow (Trans. In: Dipole methods for measuring earth conductivity, Plenum Press, New York, 1966).
2. Bhattacharya, P. K. and Patra, H. P., 1968. Direct current geoelectric sounding. Elsevier Amstardam.
3. Ebert, A., 1943. Grundlagen Zur Auswerkung geoelektrischer Tiefenmr-ssulgon. Garlands Beitrage Zur Geopysik, BZ, 10 (1), 1-17.
4. Keller, G. V. and Frischknecht, F. C., 1966. Electrical methods in geophysical prospecting. Pergamon Press, New York, 517p.
5. Koefoed, O. (1979). Geosounding Principles, 1, Resistivity Sounding Measurements, Elsevier Scientific Company, Amsterdam, The Netherlands, 276 p.
6. Rijkswaterstaat, 1969. Standard Graphs for Resistivity Prospecting. EAEG, The Netherlands.
7. Yadav, G. S., 1988. Pole-dipole resistivity sounding technique for shallow investigations in hard rock areas. PAGEOPH 127, 63-71.
8. Yadav, G. S., 1995. A FORTRAN Computer Program for the Automatic Iteractive Method of Resistivity Sounding Interpretation. Acta. Geod. Geoph. Hung. 30 (2-4), 363-377.
9. Yadav, G. S., Singh, P. N., Srivastava, K. M. 1997. Fast method of resistivity sounding for shallow groundwater investigations. Journal of Applied of Geophysics 36, 45-52.
10. Yadav, G. S., Singh, S. K., 2007. Integrated resistivity surveys for delineation of fractures for groundwater exploration in hard rock areas. J. Appl. Geophys., 62: 301-312.
11. Yadav, G. S., Singh, S. K., 2008. Gradient profiling for the investigation of groundwater saturated fractures in hard rocks of Uttar Pradesh, India. Hydrogeology Journal 16: 363-372.
12. Yadav, G. S., 2015. Detection of groundwater saturated fractures using geoelectrical techniques of gradient profiling in the RGSC of Banaras Hindu University, India. International Journal of General Engineering and Technology (IJGET) 4(3): 23-34 (IASET).