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Geoelectrical Sounding to Identify Sub-surface and Groundwater State at Village Banauli, Singrauli District, Madhya Pradesh, India

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ABSTRACT

Electrical resistivity (Geoelectrical) methods are well-known and common techniques for investigating the groundwater potential zone. These methods are economically viable and have the highest resolving power compared with other geophysical methods. A total of fifteen Vertical electrical soundings were conducted in the village of Banauli, located in Singrauli district in Madhya Pradesh, India. Vertical electrical sounding was carried out using Schlumberger electrode configuration with the maximum current electrode (AB) spacing of 200 m and potential electrode (MN) spacing of 10 m. For interpretation of measured resistivity, the Partial curve matching technique was used to calculate the layer parameters (resistivity and thickness) and further depict the depth section of the profile. In this study, the maximum five-layer model is obtained, and most curves are of HAK types. The first layer has a mean resistivity value of 12.41 Ωm and a mean thickness of 0.94 m. The second layer has mean resistivity of 7.93 Ωm and a mean thickness of 4.79 m. The third layer has a mean thickness value of 10.55 m and a mean resistivity value of 16.54 Ωm. The fourth layer has a mean resistivity value of 20.17 Ωm and a mean thickness of 9.20 m, and finally, the fifth layer, the bedrock, has a higher mean resistivity value of 59.92 Ωm. Thus, the obtained results may be used for identifying the drilling site for the groundwater potential zone.

INTRODUCTION

Groundwater is very important for industry, irrigation, and domestic purposes. Irrigation is the lifeline of agriculture in Arid and semi-arid regions. The demand for groundwater for irrigation is increasing day by day because of the induction of modern technology and the introduction of high-yielding varieties of seeds, pesticides, insecticides, chemical fertilizers, etc and due to the progress of the green revolution, the demand for groundwater in agriculture has increased a lot as compared to surface water (Gupta 2010). As a result, in some regions of India, water levels have declined significantly (CGWB 2009). Day by day decrease in the levels of groundwater has resulted in failure of bores holes, the drying up of dug wells and reduction in individual good yield, and an increase in power consumption (Gupta et al. 2021). Therefore, the availability and sustainability of safe groundwater are of great importance and demand and need a scientific action plan to ensure water security in the region Groundwater is often developed without fully understanding its temporal and spatial formation and therefore in danger of its Overuse and pollution (Kumar et al. 2011). Therefore, groundwater management is key to the conflict in emerging water security problems. Knowing the depth of groundwater is a very important element in many cases, such as hydrological research, including agricultural salinity management, storage characterization, chemical seepage movement, and water supply studies (Maiti et al. 2013).

Water levels are also dropping as a result of natural and man-made activities, particularly in dry and semi-arid regions. Vertical electrical sounding (VES) surveys are beneficial and cost-effective in understanding underlying lithology and delineating potential groundwater zones (Bayowa 2020, Adagunodo & Oladejo 2020). In groundwater studies, the Schlumberger array is found to be more appropriate and common (Zhody 1969, Karlik & Kaya 2001). Many researchers have successfully used the approach to tackle groundwater problems (Karanth 1991, Janardhana et al. 1996, Balasubramanian et al. 1985). In groundwater investigation, the electrical resistivity method is the most generally recognized and used frequently (Kehinde & Oyeyemi 2018, Gupta et al. 2012). Electric currents are transmitted through electrodes into the ground, and the resistivity of rock formations is measured. In the study of groundwater, electrical resistivity techniques have become more important in exploration due to their inexpensive cost, ease of use, and ability to distinguish between fresh and saltwater (Pal & Majumdar 2001, Majumdar & Pal 2005, Narayanpethkar et al. 2006).

THE STUDY AREA

Location

Banauli village is in the Singrauli Tehsil of Madhya Pradesh Singrauli district. It is 15 km from Singrauli, which is the district and sub-district headquarters of Banauli village. According to 2019 statistics, Banouli is the gram panchayat of Banauli village. The study area lies between latitude 24°1'0''N to 24°2'30''N and longitude 82°30'0''E to 82°32'0''E as shown in Fig.1. The settlement covers a total area of 251.83 hectares, and the population of Banauli is 1,233 people. In Banauli village, there are around 281 homes. Banauli village is a part of the Devsar assembly and Sidhi parliamentary constituencies.

Geology and Hydrology

In Village Banauli and surrounding regions, Talchir and Barakar formations are dominated by arenaceous facies consisting mostly of medium to coarse and very coarse-grained white to light brown sandstones, and Grey shale, arenaceous shale, and carbonaceous shale are the most common types of shale found in coal seams (Yadav et al. 1993). The weathering of sandstone in the Barakar formation is high to moderately and poorly consolidated mostly at a depth of 65 m and even up to a depth of 100 m in certain areas (Yadav 1997). The major groundwater reservoirs in the area are sandstone and fractured shale. Groundwater is found in sandstone and shales under water table conditions and is transferred through the cleavage and bedding planes of shale and sandstones. Rainfall through direct percolation to the saturation zone in the village and adjacent region is the primary source of groundwater recharge. Due to the area's shallow soils, a large portion of the rainfall is lost as runoff. As a result, only a small proportion of rainfall reaches saturation and forms part of groundwater storage when evaporation losses are met.

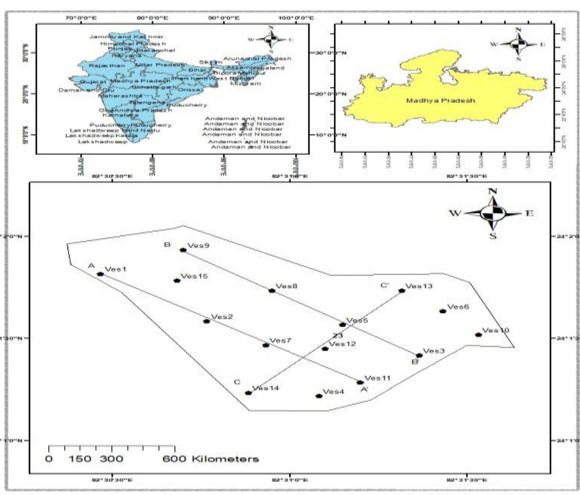


Fig.1: A map of the study area showing the location of VES points along traverses AA', BB', and CC' in Banauli village, Singrauli district, M.P., India.

MATERIALS AND METHODS

Fifteen Vertical Electrical Soundings (VES) stations were occupied with Signal Stacking resistivity meter model SSR-MP1. The SSR-MP1 IGIS Microprocessor-based Signal Enhancement Resistivity Meter is a high-quality microprocessor-based data acquisition system with many unique characteristics. The instrument's design includes numerous modern digital circuitry techniques to make it a reliable geophysical tool that produces high-quality data valuable for mineral and groundwater exploration studies. The current electrode spacing on the Schlumberger electrode array ranged from 1 to 200 m. The data was plotted on bi-log papers and was then analyzed using partial curve matching. The parameters of the initial and final layers were then obtained using WinResist1D and Ipi2win software (Bobachev 2003). This study utilized a sounding technique for analyzing and recording data. The procedure was based on the data acquisition and processing techniques mentioned by Sunmonu et al. Finally, 2D geoelectric sections were generated based on the interpretation of layer parameters. The apparent resistivity (ρa) is computed using the Schlumberger electrode configuration (Kearey & Brooks 1988).

$$\rho a = \frac{(\frac{AB}{2})^2 - (\frac{MN}{2})^2}{MN} \times \frac{\prod \Delta V}{I}$$

Where, AB = Current electrode spacing in meter

MN = Potential electrode spacing in meter

I = Current in ampere

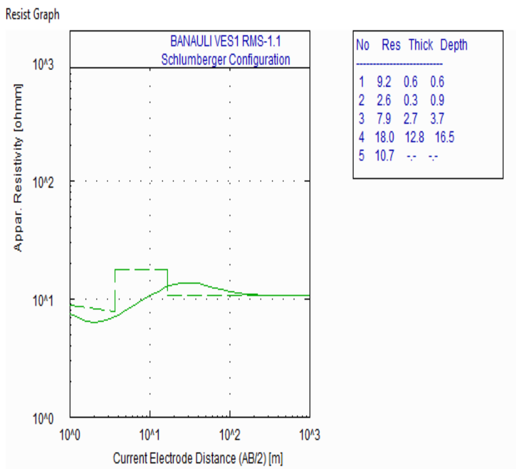
ΔV = Potential difference in mV

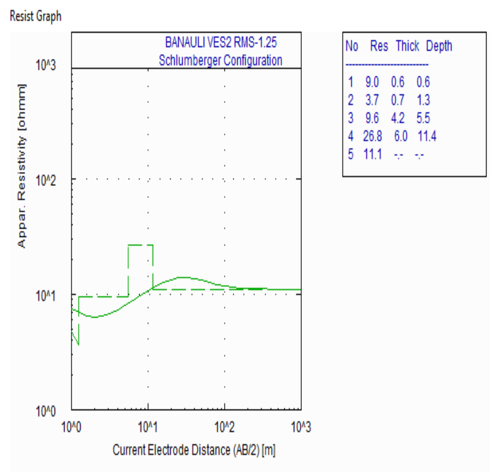
On a log-log graph, apparent resistivity vs. half of the current electrode separation (AB/2) of fifteen Vertical Electrical Sounding indicates a 3-5 layered structure in the research region (Fig.2).

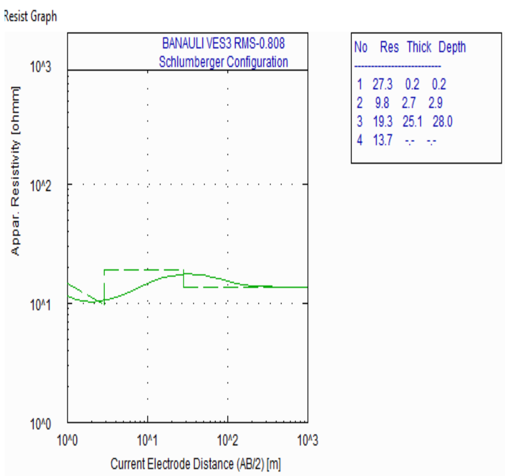
RESULTS AND DISCUSSION

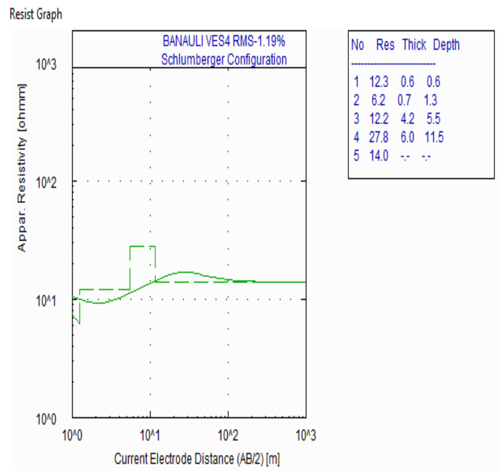
Resistivity Curve Matching

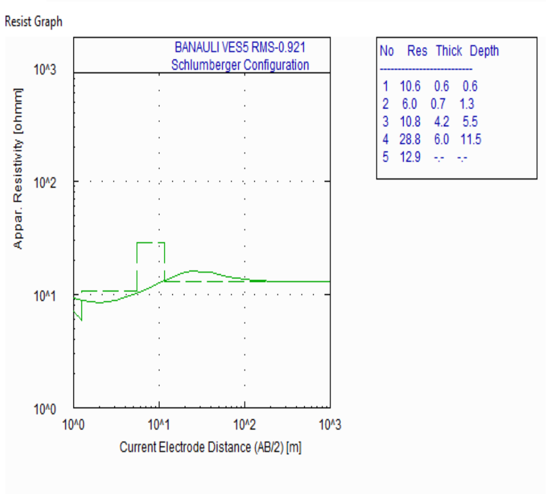
Fifteen VES data were collected from various sites in the study area. The data was collected for quantitative analysis to determine the subsurface layering, surface layers, and thickness of the groundwater layer beneath the studied sites. The field resistivity data were interpreted using Winresist and Ipi2win software. The model parameters were resolved with minimum (0.79) and maximum (3.4) RMS errors. Out of 15 VES station ,VES stations 1,2,4,5,7,9,10 and 12 shows five-layer earth section, VES stations 3,6,11,13 show four-layer earth section and VES stations 8,14,15 show 3-layer earth section.

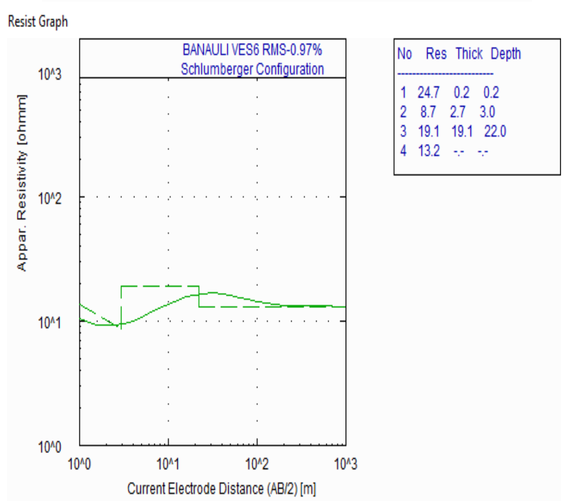












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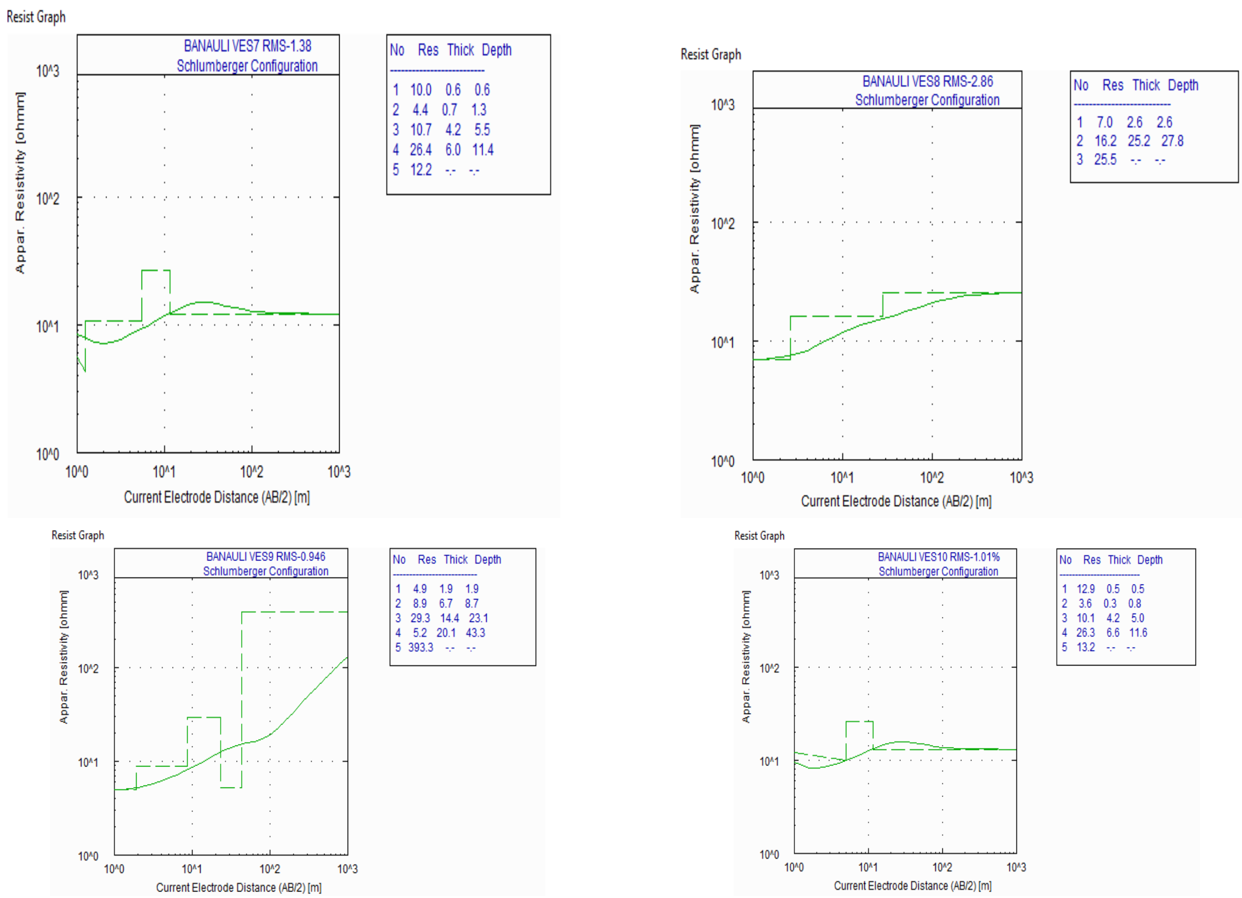


Fig. 2: Vertical electrical sounding curve of stations 1-15.

Curve Types

Curve Types A, Q, H, K, and combinations of resistivity curves were produced (Table 1). The curve matching approach using four and five-layer master curves is used to understand these curves (Singh & Tripathi 2009). The following are the several fundamental types of curves:

1. ρ1> ρ2> ρ3 Q Type
2. ρ1> ρ2< ρ3 H Type
3. ρ1< ρ2> ρ3. K Type
4. ρ1< ρ2< ρ3 A Type

If the model is established for more than three layers, a combination of the fundamental curves can be obtained. The following are examples of possible combinations:

1. ρ1> ρ2< ρ3< ρ4 Curve Type HA
2. ρ1> ρ2< ρ3> ρ4 Curve Type HK
3. ρ1< ρ2< ρ3< ρ4 Curve Type AA
4. ρ1< ρ2< ρ3> ρ4 Curve Type AK
5. ρ1< ρ2> ρ3< ρ4 Curve Type KH
6. ρ1< ρ2> ρ3> ρ4 Curve Type KQ
7. ρ1> ρ2> ρ3< ρ4 Curve Type QH
8. ρ1> ρ2> ρ3> ρ4 Curve Type QQ

In the research area, a Four to Five-layer Earth model is obtained, and the curve types are then determined; Table 1 shows the obtained resistivity as well as the thickness of each layer. Fig. 2 depicts a representative VES curve.

The first layer topsoil layer seemed to have a thickness of 0.20 m - 2.59 m and a resistivity of 4.88Ωm – 27.29 Ωm Alluvial soil, red Sandy soil. The second layer has a thickness of 0.30m -25.2m and resistivity of 2.62 Ωm-16.2 Ωm which corresponds to subsoil to fine-grained sandstone. The third layer, Fine-grained sandstone, to fractured or weathered sandstone, has a resistivity of 7.903 Ωm to 29.2 Ωm; this layer is most suitable for storage and movement of groundwater. The fourth layer has a thickness of 5.22 m to 20.14 m and resistivity of 5.19 Ωm to 28.78 Ωm. This layer corresponds to fine to medium-grained fractured or

Table 1: Interpretation results of VES 1 to 15.

VES point	ρ1[Ωm]	ρ2[Ωm]	ρ3[Ωm]	ρ4[Ωm]	ρ5[Ωm]	h1[m]	h2[m]	h3[m]	h4[m]	h5	RMS % Error	Curve type	Depth of Bedrock [m]
1	9.201	2.627	7.903	17.97	10.73	0.6188	0.3141	2.723	12.83		1.1	HAK	16.49
2	8.97	3.66	9.615	26.75	11.09	0.6	0.654	4.224	5.97		1.25	HAK	11.45
3	27.29	9.777	19.31	13.65		0.209	2.692	25.11			0.808	HK	28.01
4	12.26	6.203	12.15	27.84	14.04	0.6	0.654	4.23	5.97		1.19	HAK	11.57
5	10.63	5.962	10.78	28.78	12.92	0.6	0.654	4.228	5.97		0.921	HAK	11.45
6	24.71	8.71	19.12	13.15		0.2247	2.746	19.06			0.97	HK	22.03
7	9.96	4.358	10.65	26.42	12.23	0.6	0.654	4.223	5.97		1.38	HAK	11.45
8	6.96	16.2	25.5			2.59	25.2				2.86	A	27.8
9	4.931	8.931	29.29	5.199	393	1.933	6.746	14.45	20.14		0.946	AKH	43.27
10	12.95	3.639	10.12	26.28	13.16	0.512	0.3041	4.16	11.6		1.01	HAK	11.6
11	24.71	8.71	19.06	13.15		0.2247	2.746	19.06			0.97	HK	22.03
12	9.97	4.376	10.08	27.77	12.24	0.6011	0.6185	3.899	5.226		0.792	HAK	10.64
13	12.87	10.28	20.45	15.11		0.6	2.023	21.34			0.989	HK	23.96
14	4.88	12.7	21.3			2.14	14.1				3.4	A	16.2
15	5.9	12.9	22.9			2.11	11.8				2.55	A	13.9
Minimum	4.88	2.627	7.903	5.199	10.73	0.209	0.3041	2.723	5.226		0.792		10.64
Maximum	27.29	16.2	29.29	28.78	393	2.59	25.2	25.11	20.14		3.4		43.27
Average	12.4128	7.93553333	16.54853333	20.17242	59.92625	0.94422	4.793713	10.55892	9.2095		1.40906667		18.79

weathered sandstone, so there is storage and movement of groundwater. The fifth last basement layer has a resistivity of 10.73 Ωm to 393 Ωm, which corresponds to medium to coarse-grained sandstone. The thickness and resistivity of VES cross-sections are correlated with the presence of geological features near the sounding stations. It is suggested to associate the weathered and fractured zone with the resistivity of 5.19 Ωm to 30 Ωm and thickness of 2.7 m to 25 m. This zone is saturated with groundwater and capable of storage and movement of groundwater.

Geo-Electric Cross-Section

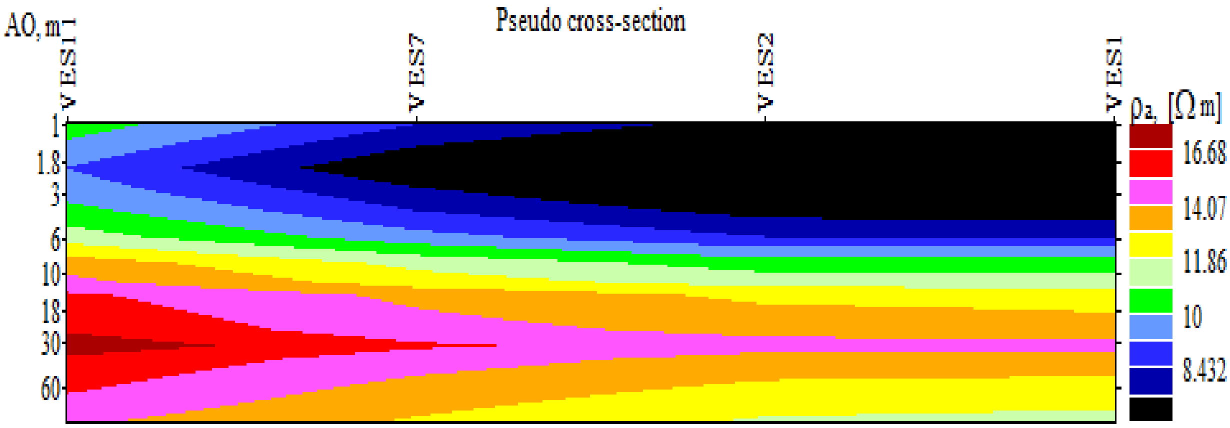
Three geoelectric cross-sections were created in the study area to analyze the subsurface features and understand the underlying aquifer bodies. AA' and BB' are the two profiles with four VES points each, and CC' is the third profile with three VES points. The profiles AA' and BB' are orientated in the NW-SE direction, while the profile CC' is oriented in the NE-SW direction.

Profile AA'

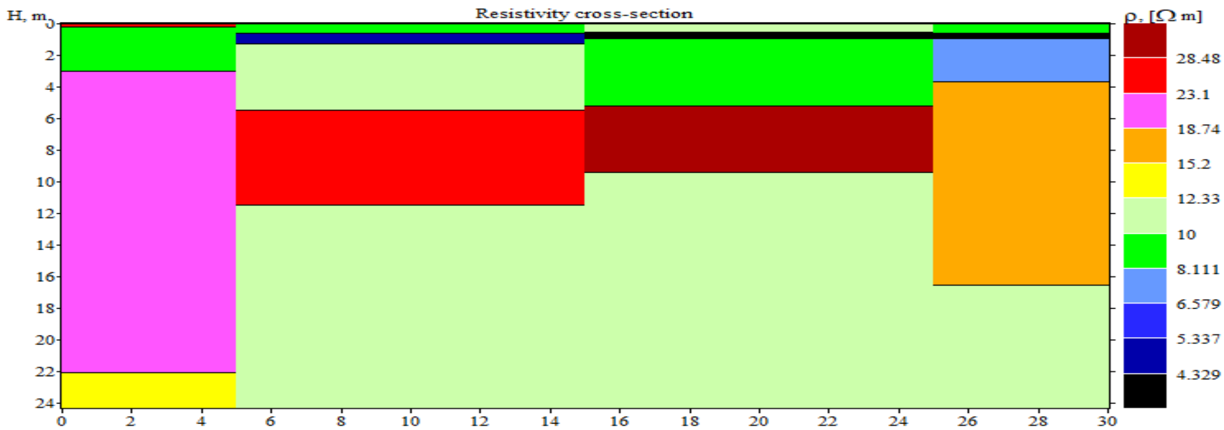
Profile AA' covers the VES stations 1, 2, 7, and 11 trending in the NW-SE direction (Fig.3). A shallow low resistive layer (8.11Ωm to 10Ωm) occurs beneath stations 1, 2, and 11 at a depth of 0.5m to 3m. This effect is due to the presence of lithomarge clay, which may contain groundwater. A high resistive feature (23.1 Ωm to 28.48 Ωm) was observed at VES7 at a depth of 6 m to 12 m and also high resistive feature was observed at VES2 of resistivity (28.48 Ωm to 390 Ωm) at a depth of 5 m to 9 m. Beneath this high resistive formation, a low resistive formation up to a depth of penetration is observed having resistivity (10 Ωm to 16.2 Ωm) and thickness (2 m to 14 am) at stations 1, 2, 7, and 11. This high resistive indicates hard and compact sandstone formation, and all these low resistive zones are likely to be a good potential zone for groundwater. Hence these sites are suitable for groundwater exploration.

Profile BB'

The profile BB' comprises VES stations 3,5,8, and 9 trendings in the NW-SE direction (Fig.4). A shallow low resistive layer (7.19 Ωm to 10 Ωm) and thickness (0-5m) were observed beneath stations 3 and 5. This low resistive layer is due to the presence of lithomarge clay, and there may be the presence of groundwater. Beneath this layer, a high resistive (19.31 Ω to 26.83 Ωm) and thickness (10 m to 14 m) were observed at VES3 and VES5. Below this layer, a low resistive layer having resistivity(10 Ωm to 13.89 Ωm) and at a depth of (10 m to 28 m) is observed at stations 3 and 5. A shallow



(a)



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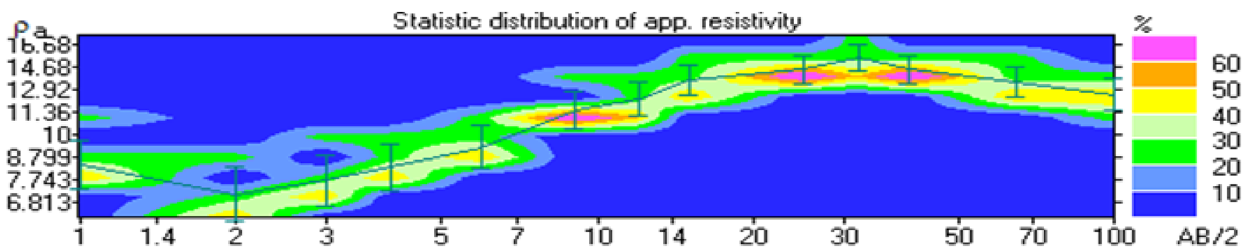


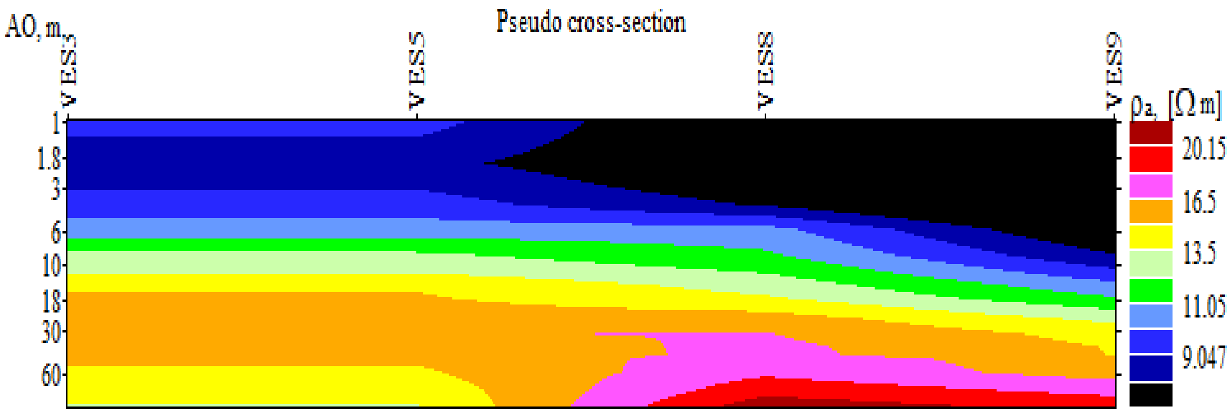
(c)

Fig. 3: (a) Pseudo cross-section,(b) Resistivity cross-section,(c) Statistic distribution of apparent resistivity.

low resistive layer(3.7 Ωm to 7.19 Ωm) and thickness (0-2.5m) are observed beneath stations 8 and 9. This effect is due to the presence of lithomarge clay, which may contain groundwater also. A high resistive layer (51.79 Ωm to 300 Ωm) occurs as a basement layer at station 9. A conductive layer of resistivity (10 Ωm to 13.89 Ωm) and thickness (5m to 30m) occur at station eight, and a low resistivity layer (5.1 Ωm to 7.1 Ωm) and thickness of 20 m occur at station 9. These all low resistive layers that are observed at stations 3,5,8, and 9 are likely to be a good potential zone for storage and movement of groundwater. Hence these sites are suitable for groundwater exploration.

Profile CC'

The Profile CC' comprises VES stations 13,12 and 14 trending in the NE-SW direction (Fig. 5). A low resistive (1Ω m to 8.43 Ωm) layer is characterized at the top surface all along with the profile, and the thickness of this low resistive layer is small at stations 13 and 14, and thickness is about 1m at VES station 14. This effect is due to the presence of clay in the soil. This layer may contain groundwater at station 14. A high resistive layer (26 Ωm to 300 Ωm) occurs at VES12 at a depth of 5 m to 10 m. This effect is due to the presence of Hard and compact sandstone. A low resistive layer (10 Ωm to13.89 Ωm) of



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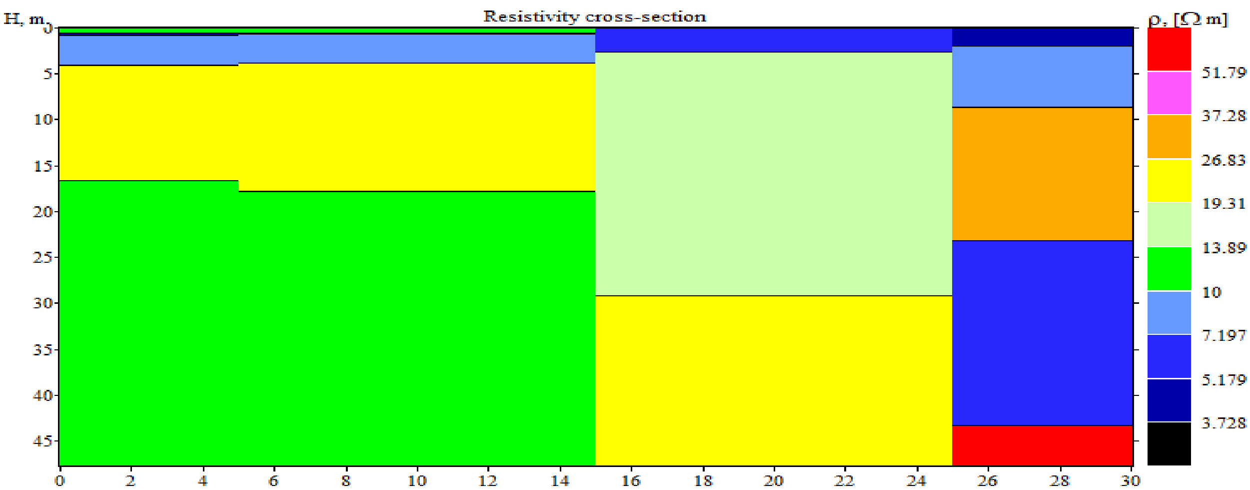

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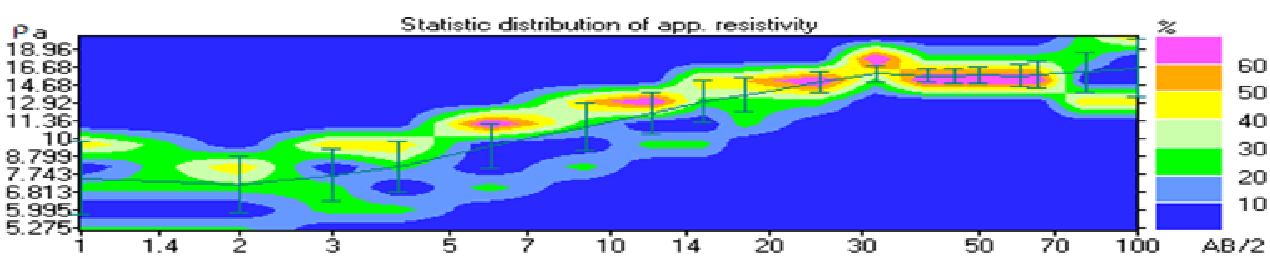
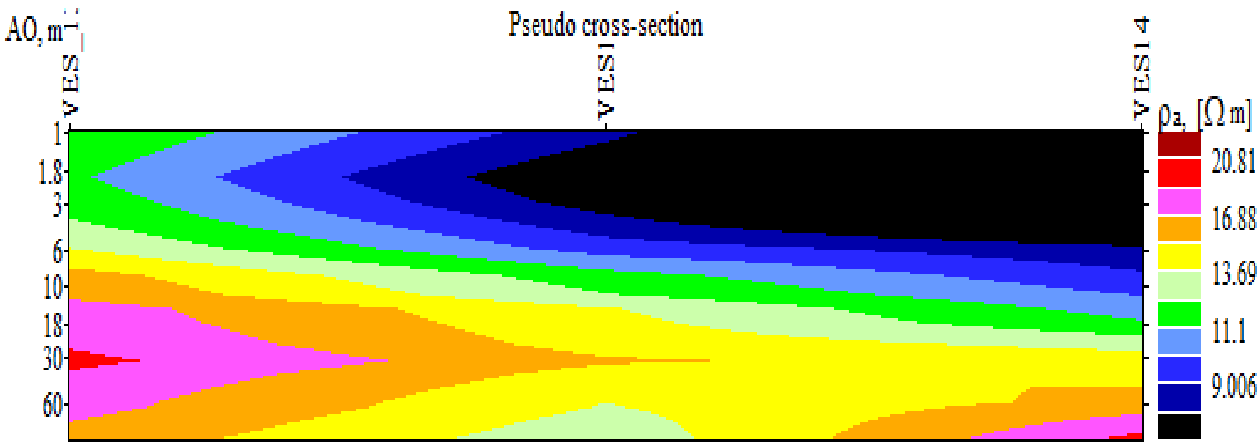


(c)

Fig.4: (a) Pseudo cross-section,(b) Resistivity cross-section,(c) Statistic distribution of apparent resistivity.



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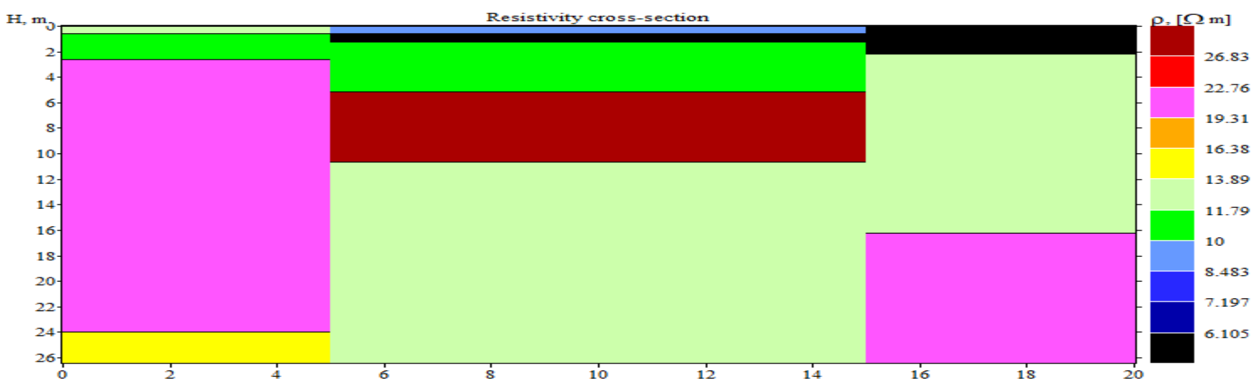

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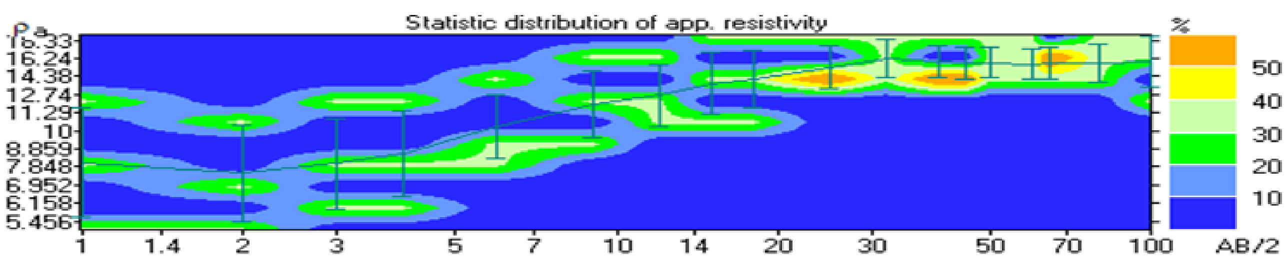

(c)

Fig.5: (a) Pseudo cross-section,(b) Resistivity cross-section,(c) Statistic distribution of apparent resistivity.

varying thickness occurs at stations 13, 12, and 14 at a depth of 0.5 m, 1 m, and 2 m, respectively. This low resistive layer is likely to be a potential zone for the storage and movement of groundwater. At a maximum depth of observation, a low resistive layer (11.79 Ωm -14 Ωm) and thickness of 15 m occur at station 12, which is likely to be a potential zone for groundwater. Hence a low resistive layer at station 13, 12, and 14 are likely to be a good groundwater potential zone.

CONCLUSION

Fifteen vertical electrical sounding data were acquired within the Village Banauli Singrauli district, in the eastern part of Madhya Pradesh, India, to delineate the resistivity and thickness of the geological formation and to assess the potential groundwater aquifer zones beneath the formation. Generally, good accumulation of groundwater occurs in weathered/fractured geological formations, In the study area, it is found that the top layer which has low resistivity may contain groundwater, but its thickness is small. By observing the layered resistivity and thickness of all fifteen VES stations, it is found that VES stations 1,2,4,5,7,9,10, and 12 have five layered Earth sections, and VES stations 3,6,11, and 13 have four layered Earth sections while VES stations 8,14,15 have three-layered Earth sections. Correlating the resistivity and thickness obtained in 15 VES stations with known lithology of the study area, it is found that the third layer of fine-grained sandstone to fractured or weathered sandstone has a resistivity of 7.903Ωm to 29.2Ωm and mean thickness of 10.55m, this layer is potential groundwater aquifer zones. Thus, the vertical electrical sounding technique has proven to achieve success and is extremely effective within the study area for the identification and delineation of subsurface structures that are favorable for groundwater accumulation in the study area. The electrical resistivity survey method utilized in this project necessitates locating favorable dug well and boreholes in the area.

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