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Ground Water Potential Zone Estimation Using Vertical Electrical Sounding (VES) in Some Parts of Bundelkhand Region of Jhansi District of Uttar Pradesh, India

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Abstract This study employed Vertical Electrical Sounding (VES) surveys with the Schlumberger array configuration to identify groundwater potential zones in the Moth block of Jhansi district. Schlumberger soundings offer high resolution, depth probing, and field efficiency, which were particularly beneficial in hard rock terrains for studying weathering, fractures, and geomorphological features. Using a DDR-2 resistivity meter, the study successfully discerns water-bearing layers and assessed groundwater properties such as depth, quality, and thickness. The resistivity survey explores up to 60 m, and resistivity value ranges from 2.31 Ω.m. to 99 Ω.m within the surveyed region. The interpreted VES curves revealed that the subsurface lithology consisted of four to five resistive layers. And the results obtained from the distribution of potential zone with their lateral and vertical distribution in lithology signify the suitable depth of ground water well to fulfill demand agriculture needs. These findings are crucial for sustainable groundwater development in the moth block region for agricultural planning, as it helps in identifying suitable areas for groundwater extraction and inform the management borewell depth. Consequently, this plays a key role in sustainable agricultural development in regions with varying geological characteristics. *Keywords:* Groundwater potential, Vertical Electrical Sounding (VES), Resistivity, Jhansi.

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1. Introduction

Groundwater serves as a crucial water source worldwide. The development activities, population growth and agricultural practices distress the ground water potential zone [1,2] to fulfill the requirement of groundwater, identification of new ground water potential zone for the exploration is one of the most important steps towards the establishing of bore well life for domestic and agriculture purpose [3,4,5]. Groundwater serves as the primary irrigation source for agricultural purposes and green revolution in India increase the utilization the ground water resultant suppresses its potential [6]. The factors such as topography, lithology, geological structures, weathering condition of surface rock, extent of fractures, secondary porosity, landforms, drainage pattern, land use/land cover, climatic situations, and their interactions, contribute to the occurrence and movement of groundwater in a given area [7,8]. The chances of occurrence of groundwater in hard rock terrain generally irregular due to various structural discontinuities which provides partial ground water resources in many part of it [9]. In the case of fractured rock and weathered, ground water availability controlled by occurrence by joints, shear zone, faults and dykes act as barrier in ground water movement [10,11].

Studying the Groundwater in fractured hard rock terrain is notably difficult without the use of geophysical methods. These Geophysical methods have extensive application in of mapping subsurface structures, exploring groundwater, and studying subsurface stratigraphy. Electrical resistivity method is a geophysical techniques developed in the 1900s for groundwater investigation, frequently used by many geophysical professionals [12,13,14,15,16]. Due to flexibility in applicability in various geological occurrence [17,18,19]. Vertical Electrical Sounding (VES) with

Schlumberger configuration, one of many resistivity techniques, is more quickly and economically utilized to identify potential zones with subsurface information concerning water-bearing lithological data [14].

The aim of present study is the identification of suitable site for ground water exploration location with help of VES survey and data interpretation. To enhance our understanding of groundwater dynamics, contouring of resistivity values at different depths provides insights into the characteristics of subsurface. The well-established postulate of electrical resistivity data makes contract in ground lithological units with identify auriferous and non-auriferous layers within and beyond lithological unit [20]. Because of the saturation of water and its quality well related to the earth materials resistance [21,22]. To fill the aim of study efficient and cost effective VES survey carried out and data interpreted of different locations of the moth block. The outcome of the study will help in planning future wells for home and irrigation purpose which become directly beneficial to the farmers and society.

For the prospecting of groundwater, a vertical electrical sounding survey was carried out in the Moth block of Jhansi district, Uttar Pradesh (Figure 1). The study area is located in the northwestern section of Jhansi district and extends from Latitude 25.65°N to 25.9°N and Longitude 78.79°E. The major portion of moth block and Garautha tehsil area surficial covered by alluvium rest parts are the Bundelkhand Gneisses Complex [23] Betwa river passes right side of Moth block which drains the surface run off of moth block, also erodes older alluvium part in altering their course of river. Moth block cover about 31% of total canal length and area 13.36% of district [24]. The Vertical Electrical Sounding (VES) survey was conducted at a total of 18 locations within the Moth block, specifically on agricultural land, to acquire subsurface resistivity data on different kinds of lithologies (Table 1). The geophysical approach helps to get information about the ground water resource, their dynamics done from surface by using the geoelectrical methods, it can be clears about the thickness of aquifers, depth of layers by demonstrating the geoelectrical measured data in graphical forms [25,26].

2. Study Area

Table 1. VES survey locations in villages of Moth Block of Jhansi district

Survey Points	Name of Villages	Longitude (E)	Latitude (N)
VES_1	Khilli_01	79.002	25.750
VES_2	Moth_01	78.954	25.729
VES_3	Moth_02	78.957	25.722
VES_4	Sakin	78.960	25.875
VES_5	Moth_03	78.931	25.714
VES_6	Budawali_01	78.937	25.743
VES_7	Budawali_02	78.938	25.748
VES_8	Sajauni	78.954	25.930
VES_9	Khilli_02	78.947	25.690
VES_10	Moth_04	78.907	25.798
VES_11	Moth_05	78.974	25.787
VES_12	Saurai_01	78.801	25.770
VES_13	Khujj_1	78.914	25.681
VES_14	Khujj_2	78.987	25.865
VES_15	Bharosa_01	78.933	25.744
VES_16	Bharosa_02	78.923	25.735
VES_17	Amarukh	78.995	25.788
VES_18	Saurai_02	78.793	25.774

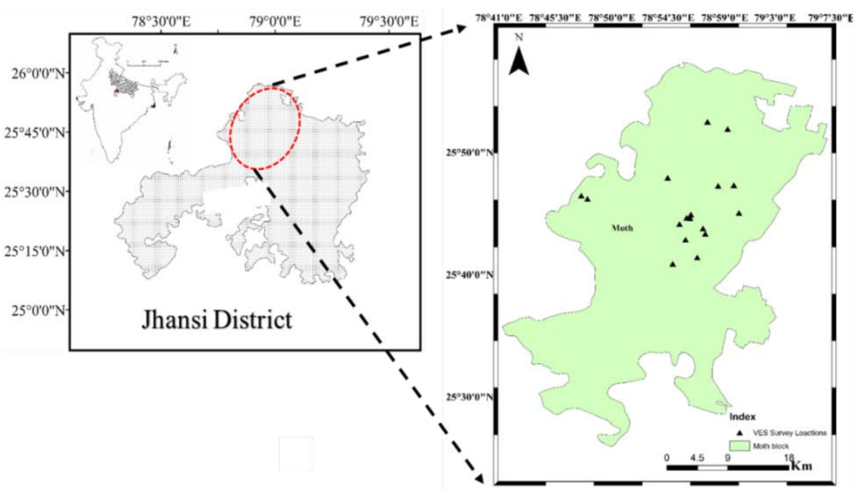


Figure 1. Locations of VES survey locations in Moth block of Jhansi district, Uttar Pradesh, India

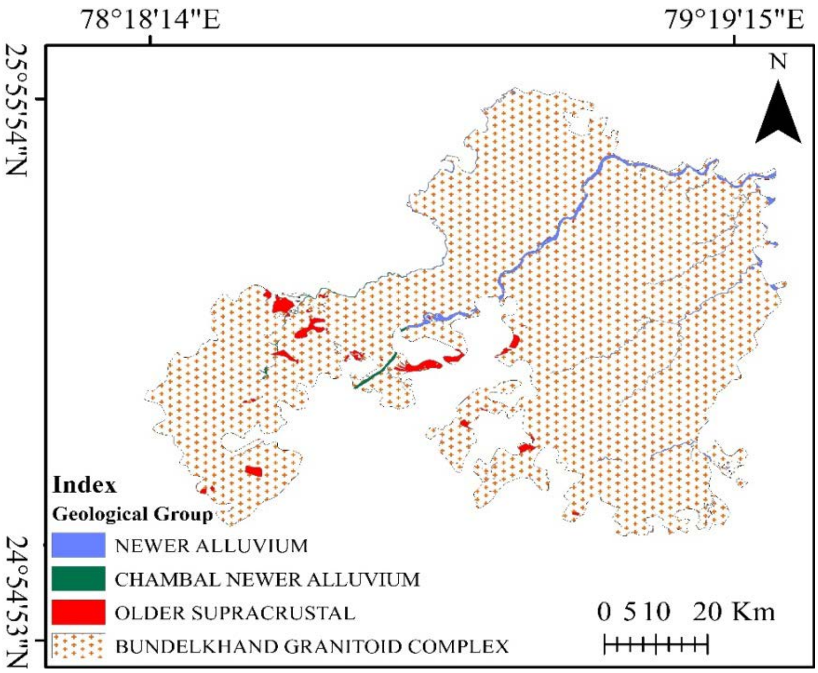


Figure 2. Geological group map of Jhansi district [42]

Table 2. Geological succession presented in the Jhansi District (Source: GSI)

AGE	GROUP NAME	FORMATION	LITHOLOGY
Holocene	Chambal newer alluvium	Sind	Sand/channel alluvium
Holocene	Newer alluvium	Terrace alluvium	Grey Micaceous sand, Silt and clay
Meghalayan		Channel alluvium	Grey sand, Silt and clay
Archaean	Older Supracrustal		Amphibolite, Diorite, Enclaves of older Metamorphics (unclassified), Metasediments, Quartz-biotite schist, Quartzite
Archaean-Palaeoproterozoic	Bundelkhand Granitoid complex		Chlorite schist, Coarse grained granite, Coarse grained, Porphyritic granite, Dolerite, Fine grained granite, Fine grained pink granite, Granite, Granite gneiss, Medium grained granite, Medium grained leucogranite, Medium grained pink granite, Migmatite, Migmatite, Pegmatite/acid intrusive/quartzofeldspathic veins, Porphyritic coarse-grained granite, Porphyritic coarse grained pink granite, Porphyritic Granite, Quartz vein, Undifferentiated granite, Granodiorite and gneisses

Geology and hydrogeology of study area

Geologically, Jhansi district in the Bundelkhand region is predominantly composed of rocks from the Archaean Age Bundelkhand Gneissic Complex (BGC), along with more recent Alluvial sediment deposits (Figure2). BGC comprises of non-foliated granitic rocks with gneisses, Banded magnetite, Ultramafic and Calc-silicates [27]. The Ultramafic rocks are associated with the meta-basic rocs in patches in Jhansi district [5].

The Jhansi district can be categorized into two main geological units. The first group comprises consolidated hard rock formations, encompassing the Bundelkhand Granitic gneisses, sandstone, and quartz reefs. The second group consists of unconsolidated materials, primarily composed of Alluvial sediments and valley fills. Moth block are the parts of unconsolidated region with base of fracture hard rock. Basal hard granitic rocks provide some potential zones of ground water by present fractures in it and weathered rock material also help in underground movement water.

The drainage system of Jhansi district is integrated into the Yamuna sub-basin of the Ganga River. The Yamuna River flows from west to east, complemented by its tributaries, including the Jamuni, Pahauj, Betwa, and Suknai rivers [28].

The aquifer system in Jhansi district is composed of multiple layers, categorized into four distinct groups. First layer aquifer lies between unconfined to semi-confined with range of 150 m below ground level (bgl), The second, third, and fourth groups exhibit semi-confined to confined conditions, with depth ranges of approximately 160 to 250 meters, 250 to 360 meters, and below 380 meters below ground level (bgl), respectively [29,30,31]. The moth block of Jhansi district lies in sub humid region of climatic condition. The Rainfall of the Jhansi district ranges from 867 to 1062 mm, with an annual average of 877 mm, and The annual temperature range varies from 28 to 43 degrees Celsius in the summer and from 9 to 24 degrees Celsius in the winter [30].

3. Material and Method

In the Moth Block of Jhansi district Vertical Electrical Sounding (VES) conducted for collection field geophysical data at 18 locations covering the 10 villages(Figure 3). The Vertical Electrical Sounding

(VES), a well-known geoelectrical technique that has been applied since the 20th century and is well-known for its flexibility and clarity, is being used for the present research's objectives [32]. In particular, VES have proved very effective in locating ground water potential zones in fractured rocks condition well sites [33,34,35,36]. VES survey is a method used to probe the subsurface geology and hydrogeology of a location. It involves calculation of the electrical resistivity of the subsurface lithology at different depths using a series of electrodes. The Schlumberger electrode array was specifically chosen for this study because of its capacity to reveal delicate vertical variations of resistivity at specific locations. This configuration aims to enhance the acquisition of lithological data, aiding in the identification of potential zones of interest for ground water. survey was carried out in the study area in the months of April and May, 2016 to acquire the resistivity data of subsurface lithology. The lightweight ABEM SAS 300 C Terrameter equipment used in fields survey which is flexible to transport and setup even in difficult terrain. The electrode spacing of AB/2 = 100 m taken, and the potential electrodes are positioned in the center of the current electrodes with of current electrodes with minute spacing between them, their spacing generally than one-fifth of current spacing at that time. Mainly surface alluvium lithology encountered during the field survey in villages of Moth block.

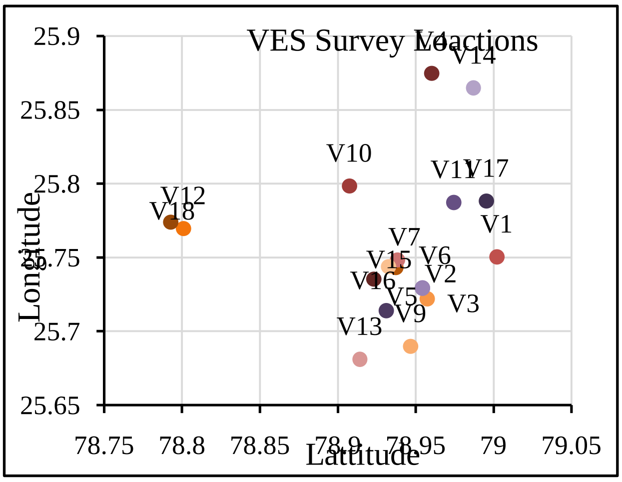


Figure 3. Plot of survey locations in Moth block area

The resistivity measurements are normally made by injecting current into the ground through two current electrodes (C_1 and C_2) and measuring the resulting voltage difference at two potential electrodes (P_1 and P_2). From the current (I) and voltage (V) values, an apparent resistivity (ρ) value is calculated as shown in below equation no.1(Figure 4)

$$\rho = k\left(V / I\right) \quad (1)$$

Resistivity meters generally measures the give a resistance value, as shown in

$$R = V / I \quad (2)$$

So, in practice the apparent resistivity value is calculated.

VES survey is a method used to probe the subsurface geology and hydrogeology of a location. It involves calculation of the electrical resistivity of the subsurface lithology at different depths using a series of electrodes. For the present study Schlumberger electrode configuration formula used to calculate the equation no.2

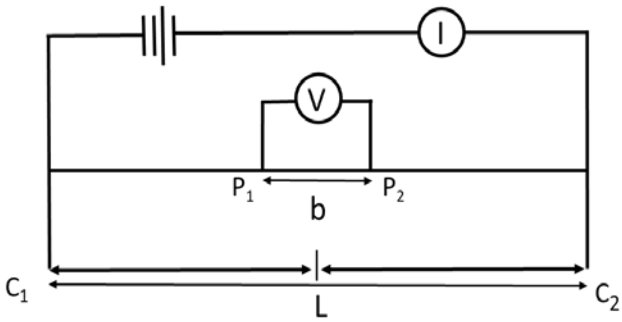


Figure 4. Demonstration of Schlumberger electrode configuration applied in the present survey

$$\rho_a = \pi\left[\ \left[(L/2)^2 - (b/2)^2\right]/b\right](V/I) \quad (3)$$

Where, the $\pi\left[\ \left[(L/2)^2 - (b/2)^2\right]/b\right]$ is the Schlumberger constant is contingent upon the electrode arrangement's geometry. The purpose of electrical surveys is to determine the subsurface resistivity of earth material using resistivity meter DDR-2 and understand its distribution by making measurements on the ground surface. The current penetration depth proportional to electrode spacing and variation in the separation give the stratification data in homogeneous ground condition [37,38]. Any of the methods, including partial curve matching [39], factor analysis [40], and the inverse methodology [41],are utilised to evaluate the field VES data in order to determine the geoelectrical layers.

Table 3. Interpretations results of the VES data

VES No.	True Resistivity Ohm-meter (Ω.m)					Thickness (m)					Depth					Explored Depth (m)
	$\rho 1$	$\rho 2$	$\rho 3$	$\rho 4$	$\rho 5$	h1	h2	h3	h4	h5	d1	d2	d3	d4	d5	
1	23.13	13.08	7.24	60.49	-	0.71	6.93	17.94	-	-	0.71	7.69	25.58	-	-	33.99
2	25.13	56.99	10.25	98.55	-	1.02	0.87	15.11	-	-	1.02	1.89	17.00	-	-	19.91
3	16.94	9.80	23.49	4.08	31.04	1.20	1.68	4.05	9.72	-	1.20	2.88	6.93	16.65	-	27.66
4	8.50	65.30	8.99	98.60	-	0.80	0.83	20.00	-	-	0.80	1.63	21.60	-	-	24.03
5	4.49	15.60	4.63	87.50	-	1.59	8.03	20.10	-	-	1.59	9.61	29.70	-	-	40.90
6	16.97	11.01	15.08	3.95	28.41	1.20	4.14	5.91	12.47		1.20	4.14	5.91	12.47	-	23.72
7	3.42	13.20	7.27	84.70	-	1.20	6.01	33.60	-	-	1.20	7.21	40.80	-	-	49.21
8	9.52	23.70	13.2	23.20	-	2.15	3.94	3.15	-	-	2.15	6.09	9.24	-	-	17.48

VES No.	True Resistivity Ohm-meter (Ω.m)					Thickness (m)					Depth					Explored Depth (m)
9	21.20	12.90	8.10	94.50	-	0.82	6.15	22.76	-	-	0.82	6.97	29.73	-	-	37.52
10	7.16	55.00	12.80	94.50	-	1.20	1.68	12.40	-	-	1.20	2.88	15.20	-	-	19.28
11	9.31	3.39	27.30	5.23	22.80	1.33	1.06	3.59	8.41	-	1.33	2.39	5.98	14.40	-	24.10
12	3.95	11.20	35.20	2.37	99.00	0.55	5.30	5.20	11.0	-	0.55	5.85	11.10	22.10	-	39.60
13	7.06	24.92	2.31	93.06	-	2.54	8.79	10.97	-	-	2.54	11.33	22.30	-	-	36.17
14	10.20	16.10	5.56	77.30	-	6.94	9.72	20.00	-	-	6.94	16.70	36.70	-	-	60.34
15	3.38	6.79	11.30	4.29	86.40	1.20	5.73	9.72	21.0	-	1.20	6.93	16.70	37.70	-	62.53
16	2.62	20.90	3.05	11.00	86.60	0.81	1.06	1.96	37.50	-	0.81	1.87	3.83	41.30	-	47.81
17	4.02	11.50	18.20	5.33	90.7	0.35	8.64	8.15	19.10	-	0.35	8.98	17.10	36.30	-	62.53
18	6.35	15.20	4.63	96.00	-	1.63	17.90	18.50	-	-	1.63	19.50	38.10	-	-	59.23

*Note: ρ and h are electrical resistivity in Ohm-m (Ω-m), and thickness in m, respectively. Suffixes indicate the layer number.

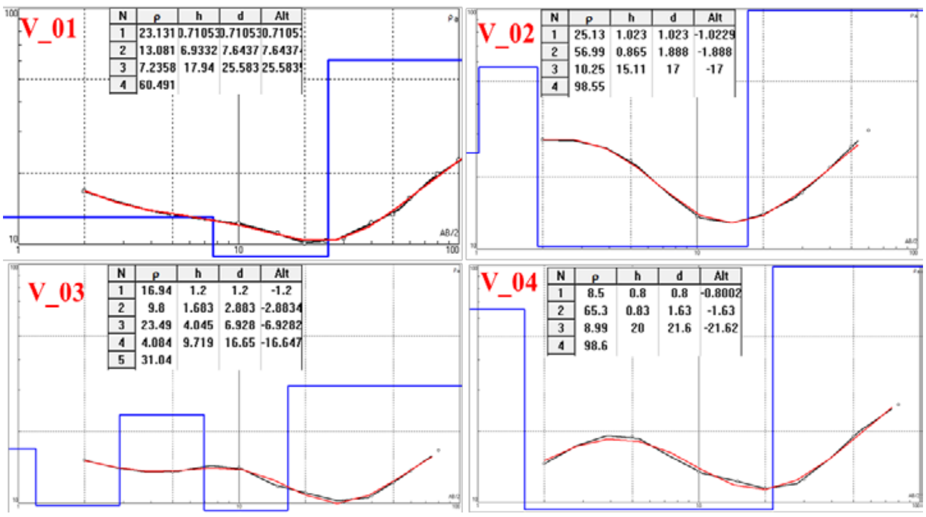
4. Results and Discussion

The study area underwent 18 Vertical Electrical Soundings (VES) utilizing the Schlumberger electrode array for investigation. The interpretation of VES survey result enables us to determine the thickness of the resistive layers based on different true resistivity values of lithotypes (Table 3). The measured true resistivity ranges from 2.31 Ω.m. to 99 Ω.m within the investigated depth range of up to 60 m. and the surface resistivity varies from 2.62 Ω.m to 25.13 Ω.m. for the sounding locations V_{16}, V_2 respectively. Maximum and minimum resistivity variation observed of 96.63 Ω.m 28.41Ω.m at the observed at V_{12} and V_{06} respectively. And explored depth varies from 17.48 m to 60.34m for the V_{08} and V_{14} sounding locations respectively.

The true resistivity values and thickness of the different layers for all the vertical sounding data, has been evaluated with the help of partial curve matching technique for evaluation of last layer thickness, an asymptotic method has been used. Weathered and fractured horizons have been identified in the study area underlying VES stations, and all of these constitute the aquifer zones. Good prospects therefore exist for groundwater development in the study area where the depth to basement is relatively thick and has favorable low resistivity, while those with thin depth to bedrock and high resistivity value have a lower potential for an aquifer.

Interpretation of vertical electrical sounding data

The obtained resistivity data process through the IPI2win software for the 1D interpretation of VES profile. The software offers a simple workflow from data import of VES data for the inversion and visualization, while still offering full control over inversion parameters for advanced users. the analysis and interpretation of resistivity data, which is frequently employed during exploration research, there are numerous tools available. These distinctive characteristics features in apparent resistivity curves were characterized by the considerable spatial variability of groundwater quality and homogeneity of subsurface aquifer conditions. VES data of 18 point (Table 1) processed for calculation of apparent resistivity, the expression for the apparent resistivity is as follows:



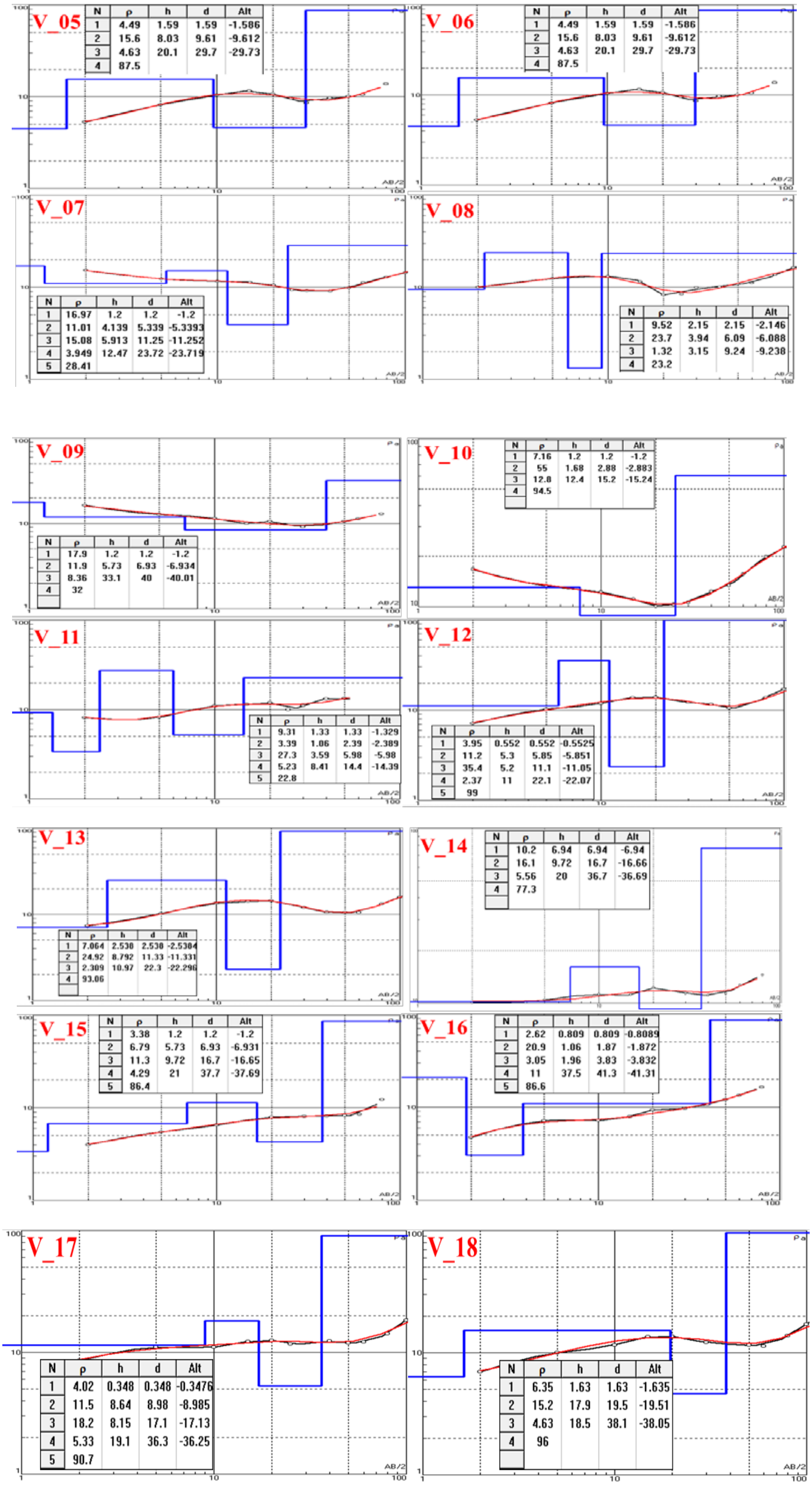


Figure 5. Interpreted VES data and its curve of study area

The interpreted curve of VES consists of four and five resistive layers, so the characteristic of curve formed by composite sounding curve types for more than three resistive layers. The whole set of curves is mainly grouped in to four and five resistive layers.

Table 4. Summary of various composite curves distribution within the study's area

Sr. No.	Curve type	Resistivity model	VES locations
1	QH	$\rho 1 > \rho 2 > \rho 3 < \rho 4$	VES_9 VES_1
2	KH	$\rho 1 < \rho 2 > \rho 3 < \rho 4$	VES_2 VES_4 VES_5 VES_7 VES_8 VES_10 VES_13 VES_14 VES_18
3	HKH	$\rho 1 > \rho 2 < \rho 3 > \rho 4 < \rho 5$	VES_11 VES_6
4	AKH	$\rho 1 < \rho 2 < \rho 3 > \rho 4 < \rho 5$	VES_12 VES_15 VES_17
5	KHA	$\rho 1 < \rho 2 > \rho 3 < \rho 4 < \rho 5$	VES_16
6	KQH	$\rho 1 < \rho 2 > \rho 3 > \rho 4 < \rho 5$	VES_3

Lateral characteristics of resistivity layer within explored depths:

The resistivity values at varying depths in the study area show a wide range, reflecting the subsurface lithology's characteristics (Figure 6). These values change significantly from location to location, indicating variations in groundwater dynamics and lithology. At the surface, resistivity ranges from 2.62 Ω.m. to 25.13 Ω.m., with higher values in the South–East corner (Figure 6). At 10m depth, it varies from 4.08 Ω.m. to 86.6 Ω.m., with lower resistivity.

in the South –East portion. At 20m depths, resistivity extends from 2.31 Ω.m. to 98.6 Ω.m. with lower values in the South–East corner and also spread all over area (Figure 6). And at 30 m and 40 m depth resistivity varies from 4.29 Ω.m. to 99 Ω.m., respectively, with higher values covering more than half of the area with same pattern continues especially towards the south west region. This trend persists down to depths of 60 meters, at 50m and 60m, the resistivity varies between 22.8 Ω.m and 99 Ω.m. Notably, high resistivity encompasses more than half of the study area's extent. This remarkable shifting of high resistivity zones after the indicative of low conductivity directly specify absence of water or less amount of water with increasing depth provide insights into each layer's characteristics. The groundwater potential layer, as observed from the interpreted curve fitting method, shows a thickness variability ranging from 1.9 meters (v16) to 33 meters (v9) out of the total four to five layers present in the study area.

From surface to up to 10m depth, resistivity contour of lithology suggests viability of ground water beyond that depth water bearing lithology's covering the South-West and south-East region to contracting into East region of moth block.

5. Conclusion

The Vertical Electrical Sounding (VES) technique showed its efficiency to identify ground water potential zones. The VES results revealed variations in subsurface lithological resistivity both vertically and laterally within parts of the Moth block in Jhansi district. The resistivity survey within the study area explored up to 60 m depths and resisvity values ranges from 2.31 Ω.m. to 99 Ω.m. The interpretation of VES data revealed various types of curves, including the QH, KH, HKH, AKH, KHA, and KQH, with KH types predominantly found among the results of 18 survey points. The groundwater potential layer, as observed from the interpreted curve fitting method, shows a thickness variability ranging from 1.9 meters (v16) to 33 meters (v9) out of the total four to five layers present in the study area. The Contour plots of resistivity data, with a depth interval of 10 m, depict both lateral and vertical variations, indicating significant groundwater potential zones up to a depth of 10 m. The primary implication of the present study is the identification of suitable sites for groundwater bore wells to ensure maximum bore well lifespan.

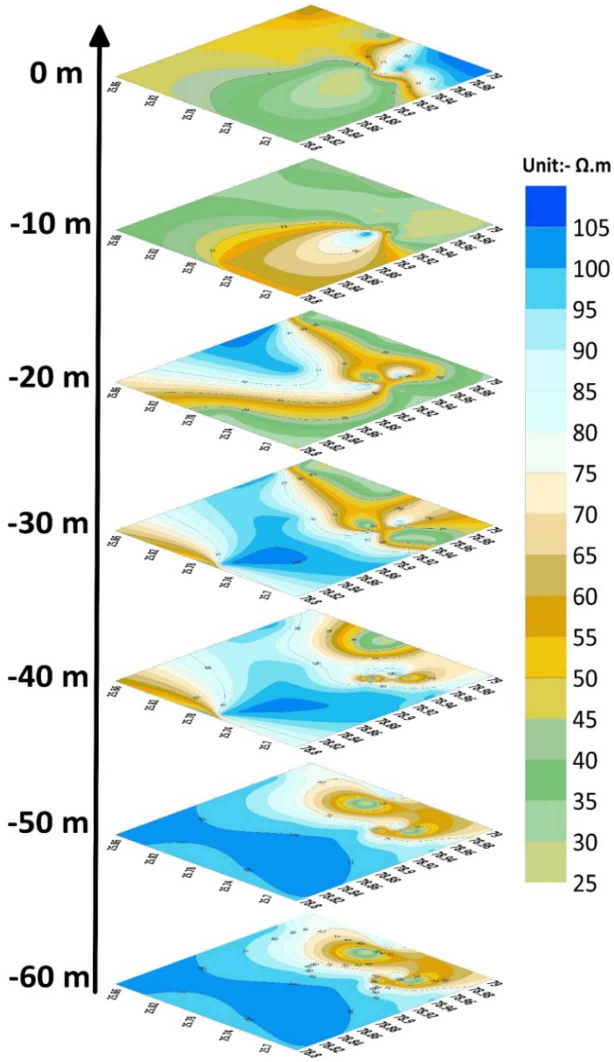


Figure 6. Resistivity contour map data and its curve of study area

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Declarations

Competing interests

(always applicable and includes interests of a financial or personal nature)

This is to declare by all the authors that no financial and personal relationships with other people or organizations have been taken and there is no conflict of interest with other people or organizations.

Authors' Contributions

(applicable for submissions with multiple authors)

Jayant Nath Tripathi: Conceptualized the problem, resources and supervision;

Som Nath, JN Tripathi VK Upadhyay: methodology and formal analysis, original draft preparation

Som Nath, JN Tripathi VK Upadhyay, HK Verma: writing—discussion, review and editing

All authors have read and agreed to the published version of the manuscript.

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Availability of Data and Materials

(a statement on how any datasets used can be accessed)

Data and material are given in the manuscript.

Ethical Responsibilities of Authors

Authors declare that they follow the ethical responsibility of the Journal.

The manuscript is original.

The manuscript in part or in full has not been submitted or published anywhere and will not be submitted elsewhere until the editorial process is completed.

Manuscript does not content publication of conference proceedings, letters to journals and brief communications, or as pre-prints on repositories.

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