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Geophysical Exploration analysis on Varthur catchment area of Dakshina Pinakini river basin, Karnataka, India, using GIS and Remote Sensing techniques.

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Abstract

Geophysical exploration analysis like Vertical Electrical soundings and profiling have proved to be very valuable tools in prospecting for geothermal energy in many countries. Three principal variations of direct current methods have found use in geothermal energy exploration. The selected area. In general, the crystalline terrain in Bangalore has four-layer subsurface configurations such as top soil zone followed by weathered zone, fractured zone and massive rock. The resistivity data were interpreted through inverse slope method and estimated the thickness of weathered zone, fractured zone and depth of bed rock. The thickness values were plotted in the respective VES location and contour maps were generated for weathered zone and fractured formation and depth to bed rock.

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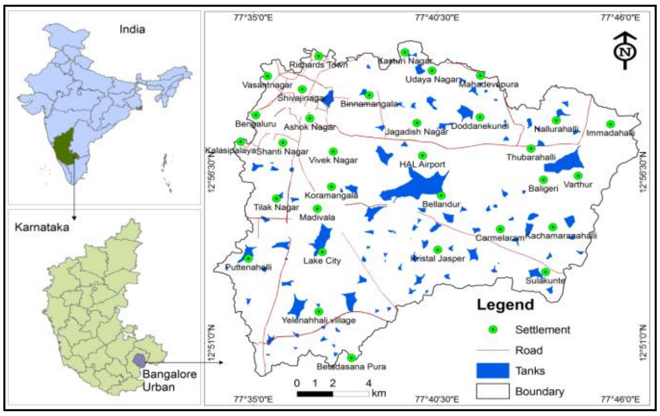
Introduction

Geophysical resistivity observations offer important insights into the subsurface lithological characteristics at considerable depths. Among the various techniques used for groundwater exploration, resistivity surveys are widely regarded as a dependable and effective method. Crystalline hard rock regions typically show heterogeneous conditions, with significant variations in the thickness of weathered layers. Conducting closely spaced Vertical Electrical Soundings (VES) helps to acquire more precise information regarding the depth and extent of both the weathered zone and the fractured zone. Geophysical resistivity methods have emerged as a primary tool for groundwater exploration in hard rock terrains of India, where aquifers are discontinuous and structurally controlled. Recent studies demonstrate that resistivity surveys effectively delineate weathered and fractured zones, which are critical for groundwater occurrence in crystalline formations. The integration of resistivity data with hydrogeological parameters has improved aquifer characterization in semi-arid regions [1, 2]. Thus, electrical current propagation (process) is influenced by subsurface resistivity contrasts, enabling identification of potential groundwater zones. The investigated area is predominantly composed of hard rock which is devoid of primary porosity. In this type of terrain, the occurrences of groundwater mostly confined at the base of the weathered layer or within the fractured portion of basement rock. But locating such fracture-zone aquifer under a thick, weathered mantle is a major hydrogeological task. It is because of heterogeneity and complexities involved in the crystalline rocks, which exhibit anisotropic behavior. The amount of groundwater is related to factors such as fracture density, fracture aperture, and recharge conditions, etc. The resistivity method is a versatile technique used in groundwater exp1oration for identifying potential well sites. Due to its wide variability in resistivity of different formations and due to its economic advantage in operation, the technique is widely used for the groundwater prospecting. Hence, a geoelectrical investigation was conducted to evaluate the subsurface lithological condition.

Location of the Study area:

The study area Varthur Lake is situated in the southern parts of the Karnataka State, between 12°48′24.52″ and 12°53′59.85″ North latitude and 77°24′59.95″ to 77°30′6.72″ East Longitude and spreads over a region of 284 sq.km (Map .1). It gets precipitation from both upper east and the southwest storms with yearly aggregate precipitation of around 900 mm.



Map 1: Location of the study area

Material and Methods: -

Electrical resistivity surveys were carried out at 46 different locations within the study area to obtain geophysical information using the Electrical Resistivity method (Map 2). The resistivity sounding curves were first interpreted by the curve matching technique [3]. Using the layer parameters, the interpretation was further refined by computer aided technique [4] by changing layer parameter in an iterative manner to achieve better match between the observed and the computed curves. In all, 46 sounding curves starting from simple two layer earth, complex three layer earth sections were obtained. The number of three layer sequence more in the study area. Unlike sedimentary and metamorphic terrains, the igneous terrain has no clear-cut layering. There are different zones consisting of weathered rocks, fractured charnockite and gneissic rocks. The resistivity of weathered rock is in the order of ~50-120 ohm-m and that for hornblende gneiss and charnockite from 200 ohm-m to sometimes very high values. Besides electrical resistivity sounding technique, for regions of smaller areal extent resistivity profile is carried out to determine lateral variations in resistivity values to locate shallow aquifers.

Integrating hydrogeomorphological data with geophysical investigations, Teeuw [5], Shahid et al. [6]

Electrical resistivity measurements

The upper subsurface layer is interpreted as weathered charnockite or fractured gneiss formations containing groundwater, while the highly resistive intermediate layer indicates compact and impermeable hard gneiss resting above hornblende gneiss at greater depth. Borehole lithological investigations identified a weathered surface zone along with granitic gneiss extending to nearly 6 m depth. Beneath this, fractured formations of about 9 m thickness were encountered, followed by a thick massive charnockite layer extending up to 71 m. Water-bearing granitic gneiss was identified below the massive charnockite horizon. Although the resistivity interpretation indicated a single thick resistive middle layer with resistivity around 120 ohm-m, drilling data further differentiated this zone into a fractured layer of nearly 14 m thickness and an underlying massive charnockite unit of about 75 m thickness.However, on the whole, there is a good correlation between the resistivity model and the borehole lithology data. To assess the accuracy of the VES interpretations, a sounding was carried out in close proximity of an existing well. The results from sounding close to a successful borehole indicate four geoelectric layers with absolute resistivities of 35, 189 and 60 ohm-m respectively, for the first three layers. The bottom-most layer has very low resistivity. The top layer of the formation 250 ohm-m which extends down to a depth of 0.82m from the surface correlates to the clayey sand of the available borehole logs with an overburden thickness of 1.6 m. The second geoelectric section is partly weathered with layer thickness of 5.12 m which corresponds to the borehole of layer thickness 6.2 m. The third layer shows a decreasing trend in resistivity, indicating weathered layer exhibiting a low resistivity of 60 ohm-m up to a depth of 23 m which correlated with gravel clay of an existing borehole of depth 22 m. The last layer has a low resistivity value of 210 ohm-m, thus the layer is fractured (Table.1). Sub-surface layer thickness vs. resistivity data obtained from geophysical resistivity data analysis

Subsurface layer configuration

The interpretation of the resistivity soundings provides very useful subsurface information. In cases where the soundings have been taken only at a few stations, the resistivity variation with depth and its correlation with the local geology at those few points can be considered. However, in situations where 2D coverage of the soundings spread over the area has been made, it is possible to prepare maps of elevation contours of the subsurface interfaces of different layers obtained from resistivity soundings. These elevation contour maps, called structure contour maps [7], provide a qualitative regional correlation between the subsurface geology and the electrical resistivity. The electrical resistivity in turn can delineate possible aquifers.

In structure contouring, the interfaces of different layers are conceptually visualized by progressively stripping the top or the first layer, then the combined first and the second layer and so on. It is different from the isopach maps, where the thickness of the individual layers is contoured. As the surfaces of the deeper horizons are exposed one after another, the interpreter progressively gets nearer to the ground water table, the unconfined aquifers, the impervious layers and the confined aquifers. The flow systems or flow patterns for each of the aquifers in a multiple aquifer system are also visualized. That is to say one moves to deeper horizons in stages. This technique is qualitative in nature.

The structure contour maps have been prepared for the study area (Maps 3 to 5). If one imagines that the entire top layer material is removed, the surface of the second layer will be exposed. This pseudo-surface takes the form as shown in the elevation contour map. It is interesting to note that these elevation contours resemble those of the observed groundwater table. The ground water potential zones on the basis of the resistivity soundings corroborate these findings. Map 4 represents the structural contours at the top of the third layer, i.e. both the first and the second layers have been removed in a similar fashion as obtained in Map 5. These contours no more resemble the groundwater table contour. The maximum contour (16 m on NE corner) and the minimum elevation (6 m on SW corner) show a difference of about 10 m. The contours show a large number of closures, thereby indicating a heterogeneous subsurface condition. The western and a portion of the central parts enclosed by 8m contour indicate a number of depressions near Vembavur and some of these are good aquifers.

Apparent Resistivity Contour

Electrical resistivity investigations were carried out using Wenner and Schlumberger electrode configurations to assess subsurface hydrogeological conditions. In the Wenner array, the depth of investigation is approximately related to the electrode spacing (a), where larger spacing provides information from greater depths. Accordingly, apparent resistivity contour maps were prepared for electrode spacings of 50 m and 75 m. The Schlumberger method, in which the current electrodes are expanded while keeping the potential electrodes relatively close, was also employed to obtain detailed vertical variations in subsurface resistivity. Comparison of resistivity contour maps with structural contours showed close similarity in the northern part of the study area, whereas weaker correlation was observed in the southern region. This indicates the presence of shallow aquifer systems in the north and relatively deeper subsurface formations in the southern sector. The thickness of the weathered zone in the study area varies between 10 m and 70 m, although in most locations it is limited to nearly 30 m. Highly weathered formations are confined to only a few pockets within the watershed. Field investigations revealed that groundwater development for irrigation mainly depends on dug wells excavated through shallow weathered zones and extended up to the massive bedrock in several locations.

Iso-Thickness Maps

The thickness of soil and weathered layers are also very important from the point of groundwater potential zones, as the percolation of rainwater is mainly controlled by these layers. The thickness of the first (h1) and second (h2) layers are varies from 1 to 1.9 m with an average of 1.62 m. The thickness of second layer varies from 6.7 to 14.6 m and an average of 8.9 m. The variation in the thickness mainly due to the variation in lithology and landforms. The Iso-thickness map of h1 and h2 (Maps 6 and 7) shows the anomalous zones in northern, western, central, southern and southeastern parts of the study area. The lithologies of these anomalous zones are weathered gneisses and granites. They have more chance for infiltration of rainwater and are the potential zones of groundwater.

Longitudinal Conductance (S)

Longitudinal conductance (S) is an important geoelectrical parameter derived from resistivity sounding data and is expressed as:

$$S = \sum \mathrm{hi}/\mathrm{\rho i}$$

Where ‘hi’ is the thickness and ‘ρi’ is the resistivity of the ith layer.

The parameter represents the protective capacity of the overburden, particularly its ability to attenuate or retard the downward migration of contaminants into underlying aquifers. Higher values of S generally indicate the presence of conductive materials such as clay, which provide better protection, whereas lower values indicate resistive formations such as sand or fractured rock, which offer minimal protection.

Longitudinal conductance (S) is a key geoelectrical parameter derived from resistivity sounding data and is expressed as the summation of the ratio of layer thickness to resistivity. It is widely used to evaluate the protective capacity of the overburden, particularly its ability to attenuate contaminant migration from the surface to the aquifer [8, 9]. Higher values of S indicate the presence of conductive materials such as clay and shale, which act as protective layers, whereas lower values indicate resistive formations such as sand and fractured rock that offer minimal protection.

In the present study, the computed longitudinal conductance values range from 0.09 to 0.51 Siemens, indicating significant spatial variability in subsurface conditions. The majority of the study area falls within the weak to moderate protective capacity range (0.1–0.3 S). Very low values (<0.1 S), observed in locations such as Madivala and Cox Town, suggest negligible protective capacity and a high vulnerability of the aquifer to contamination (Map 8).. These areas are likely characterized by thin overburden and the absence of clay-rich layers.

Moderate S values (0.2–0.3 S), observed in locations such as JP Nagar, Shanti Nagar, and Richards Town, indicate the presence of relatively thicker weathered formations that provide partial protection to the underlying aquifer. Higher values (>0.3 S), observed in areas such as Binnamangala (0.51 S), Mahadevapura (0.36 S), and Koramangala (0.33 S), reflect improved protective capacity due to the presence of clay-rich or well-developed weathered layers.

Overall, the spatial distribution of S values (Map 8) suggests that the study area is predominantly characterized by low protective capacity, making the groundwater system vulnerable to contamination, especially in urbanized zones. This observation is consistent with previous studies that link low longitudinal conductance with increased groundwater vulnerability [10, 11].

Transverse Resistance (T)

Transverse resistance (T) is another important Dar Zarrouk parameter defined as the summation of the product of layer thickness and resistivity. It is used to assess the aquifer potential and transmissivity, as it reflects both the thickness and resistivity characteristics of subsurface layers [8]. Higher values of T generally indicate thicker and more resistive formations, which are often associated with productive aquifers.

In the study area, transverse resistance values range from 136.4 to 1581.7 $\Omega\cdot m^2$, indicating considerable variation in aquifer characteristics. Low T values (<300 $\Omega\cdot m^2$), observed in locations such as Kristal Jasper (136.4 $\Omega\cdot m^2$) and Binnamangala (279.5 $\Omega\cdot m^2$), suggest poor aquifer potential, likely due to limited thickness or the presence of clay-dominated formations.

Moderate T values (300–1000 Ω·m²) are observed across a large portion of the study area, including Kalasipalaya, Adugodi, and Varthur, indicating moderate groundwater potential. High T values (>1000 Ω·m²), observed in locations such as Madivala (1581.7 Ω·m²), Cox Town (1195.4 Ω·m²), Bommanahalli (1299.8 Ω·m²), and Gunjur (1150.2 Ω·m²), suggest the presence of thick and resistive formations, which are indicative of favorable aquifer conditions, possibly associated with fractured rock systems.

The spatial variability in T values reflects the heterogeneous nature of the subsurface, where groundwater occurrence is controlled by localized weathering and fracturing rather than uniform sedimentary layering. This behavior is typical of hard rock terrains [11].

Integrated Interpretation of S and T

The combined analysis of longitudinal conductance (S) and transverse resistance (T) provides a more comprehensive understanding of groundwater conditions by simultaneously evaluating aquifer protection and productivity.

In the present study, areas exhibiting high T values but low S values (e.g., Madivala and Cox Town) indicate good aquifer potential but poor protective capacity. Such zones are favorable for groundwater extraction but are highly vulnerable to contamination. Conversely, areas with moderate to high S values and moderate T values (e.g., Koramangala and Mahadevapura) represent relatively balanced conditions, where the aquifer is both productive and moderately protected.

Areas with low T and low S values represent poor groundwater potential and high vulnerability, making them less suitable for groundwater development. The analysis clearly indicates that no region in the study area exhibits both very high protective capacity and very high aquifer potential, highlighting the inherent trade-off between groundwater productivity and protection.

The integrated analysis of longitudinal conductance and transverse resistance indicates that the aquifer system in the study area is predominantly characterized by moderate groundwater potential and weak to moderate protective capacity. While certain zones exhibit high transmissivity, the overall vulnerability of the aquifer to contamination remains significant due to insufficient overburden protection. This highlights the need for careful groundwater management and protection strategies, particularly in urbanized regions.

Implications for Groundwater Management

The results of the Dar Zarrouk parameter analysis indicate that groundwater occurrence in study area is largely controlled by fracture systems and weathered zones, with limited natural protection from overburden materials. The predominance of low S values suggests that groundwater is susceptible to contamination from surface activities, particularly in densely urbanized regions.

Therefore, it is essential to:

- Implement strict groundwater quality monitoring in low S zones
- Prioritize sustainable extraction practices in high T zones
- Integrate geophysical results with land use and hydrochemical data for effective groundwater management

Conclusion:

The fractured zone estimated from geophysical resisitivity survey and well investigation show it ranges from 10m to 90m. Again, the high thickness of fractured zone restricted to central part of the WS, particularly near the Vasishta nadi. Overall, the weathered zone and fractured zone follow same trend in the WS. Wherever both layers are in appreciable thickness, it favors for bore well irrigation. The continuous usage of groundwater and decline of water table condition lead to failure of many dug wells and farmers force to install borewells. The weathering and fractured condition is significant in gneissic formation, however, in charnockite formation this condition is very much restricted. The fractured zone thickness in the study area estimated through geophysical resistivity survey and well investigation is divided into less thickness of fractured zone, moderately thick and high thickness of fractured zone. The map has clearly indicated that the major part of the area is covered by less thickness of fractured zone. The weathered zone and fractured zone maps were useful in further ground water development or water management practices in the WS.

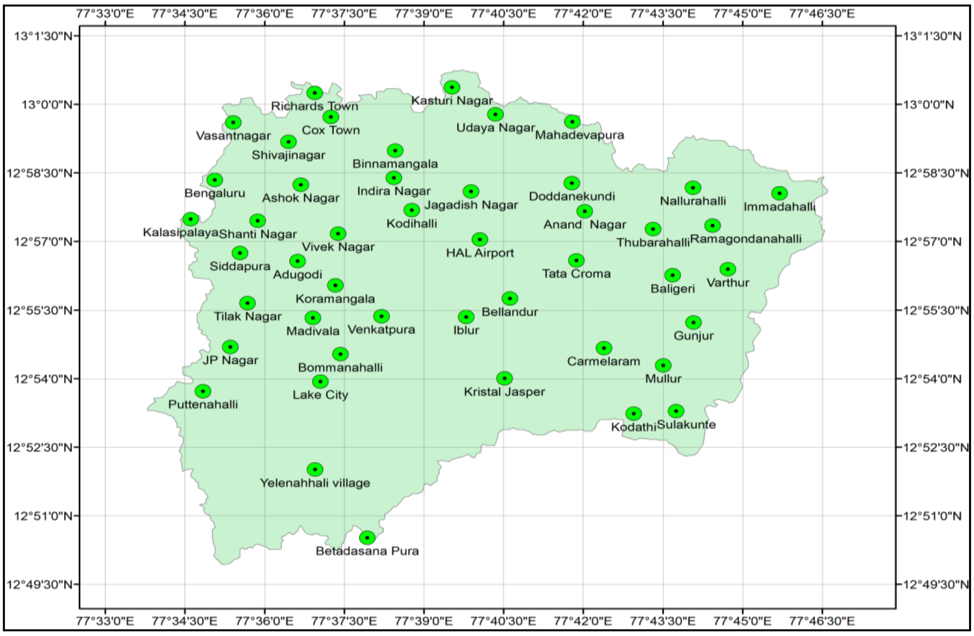
The detailed well investigation and geophysical resistivity survey provide subsurface geological condition such as thickness of weathered zone, fractured zone in the WS. These data provide the thickness of aquifer in the study area. Based on aquifer thickness, the area is divided into four categories as very high aquifer thickness, high aquifer thickness, moderately thick aquifer, low thickness of aquifer. Though major portion of the study area is covered by moderate thickness of aquifer, the yield is depending upon the rainfall and recharge condition.

Longitudinal conductance values indicate that most parts of the area possess weak to moderate protective capacity, making the aquifer vulnerable to contamination, particularly in urbanized zones. Transverse resistance analysis identified moderate to high groundwater potential associated with weathered and fractured formations. The integrated interpretation of longitudinal conductance and transverse resistance demonstrates that zones with high aquifer potential often exhibit poor protective capacity, indicating a trade-off between groundwater productivity and aquifer protection. The study highlights the effectiveness of resistivity-based geophysical techniques in groundwater characterization and emphasizes the need for sustainable groundwater management and contamination monitoring in hard rock terrains.

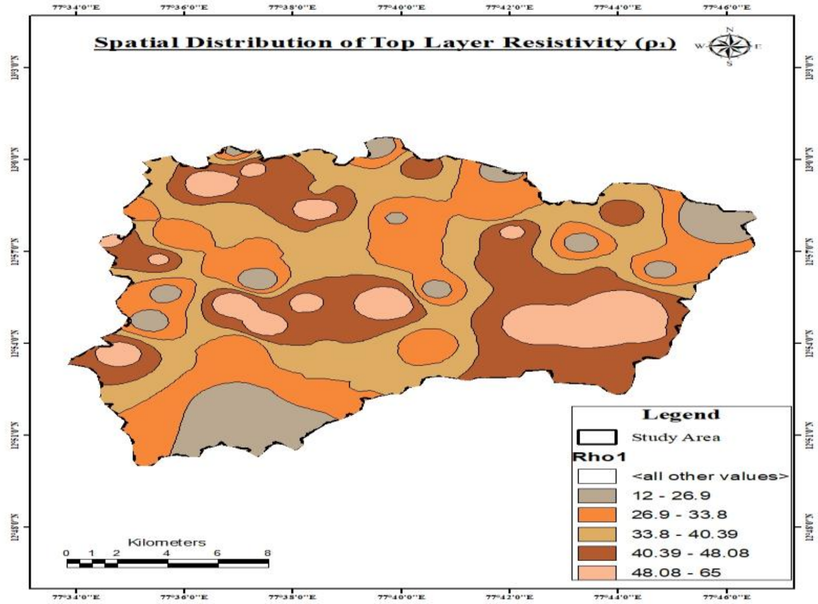
Table 1. Layer Parameters for the VES Data

ID	Location	ρ1	ρ2	ρ3	h1	h2	Total Thickness	S' Longitudinal Conductance	T' Transverse Resistance
1	Kalasipalaya	54	76	126	1.9	7.35	9.25	0.13	661.2
2	Puttenahalli	54	74	120	1.9	7.35	9.25	0.13	646.5
3	Bengaluru	28	46	365	1.8	7.2	9	0.22	381.6
4	JP Nagar	21	46	132	1.6	8.2	9.8	0.25	410.8
5	Vasantnagar	36	78	156	1.2	9.3	10.5	0.15	768.6
6	Siddapura	52	125	162	1.6	8.1	9.7	0.10	1095.7
7	Tilak Nagar	22	56	385	1.6	9.3	10.9	0.24	556
8	Shanti Nagar	22	56	226	1.8	9.5	11.3	0.25	571.6
9	Shivajinagar	62	78	156	1.9	9.3	11.2	0.15	843.2
10	Adugodi	32	63	126	1.2	8.1	9.3	0.17	548.7
11	Ashok Nagar	35	64	120	1.9	14.2	16.1	0.28	975.3
12	Madivala	64	157	248	1.9	9.3	11.2	0.09	1581.7
13	Richards Town	23	46	128	1.9	9.3	11.2	0.28	471.5
14	Yelenahhali village	20	39	184	1.5	6.84	8.34	0.25	296.76
15	Lake City	22	47	132	1.6	8.1	9.7	0.25	415.9
16	Cox Town	52	135	152	1.7	8.2	9.9	0.09	1195.4
17	Koramangala	12	56	225	1.9	9.5	11.4	0.33	554.8
18	Vivek Nagar	32	51	84	1.2	6.84	8.04	0.17	387.24
19	Bommanahalli	57	82	224	1.8	14.6	16.4	0.21	1299.8
20	Betadasana Pura	12	44	152	1.5	7.6	9.1	0.30	352.4
21	Venkatpura	52	84	380	1.3	9.8	11.1	0.14	890.8
22	Indira Nagar	62	78	156	1.9	9.3	11.2	0.15	843.2
23	Binnamangala	39	22	132	1.3	10.4	11.7	0.51	279.5
24	Kodihalli	36	54	84	1.2	6.84	8.04	0.16	412.56
25	Kasturi Nagar	21	45	187	1.5	6.84	8.34	0.22	339.3
26	Iblur	64	85	386	1.8	10.2	12	0.15	982.2
27	Jagadish Nagar	25	53	112	1.75	8.5	10.25	0.23	494.25
28	HAL Airport	25	45	225	1.9	9.5	11.4	0.29	475
29	Udaya Nagar	46	54	126	1.5	6.8	8.3	0.16	436.2
30	Kristal Jasper	26	58	120	1.9	1.5	3.4	0.10	136.4
31	Bellandur	21	33	535	1.7	8.2	9.9	0.33	306.3
32	Doddanekundi	27	46	365	1.8	7.2	9	0.22	379.8
33	Mahadevapura	23	45	112	1.2	14	15.2	0.36	657.6
34	Tata Croma	46	65	270	1.6	14.2	15.8	0.25	996.6
35	Anand Nagar	53	74	122	1.8	7.4	9.2	0.13	643
36	Carmelaram	55	65	125	1	8.9	9.9	0.16	633.5
37	Kodathi	45	84	165	1.6	11	12.6	0.17	996
38	Thubarahalli	20	45	112	1.2	12	13.2	0.33	564
39	Mullur	53	77	125	1.8	7.21	9.01	0.13	650.57

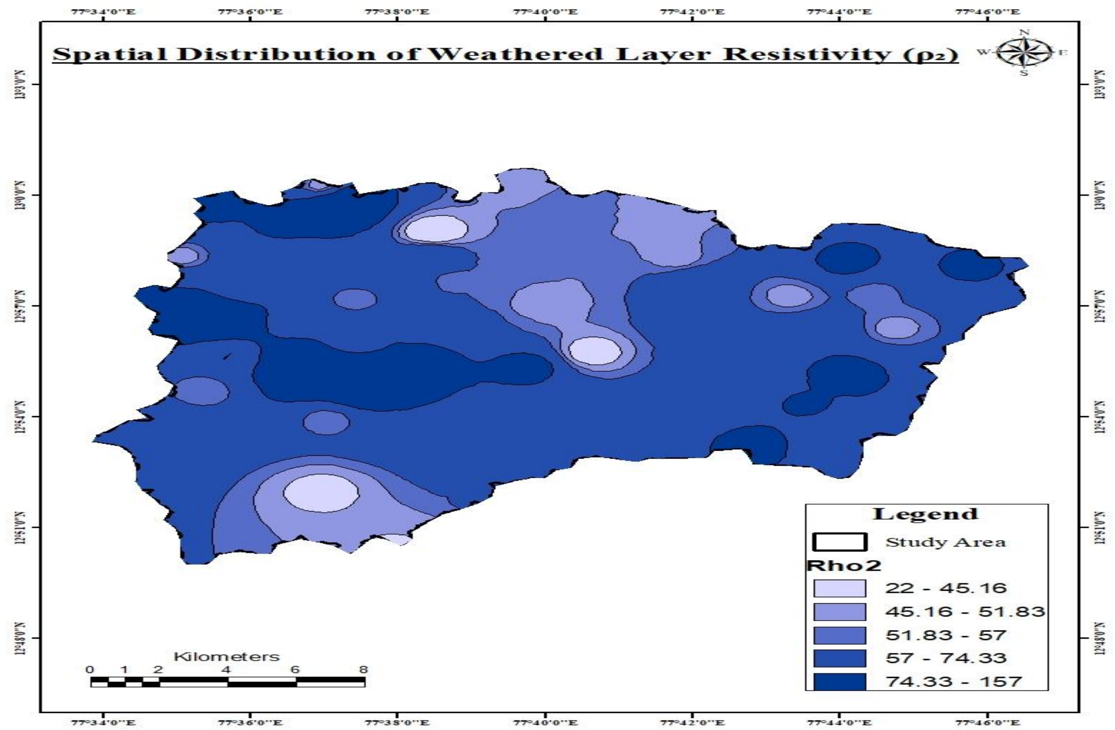
40	Baligeri	42	74	164	1.8	11.3	13.1	0.20	911.8
41	Sulakunte	41	56	132	1.3	9.6	10.9	0.20	590.9
42	Nallurahalli	46	85	166	1.5	8.1	9.6	0.13	757.5
43	Gunjur	65	84	385	1.8	12.3	14.1	0.17	1150.2
44	Ramagondanahalli	36	52	96	1.8	6.7	8.5	0.18	413.2
45	Varthur	22	46	128	1.7	7.11	8.81	0.23	364.46
46	Immadahalli	15	78	200	1.8	7.51	9.31	0.22	612.78



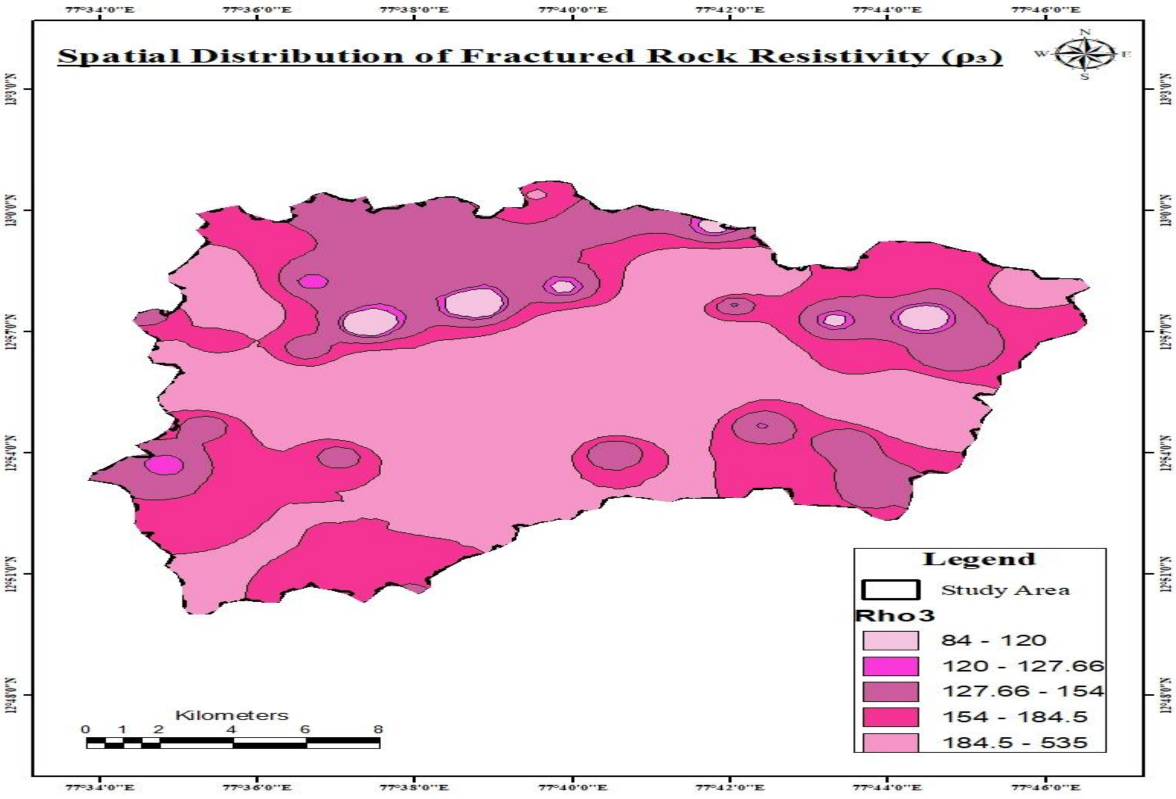
Map 2: Location of Vertical Electrical Sounding (VES) stations in the study area.



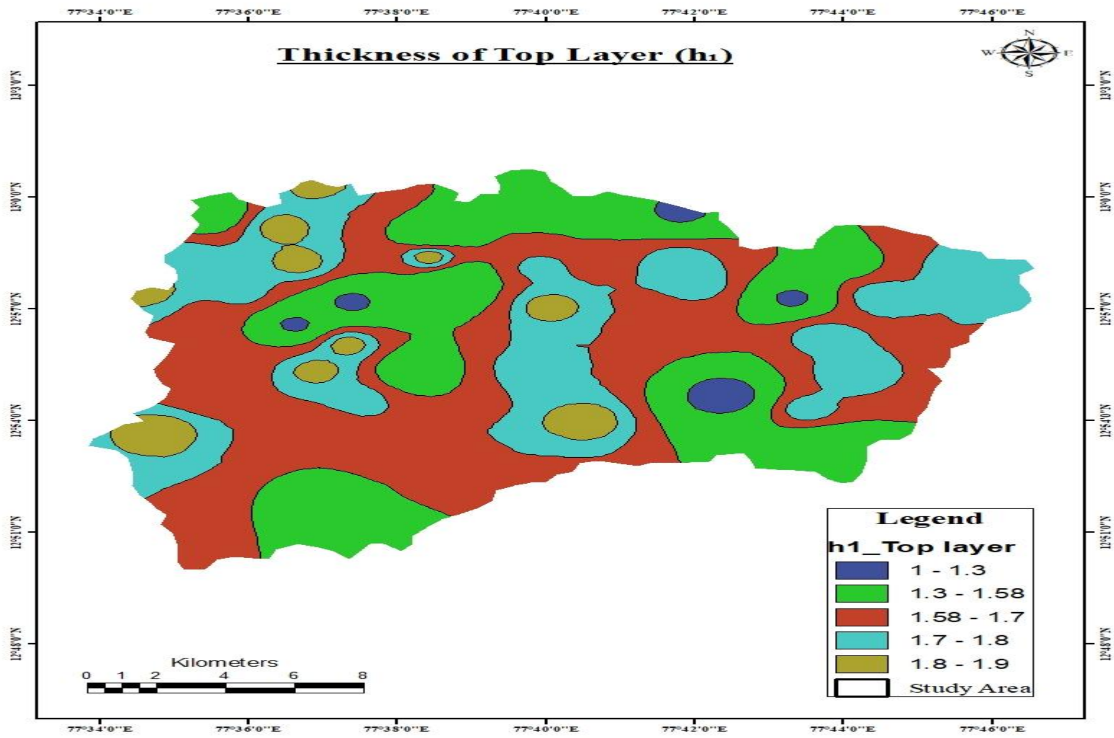
Map 3: Structural contour map at the base of the first geoelectric layer (depth in metres).



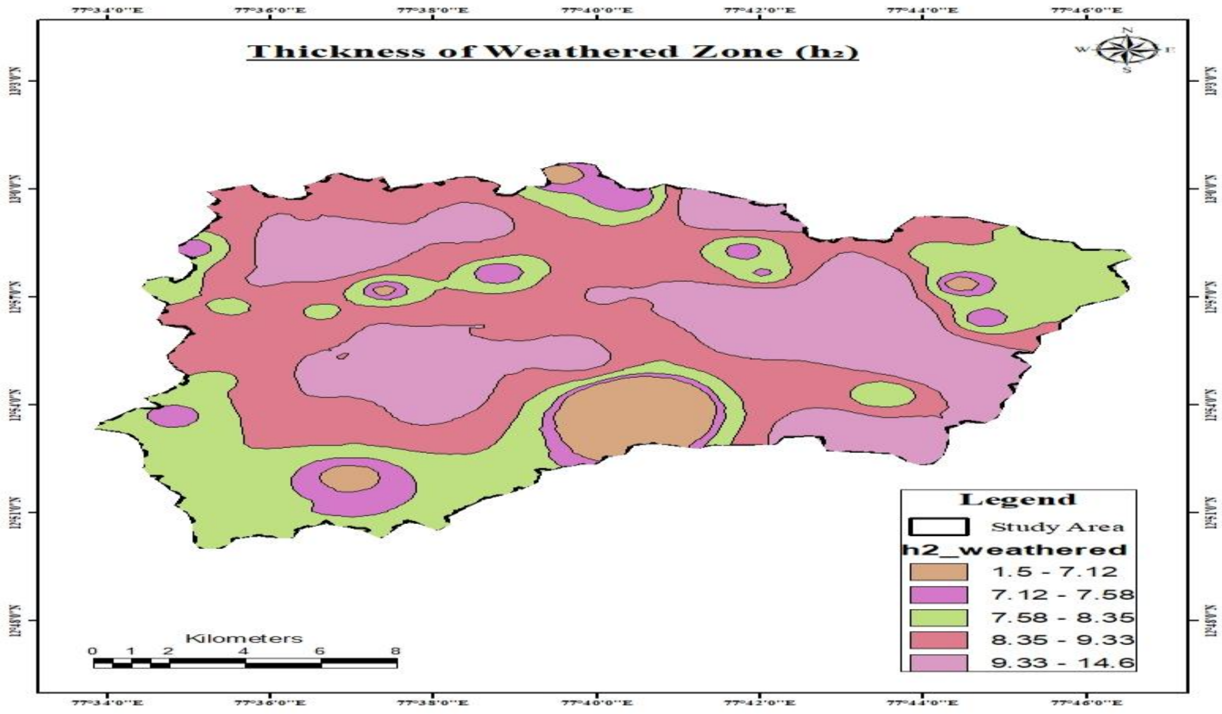
Map 4: Structural contour map at the base of the second geoelectric layer (depth in metres).



Map 5: Structural contour map at the base of the third geoelectric layer (depth in metres).

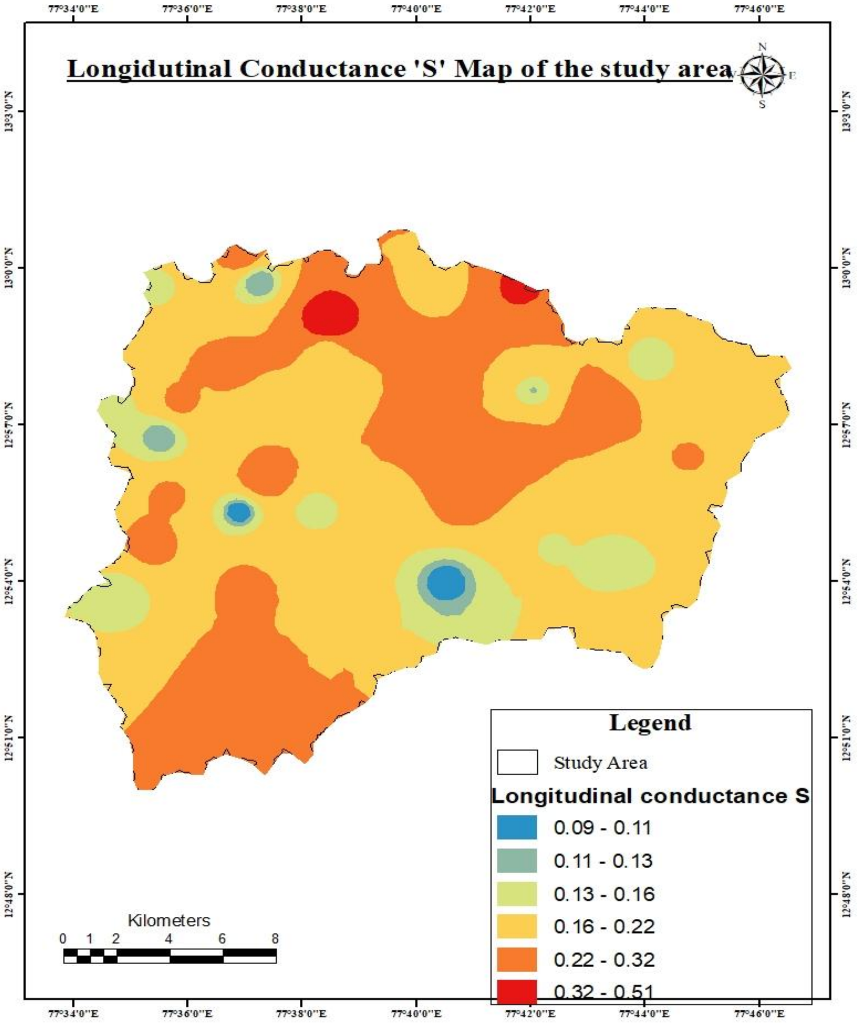


Map 6: Iso-apparent resistivity map for electrode separation a = 50 m.



Map 7: Iso-apparent resistivity map for electrode separation a = 75 m.

Map 8: Iso-longitudinal conductance (S) map of the study area.



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