GEOPHYSICAL ASSESSMENT OF GROUNDWATER POTENTIAL IN HARD ROCK TERRAIN OF MARKANDAHALLA, KOLAR (KARNATAKA) USING REMOTE SENSING AND GIS.

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Abstract: This study employs electrical resistivity techniques to investigate groundwater potential zones in a challenging rock terrain. 52 Vertical Electrical Soundings (VES) were conducted using the Schlumberger array. The resistivity data were interpreted using standard curve matching and inversion techniques. Isoresistivity maps at various depths (AB/2 = 45 m, 90 m, 180 m, and 360 m) were generated to delineate subsurface lithology and aquifer zones. Results show that weathered and semi-weathered zones with moderate resistivity values (50–250 Ωm) favor groundwater occurrence. The study further assesses bedrock depth and longitudinal conductance to evaluate aquifer protection and transmissivity. Integrating resistivity profiles with lithological and yield data confirms the method's effectiveness in groundwater exploration in crystalline terrains.

***keywords* - Groundwater exploration, Electrical resistivity, VES, Isoresistivity maps, Hard rock aquifers, Longitudinal conductance**

I. INTRODUCTION

Groundwater is recharged by precipitation and snowmelt or from water that leaks through the bottom of some lakes and rivers. Groundwater can also be recharged when water supply systems leak, and crops are irrigated. An aquifer is a geological formation or part of it consisting of permeable material capable of storing/yielding significant quantities of water. Aquifers can consist of different materials: unconsolidated sands and gravels, permeable sedimentary rocks such as sandstones or limestones, fractured volcanic and crystalline rocks, etc.

Groundwater can be found almost everywhere. The water table may be deep or shallow depending on several factors, such as the physical characteristics of the region, the meteorological conditions, and the recharge and exploitation rates. High rains may increase recharge and cause the water table to rise. On the other hand, an extended period of dry weather will cause the water table to decline.

II. STUDY AREA

The water basin Markandahalla, which has an area of about 823.89 sqkms, is between 13.118 to 12.659 N latitudes and 78.015 to 78.148 E longitudes. The Markandahalla originates from the Northeast of Gollahalli, which is 2.4 km from Narsapura and joins the Ponnaiyar River at Nedusalai, Tamil Nadu. About 5% of the study area, towards the Southern part, falls under the Tamil Nadu state. The study area consists of four small tributaries, Koppakerehalla, Naiyallahalla, Basavanahalla, and Markandahalla, where Markanda Halla nadi flows about 46.778 sqkms from the North, Koppakerehalla tributary of about 27.017 sqkms from the Southwest, Basavanahalla about 13.564 sqkms from North and Naiyallajalla about 16.681 sqkms from the southwest. All three- Fifth order stream meets near a Verupasandiram village in Krishnagiri district, Tamil Nadu. The Markandahalla flows from the North and joins the river Ponnaiyar.

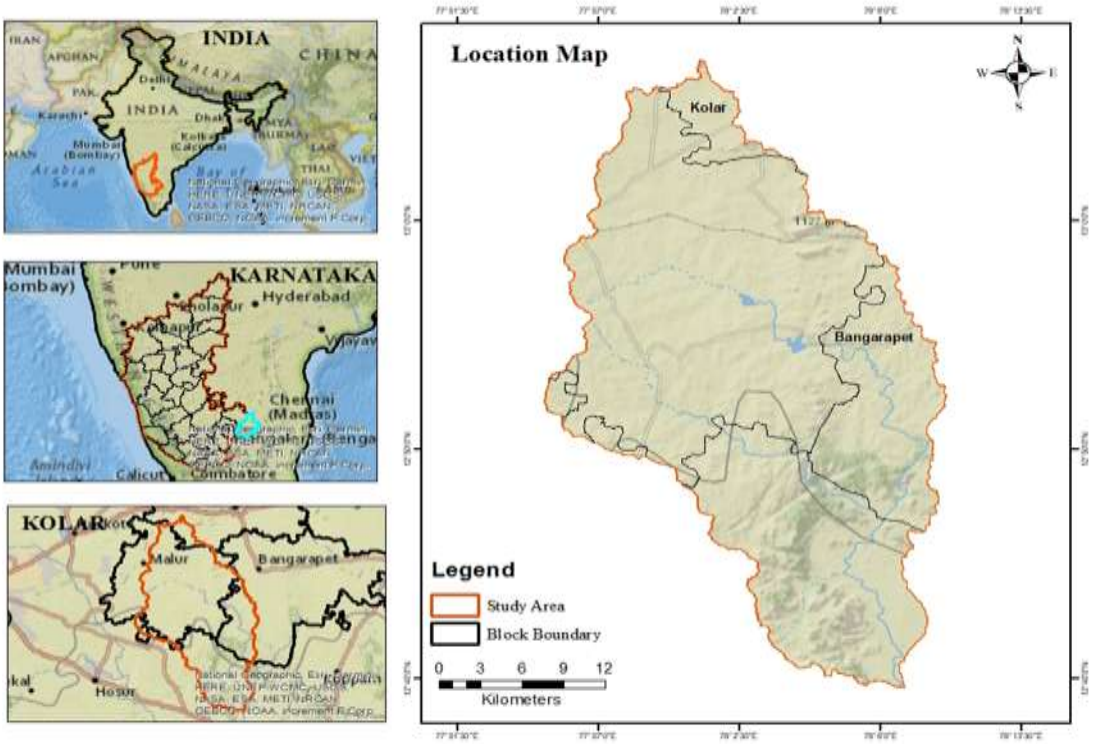


Figure 1: Location of the study area

III. MATERIAL AND METHODOLOGY

The present study was conducted in a challenging rock terrain of Kolar district, Karnataka, where secondary porosity primarily controls groundwater due to weathering and fracturing. The Schlumberger electrode configuration conducted 52 Vertical Electrical Soundings (VES). It is well-suited for groundwater exploration in hard rock areas due to its deeper penetration and efficient field deployment.

A digital resistivity meter was employed to measure apparent resistivity by injecting current into the ground through two outer electrodes (A and B) and measuring the resulting potential difference through two inner electrodes (M and N). Electrode spacing was varied with maximum AB/2 spacing reaching up to 360 meters to probe different depths.

The field data were interpreted using curve-matching techniques with standard master curves, and geoelectrical models were developed using 1D inversion. Piezoresistivity maps were prepared at different AB/2 spacings (45 m, 90 m, 180 m, and 360 m) from the interpreted resistivity values and layer thickness. In addition, depth to bedrock and longitudinal conductance were calculated to assess the aquifer's protective capacity and groundwater potential. These results were compared with healthy yields to validate geophysical interpretations.

VI. ELECTRICAL RESISTIVITY METHOD

The objective of the electrical resistivity method is to obtain information about the subsurface. As implicit in the name, in the electrical resistivity method, we get this information from measuring and interpreting the electrical properties of the subsurface.

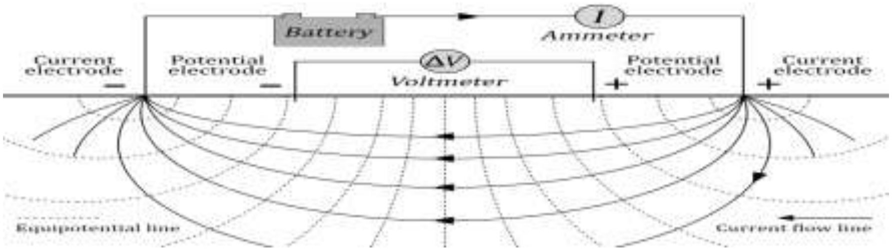
This involves the following steps:

1. Measuring the electrical resistivity of the subsurface at different locations using a special instrument (a resistivity meter)
2. Processing these measurements into a 1D, 2D, 3D, or 4D distribution of electrical properties of the subsurface and
3. Interpreting this distribution in the context of certain questions.

As the electrical resistivity is a function of different properties of the subsurface (such as porosity, saturation, water chemistry, lithology, biogeochemical processes, and temperature) electrical resistivity is a very versatile method. The resistivity values in the different depth configuration were analyzed to indicate different landforms with aquifer conditions (Jothibasu & Anbazhagan, 2016).

4.1 Resistivity measurements

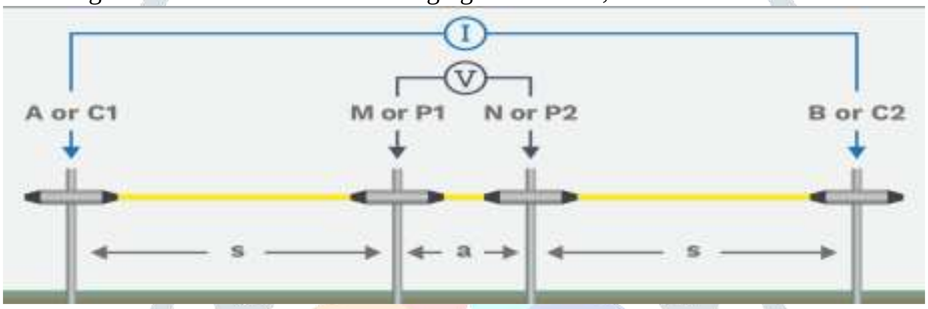
The standard method of measuring electrical resistivity is through a four electrode measurement in which we use two current electrodes and two potential electrodes. The electrical resistivity of a formation depends mainly on the salinity of its fluid content, saturation, aquifer lithology and porosity (Shaaban, 2002). Such a measurement is schematically shown in the figure below.



4.2 Schlumberger configuration

The Schlumberger array consists of four collinear electrodes. The outer two electrodes are the current (A and B), and the inner two are the potential (M and N). The potential electrodes are installed at the center of the electrode array with a slight separation, typically less than one-fifth of the spacing between the current electrodes. The current electrodes are increased to a greater separation during the survey, while the potential electrodes remain in the same position until the observed voltage becomes too small to measure.

The Schlumberger array requiress fewer electrodesto each sounding, and the potential electrodes need shorter cable lengths. Schlumberger soundings generally have better-probing depth, resolution, and less time-consuming field deployment. Since the Schlumberger method is in vogue and more suited for challenging rock terrain, the same has been used in the present study.



All four electrodes are placed along a straight line on the earth’ s surface in the same order, AMNB with AB ⩾ 5 of MN. For any linear, symmetric array AMNB of electrodes, the equation is in the form;

$$\rho_{app} = K. = \frac{\Delta_u}{I}$$

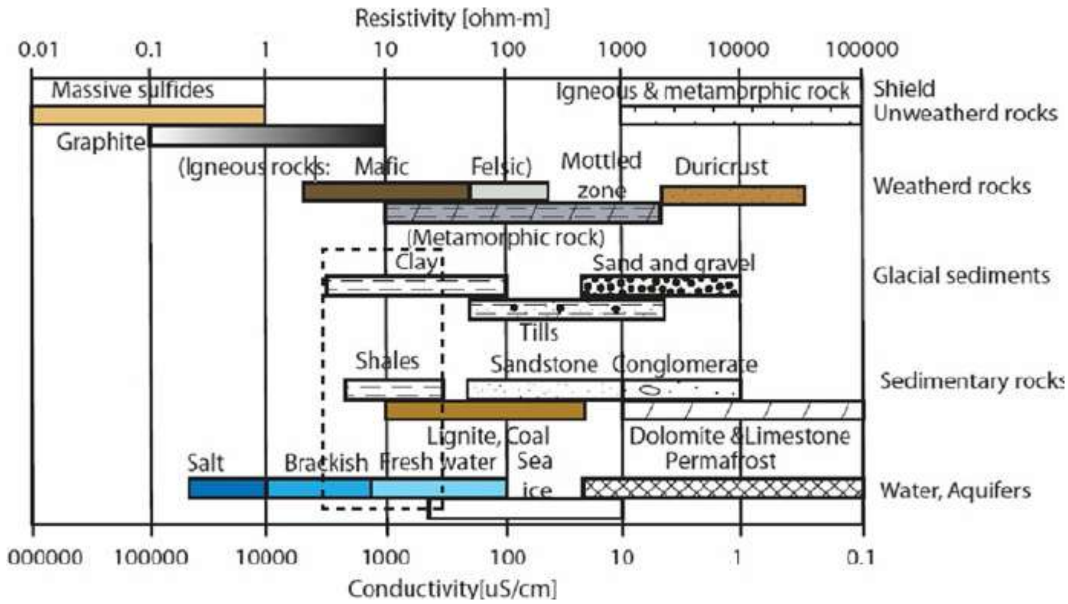
K = configuration constant, u = potential difference between the potential electrode, and I = current.

4.3 Electrical Resistivity of Water-bearing Rocks

In most rocks near the earth‘s surface, the conduction is dominated by electrolytic conduction in aqueous solution of common salts distributed through the pores of the rock and/or at the rock-water interface. The rock matrix itself is usually an insulator. The resistivity of geological subsurface formations differs broadly from formation to formation and within the lithological unit. The electrical resistivity of rocks depends on

- The material's size, shape, density, porosity, and pore size
- Quality of water and density of the aquifer horizons.
- Water distribution in the rocks is due to structural and textural characteristics.
- The temperature of the sub-surface water environment.

The most important factors are the porosity, temperature, salinity, and water-rock interaction. In geothermal areas, the rocks are water-saturated. Ionic conduction in the saturating fluid depends on the number and mobility of ions and the connectivity of flow paths through the rock matrix. Usually, the saturating fluid is among the dominant conductors in the rock, and the degree of saturation is of great importance to the bulk resistivity. The pressure dependence is negligible compared to the temperature dependence, provided that the pressure is sufficiently high, so there is no phase change.



4.4 Interpretation of VES Data

The discussions are based on 52 VES data (Map - 6.1). The curves plotted are quantitatively interpreted using standard curve-matching techniques based on the curves published by Rijkswaterstaat (1975)—the plotting field data show two- or three-layer situations. The predominance of `H' type curves in the study area indicates a weathered layer overlying the basement.

4.5 Resistivity Behaviour of the Formations in the Study Area

The VES data has been used for layer interpretation and to draw Isoresistivity maps for AB/2 spacing of 45, 90, 180, and 360 meters. The maps are used to interpret the variation of resistivity characters of lithological units over the study area and its relation to yield and transmissivity. Weathered and semi-weathered zones can be identified from the resistivity values. Ramachandra Rao (1971) noted that the water-filled zones have resistivity ranging from 50 to 250 Ohm meters. According to Ramanujachary (1974) and Balakrishna (1980), the resistivity values generally vary as below:

Highly weathered layer	20 - 50 Ohm mtrs.
Semi-weathered layer	50 -210 Ohm mtrs.
Fractured and jointed granites	120 - 200 Ohm mtrs.
Hard granites	> 200 Ohm mtrs.

In a typical challenging rock terrain, the cross-section is as follows: first, there may be a top layer of transported or in situ soil. The resistivity varies with local conditions and moisture content. The second layer is a saturated part of the weathered zone, with fractured or jointed zones gradually merging with the bedrock. The resistivity gradually increases, and the bedrock has the highest resistivity.

Layer	Thickness (mtrs.)	Avg. Thickness (mtrs.)	Resistivity (Ω mtrs.)	Avg. Resistivity (Ω mtrs.)
Soil cap	0.5 - 27	2.4	1 - 800	124
Weathered Zone	1.65 - 42	12.4	3 - 4600	286
Bedrock	-	-	7 - 8000	1341

4.6 Isoresistivity of AB/2 - 45 mtrs.

The iso-resistivity map of AB/2 - 45 mtrs. Shows the variation of resistivity over the watershed (Map - 2). The central area covered has a resistivity ranging from 54 to 404 ohm mtrs. This also indicates the soil cover/ weathered zone. The few anomalous zones seen can be related to the local soil and geology. A few zones with increasing resistivity are noticed in the northwest and eastern flanks due to sandy clay soil and loamy sand. The wells on these anomalous zones have casing varying from 6 to 12 mg, indicating soil or weathered zone.

4.7 Isoresistivity of AB/2 - 90mtrs.

Descriptive Statics has been used to find the maximum, minimum, standard deviation, mean and normally distribution of the data of all the variables of the study. Normal distribution of data shows the sensitivity of the variables towards the periodic changes and speculation. When the data is not normally distributed it means that the data is sensitive towards periodic changes and speculations which create the chances of arbitrage and the investors have the chance to earn above the normal profit. But the assumption of the APT is that there should not be arbitrage in the market and the investors can earn only normal profit. Jarque bera test is used to test the normality of data.

4.8 Isoresistivity of AB/2 - 180 mtrs.

The resistivity ranges from 164 to 1050 ohm mtrs. On the Northeastern flank, the resistivity values are high (Map - 4). This high resistivity value as a small patch is due to complex formations, which are seen very close to the surface. These zones have less potential for groundwater. The rest of the study area has uniform resistivity, indicating moderate to good groundwater potentiality, which is also influenced by the structures. A comparison of this map with yield and transmissivity suggests that the regions of higher resistivity are the regions of lower transmissivity and yield. The remaining area has moderate to good transmissivity and yield, which makes it a table zone for groundwater exploitation.

4.9 Isoresistivity of AB/2 - 360 mtrs.

In AB/2 spacing of 360 mtrs., the anomalous zones are seen in the northern parts of the study area (Map - 5). The central and north parts have uniform resistivity, confirming the formations' homogeneity in these regions. The resistivity ranges from 274 to 1058 Ohm mtrs. A comparison of resistivity with yield shows the presence of high-yielding wells in low-resistivity areas. High-yielding wells in some high-resistivity regions may be due to the presence of lineaments.

4.10 Depth of Bedrock (T)

The soil thickness and weathered zones are essential from the groundwater point of view. Soils and weathered zones mainly control the percolation of rainfall. The depth of the bedrock in the study area varies from 1.9 to 27.8 meters. The depth of the bedrock is generally shallow in the study area except for a patch in the northern part.

4.11 Longitudinal Conductance (S)

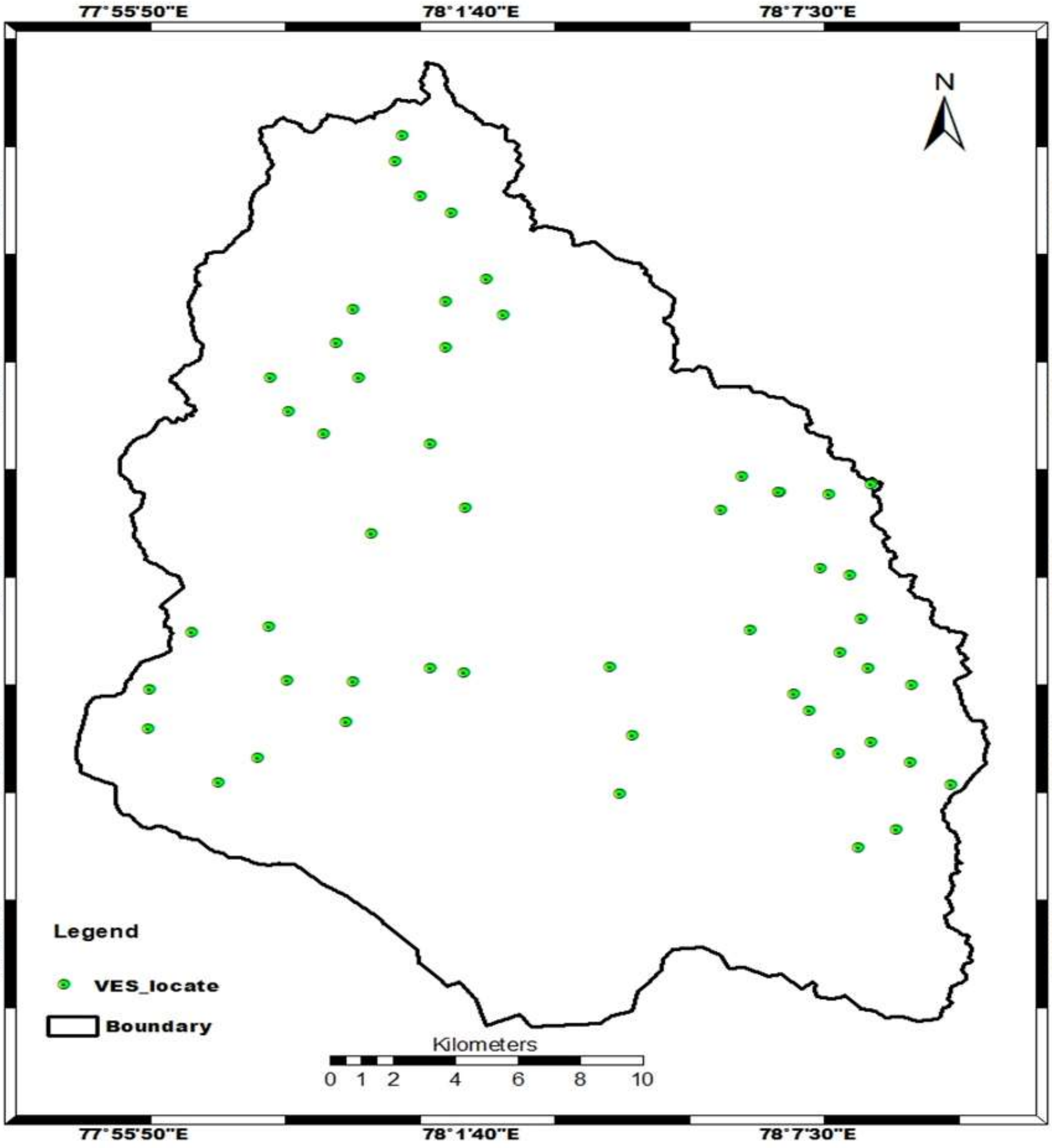
The longitudinal conductance of the `n ' layered section overlying an infinite substratum is given by

$$S = \left(\frac{h_1}{\rho_1} + \frac{h_2}{\rho_2} + \cdots \frac{h_n}{\rho_n}\right) \quad (\text{Siemen} = \text{mho})$$

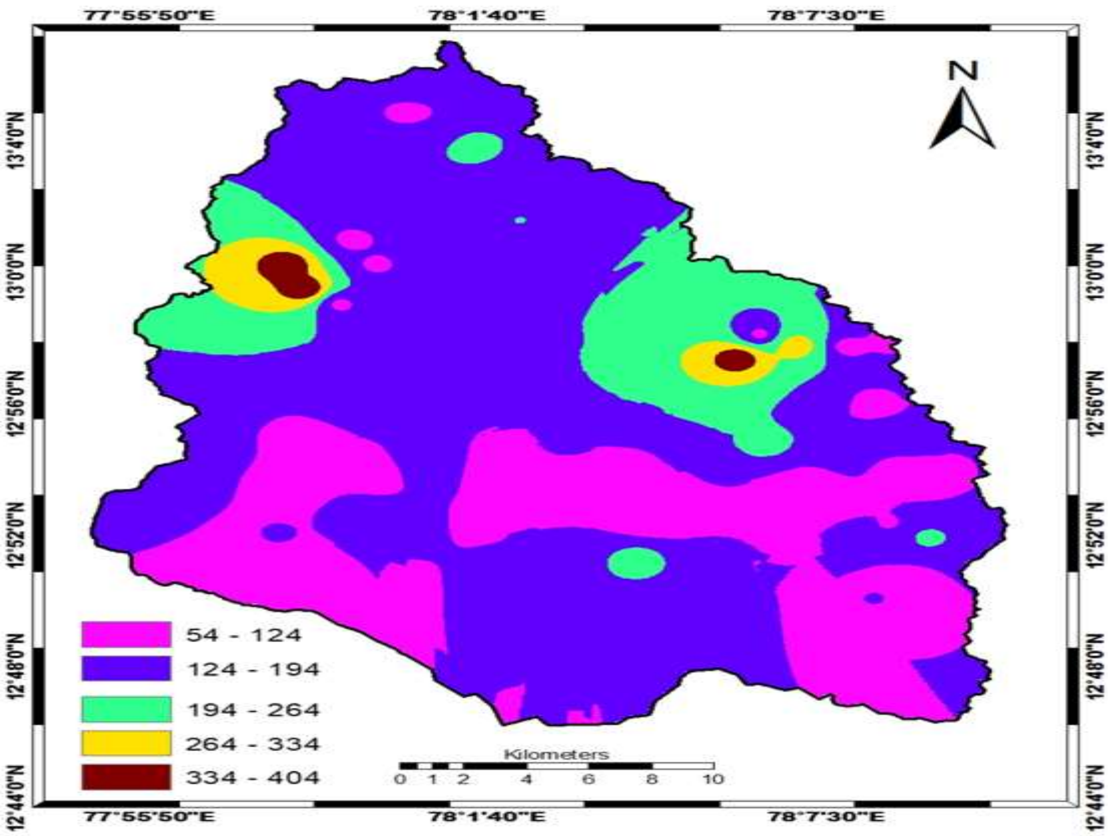
here h1 h2 are the thickness of different layers and$\rho 1$ and $\rho 2$ are the corresponding resistivities. The field curves can estimate the longitudinal conductance when bedrock resistivities are high. The conductance value for the study area, on average, is 0.41siemens/m. With the lowest value of 0.01 and the highest value of 1.4 siemens/m

		ρ_1	ρ_2	ρ_3	t_1	t_2	t_3	S	T	Curve
Sl.No	**Locations**	**(Ωm.)**	**(Ωm.)**	**(Ωm.)**	**(m.)**	**(m.)**	**(m.)**	**(μs)**	**(m.)**	**Type**
1	K G Halli	145	75	1250	4.7	1	∞	0.04	11	A
2	Makarahally	173	84	∞	15	15	∞	0.10	7.2	H
3	Tekal	183	90	400	15	0.8	∞	0.15	11.9	H
4	K G Halli	208	109	-	14.4	0.9	∞	0.36	5.1	A
5	Trunasi	217	125	690	13.12	1	∞	0.12	3.6	H
6	Trunasi	244	137	-	3.24	2.1	∞	0.34	24	A
7	Mavahalli	267	149	475	8.5	1.2	∞	0.16	11.7	H
8	Magondi	294	164	1245	10.5	0.7	∞	0.01	1.9	A
9	Lakkuru	326	171	500	3	2	∞	0.16	10.4	H
10	Baliganahalli	330	182	115	7	2	∞	0.60	16.8	H
11	Jayamangala	343	184	420	∞	0.9	∞	0.18	11.7	A
12	Tekal	359	197	-	6.5	0.82	∞	0.36	5.1	A
13	Rajendrahalli	368	212	600	10.2	0.81	∞	0.12	3.6	H
14	K G Halli	380	222	425	3.4	0.7	∞	0.34	24	A
15	Sulikunte	385	228	∞	2.8	0.9	∞	0.11	14.4	H
16	Gulahalli	396	235	∞	∞	2	-	0.07	26	A
17	Chikkaankandahalli	413	251	142	10.4	2	∞	0.17	9	H
18	Chinnakote	435	262	350	∞	12	∞	0.11	14	A
19	Magondi	447	145	1	9.6	0.8	∞	1.41	10.4	H
20	Sulikunte	456	173	428	14.4	1.7	∞	0.41	6.3	H
21	Inorahosahalli	469	183	360	10.8	0.7	-	0.39	21	A
22	Kamasamudra	480	208	470	6.5	2	∞	0.42	27.3	A
23	Jayamangala	488	217	548	10.2	2	-	0.31	8.4	H
24	Mavahalli	503	244	720	3.4	0.9	∞	0.47	4.9	H
25	Chikkankondahalli	516	267	135	2.8	0.82	∞	0.26	18	H
26	Sulikunte	528	294	2	∞	0.81	∞	0.81	17	H
27	Srinivasasandra	536	326	620	10.4	0.7	∞	0.10	15.3	H
28	Jakkarasanakuppa	84	330	-	∞	0.9	∞	0.24	13.94	H
29	Bethamangala	105	343	∞	9.6	13.12	∞	0.03	4.05	H
30	kethaganahalli	119	359	1250	14.4	3.24	∞	0.30	9.1	H
31	Inorahosahalli	124	368	∞	10.8	8.5	∞	0.26	11.7	H
32	Ramsagara	150	380	400	10.4	10.5	∞	0.05	3	H
33	Muduvadi	167	385	-	24	3	∞	0.09	9	H
34	Ramsagara	177	396	690	4	7	∞	0.04	11	A
35	Srinivasasandra	194	413	-	∞	0.7	∞	0.10	7.2	H
36	Vengasandra	209	435	475	6.3	0.9	∞	0.15	11.9	H
37	Marikuppa	224	447	1245	5.7	2	∞	0.36	5.1	A
38	Kysambally	242	456	∞	27	2	∞	0.12	3.6	H
39	Ramsagara	264	469	600	27.2	12	∞	0.34	24	A
40	Jakkarasanakuppa	276	480	425	7.7	0.8	∞	0.16	11.7	H
41	Inorahosahalli	290	488	∞	4.7	1.7	∞	0.01	1.9	A

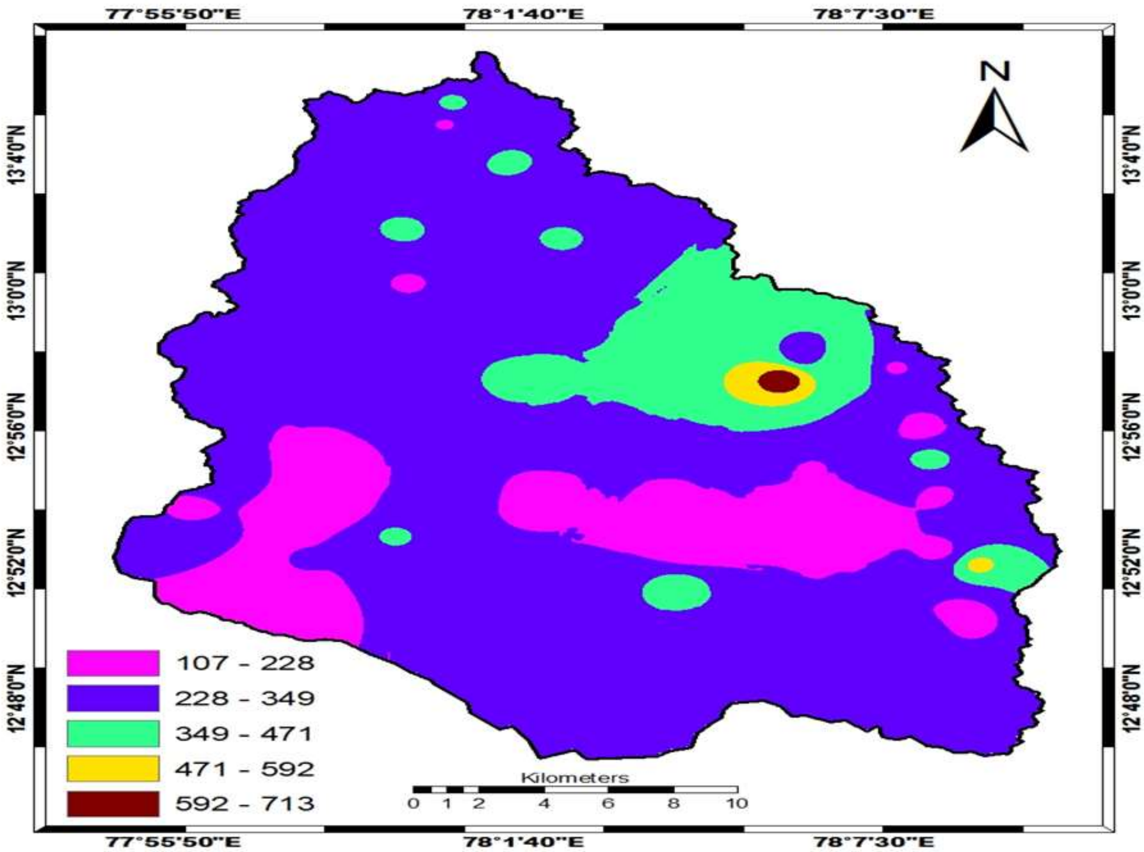
42	N G Hulkuru	304	503	∞	15	1.7	-	0.16	10.4	H
43	Jakkarasanakuppa	322	516	1420	15	0.9	∞	0.60	16.8	H
44	Kangandalahalli	338	528	350	14.4	26	∞	0.18	11.7	A
45	Ramsagara	355	536	1	13.12	1.3	∞	1.41	10.4	H
46	Hulkuru	119	343	428	27	1.7	∞	0.41	6.3	H
47	Marikuppa	124	359	3600	27.2	0.8	-	0.39	21	A
48	N G Hulkuru	150	368	470	7.7	2.6	∞	0.42	27.3	A
49	K G Halli	167	380	548	4.7	0.9	-	0.31	8.4	H
50	Ramsagara	177	385	720	15	0.9	∞	0.47	4.9	H
51	Muduvadi	167	396	421	15	26	∞	0.26	18	H
52	Ramsagara	177	413	241	14	1.3	∞	0.81	17	H



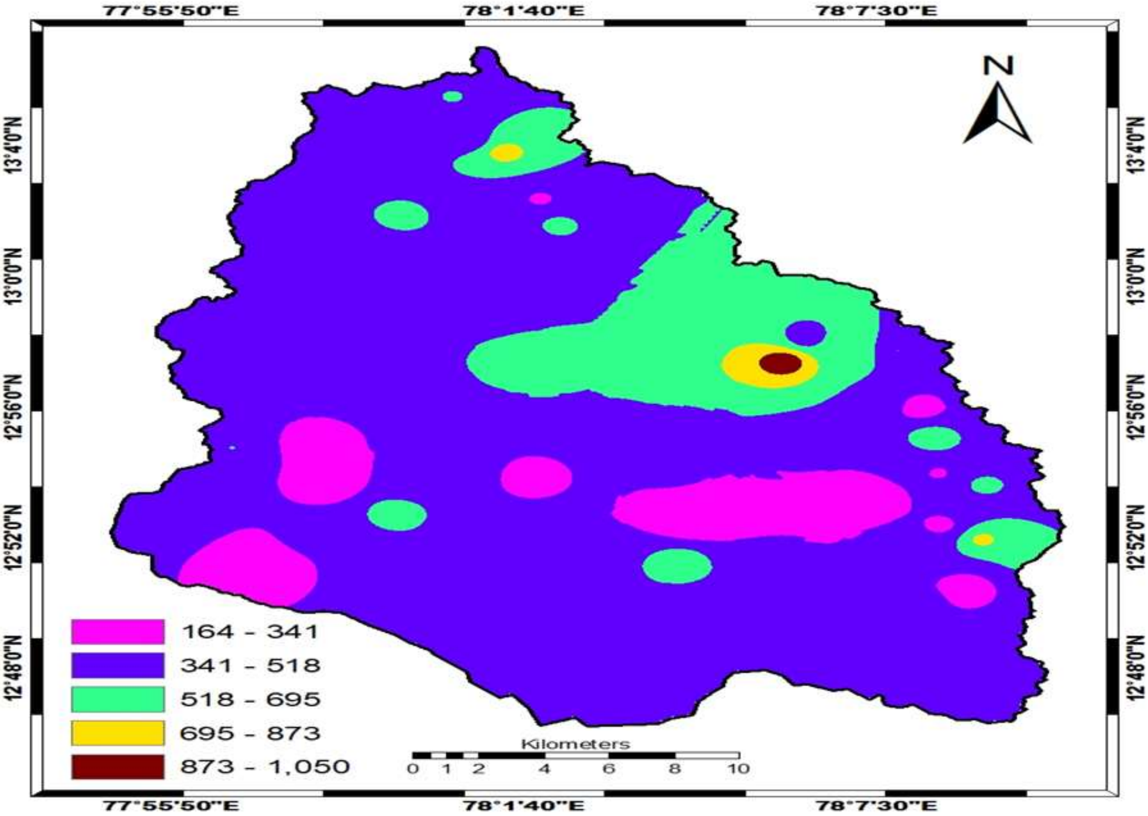
Map – 1: VES Locations



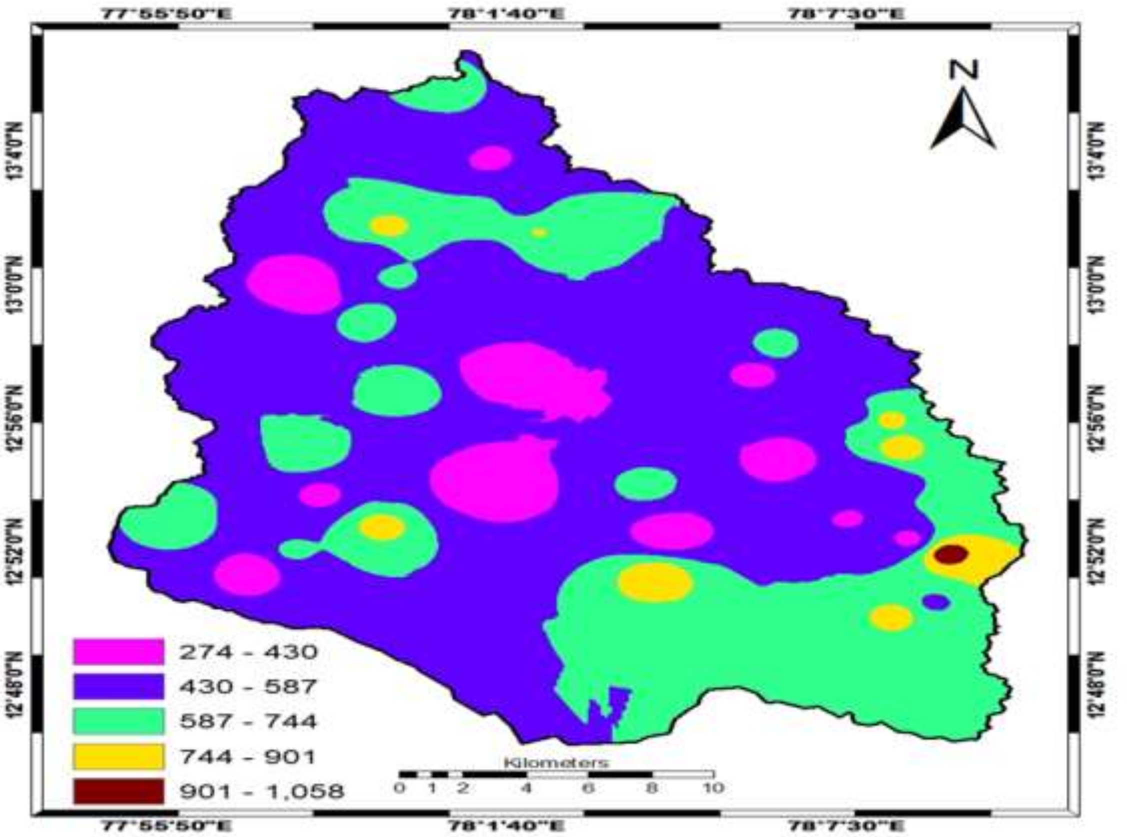
Map – 2: Isoresistivity of AB/2 - 45 mtrs.



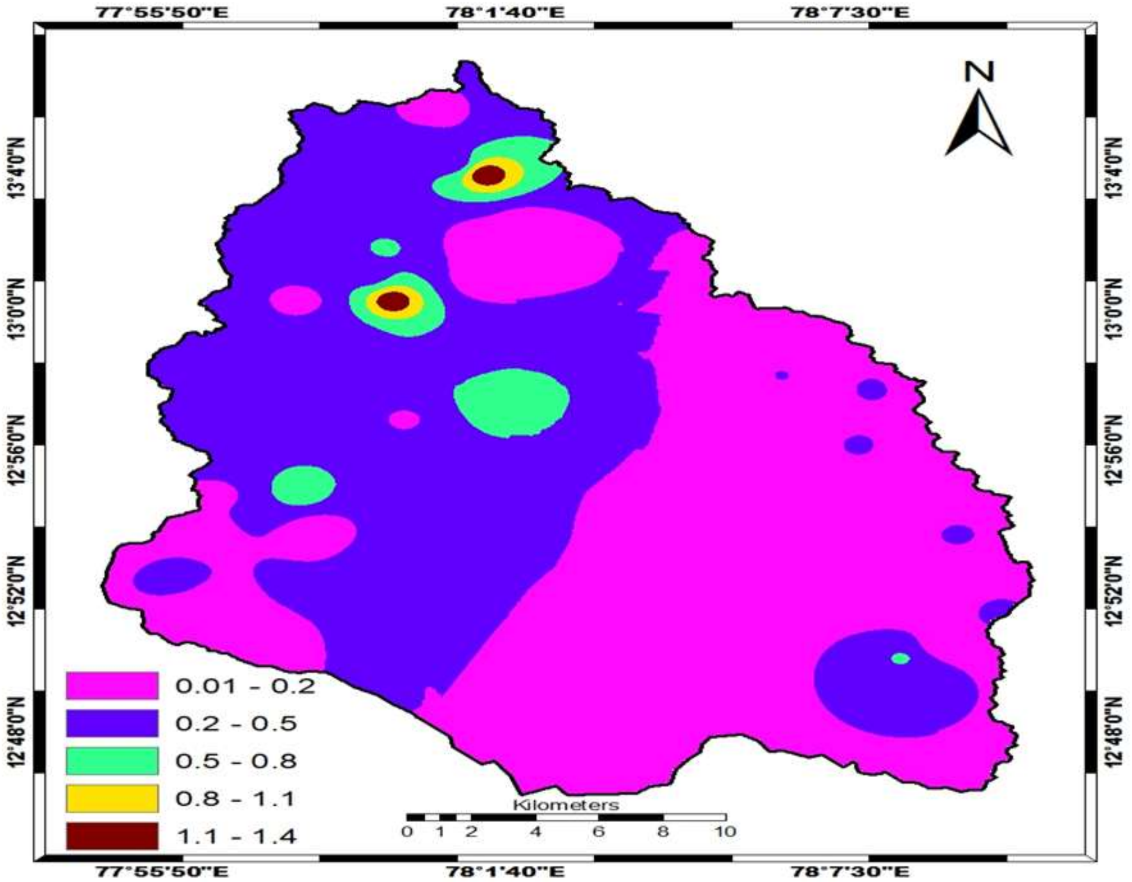
Map – 3: Isoresistivity of AB/2 - 90 mtrs.



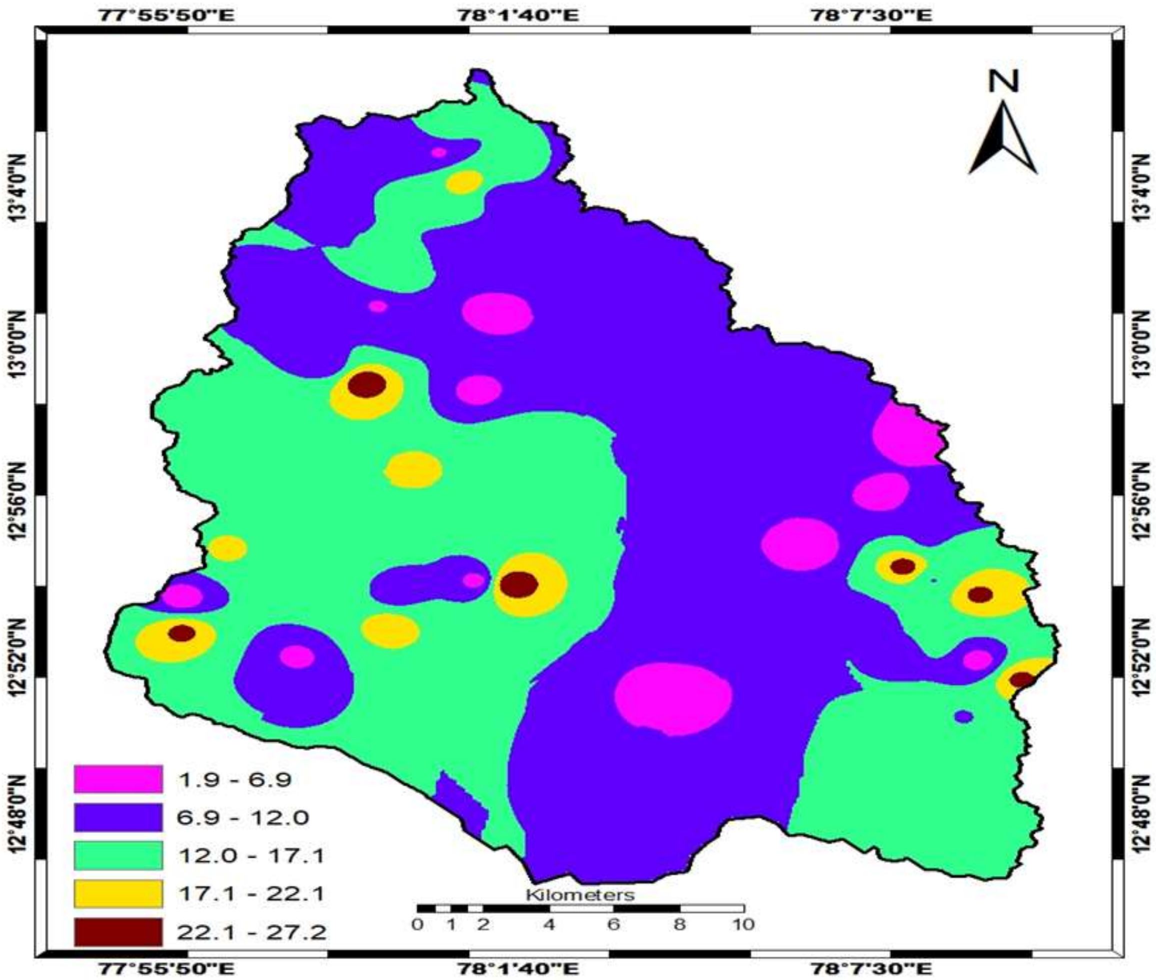
Map – 4: Isoresistivity of AB/2 - 180 mtrs.



Map –.5: Isoresistivity of AB/2 - 360 mtrs.



Map – 6: Longitudinal Conductance (S)



Map – 7: Depth of Bedrock (T)

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