

Deciphering Groundwater Bearing Zones in a Complex Terrain through Geoelectrical Data: A Case Study from Tittagudi Taluk of Tamil Nadu, India

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ABSTRACT: Electrical resistivity investigation was carried out in Tittagudi Taluk, Tamil Nadu, to assess the groundwater prospective of the area consisting of hard, crystalline and sedimentary rock formations. Vertical Electrical Soundings (VESs), adopting Schlumberger electrode configuration, were taken. Thirty soundings were conducted with maximum current electrode separation (AB/2) of 100 m. The observed resistivity values range from 0.5 and 2775.5 Ω m. Majority of resistivity curves belong to 'A' type. Four sets of geoelectrical section (AB, CD, EF and GH) bearing NW-SE and NE-SW directions have been constructed representing the study area. The geoelectrical section AB falls in sedimentary area, the sections CD and EF fall in the crystalline hardrock area, and the section GH falls in the crystalline and sedimentary area, i.e., in the contact zone. The section AB reveals that the quality of groundwater and the yield from the aquifers in this section are moderate due to the intercalation of sand with clay layer. The section CD represents the fractured formations zone located at the depth of 50 to 60m. The EF cross-section exhibits three-layered curve, wherein the bottom-most layer is moderately conductive, which may be due to sizeable and adequate fractures and being a water-bearing zone. The GH section represents the contact zone between crystalline and sedimentary rock formations.

KEYWORDS: Vertical electrical sounding, Schlumberger electrode configuration, Geoelectrical sections, Tittagudi Taluk, Tamil Nadu.

I. INTRODUCTION

Groundwater is explained as water situated below the ground surface in soil pore spaces and in the fractures of lithologic formations. A geologic unit of rock or unconsolidated deposit is called an aquifer when it is capable of receiving, holding, conducting and yielding a usable quantity of groundwater by Alabi et al. [1]. Groundwater exploration is gaining more and more importance in India owing to the ever increasing demand for water supplies, especially in areas with inadequate surface water supplies (Srinivasa Gowd)[2]. Electrical resistivity method is one of the geophysical methods for groundwater delineation. This method is followed using Vertical Electrical Sounding (VES) technique. In this technique, the apparent resistivity is measured directly and quantitative parameters of the geological sub-surface formations are drawn. The true resistivity of different conducting zones and their thickness are determined from the vertical electrical sounding data. This method is valuable in deciphering the nature of horizontally stratified subsurface formations. Some researchers have applied this technique for delineating groundwater bearing zones in composite terrains consisting of crystalline and sedimentary formations (Oseji [3]; Asfahani [4]; Ahilan and Senthilkumar [5]; Anomohanran [6]).

The area under exploration is a complex terrain consisting of hard crystalline and sedimentary formations. About 75 % of the area comprises crystalline formations and the remaining is covered with alluvium. In crystalline (igneous and metamorphic) rock formations, groundwater occurs under water table conditions in weathered, jointed and fractured formations. The study area entirely depends on groundwater source for domestic and agricultural utilization. The

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present study aimed to decipher groundwater bearing zones in the composite terrain consisting of hard crystalline and sedimentary rocks.

II. STUDY AREA

The geographical extent of the study area is 615.29 sq.km. It lies between 11° 22' 03" and 11° 36' 29" North latitudes, and 78° 52' 42" and 79° 18' 59" East longitudes in Cuddalore District, Tamil Nadu, India. The region falls in Survey of India Toposheets bearing the numbers 58M/2, 58M/3, 58M/7, 58I/14 and 58I/15. The relief ranges from 62 to 121 m above MSL. The study area's location map is shown in Figure 1.

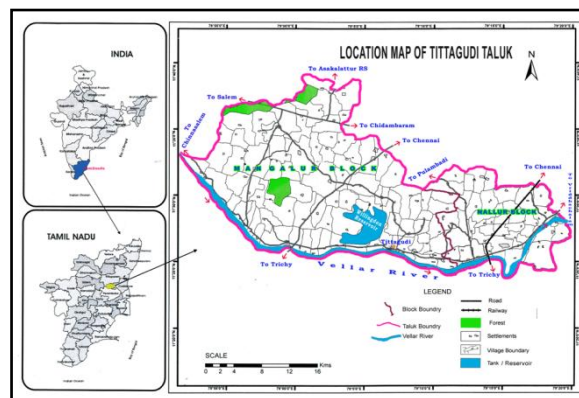


Fig. 1 Location map of study area.

1. Accessibility

Well-maintained roads in Tittagudi Taluk provide good transport facilities. Tittagudi town is connected by major and minor roads and railway line. The Chennai-Trichy National Highway and a broad gauge railway line (Chennai-Trichy-Madurai) pass through this area. Many village roads are also connected with main roads under various Government schemes.

2. Climate and Vegetation

Generally, Tittagudi Taluk is considered as a drought-prone region. This region is a plain land having limited natural vegetation. Agriculture activities are mainly on either side of the Vellar river course, canal belts and around the Wellington Reservoir area. Depending upon the availability of water in the reservoir, the irrigation period would be once in a year or once in two years. Irrigation crops are sugarcane, paddy, chillies, cotton, coriander, millets, groundnut, etc. Nangur Reserve Forest and Krishnapuram Reserve Forest (part) fall in this Taluk. The forest areas are seen in the western part of this Taluk. Industrial activity is almost non-existing but for one sugar factory located in Pennadam. This sugar factory boosts the cultivation of sugarcane in the area.

3. Drainage

Rainfall is the only source for surface water bodies and also for groundwater recharge. The study area is drained by Vellar River and Mayuranadi. The Vellar River flows in the southern part and the Mayuranadi is draining in the northern upper part. There are 76 tanks (29 tanks having area > 40 hectare and 47 tanks occupying an area < 40 hectares) and one reservoir (Wellington Lake/Reservoir). The Wellington Reservoir is the major tank as well as the major source for irrigation, which receives water from the Vellar River. Dendritic and sub-dendritic drainage patterns are mostly found in the crystalline rock zones of the study area.

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4. Geomorphology

The major geomorphic features of the study area are duricrust, pediments, shallow pediments, buried pediments, flood plains and pediments covered by reserved forest. Among the geomorphic features, shallow pediments occupy more areal extent followed by buried pediment.

5. Geology

The study is a complex terrain consisting of crystalline and sedimentary rocks. The major part of the area (about 75%) is covered by crystalline rock formations, belonging to early to middle Precambrian period. The major rock types are charnockite, charnockitic gneiss, granitoid gneiss and migmatites. The charnockite rocks are massive, while the charnockitic / granitic gneisses show lineation/foliation and the foliations usually trend ENE–WSW with an average dip of 45° towards south. The charnockite rocks show different thickness of weathered zone. The eastern part of the study area is covered by Quaternary sedimentary formations represented by semi-consolidated sand, sandstone and clays. The geology of the area is presented in Figure 2.

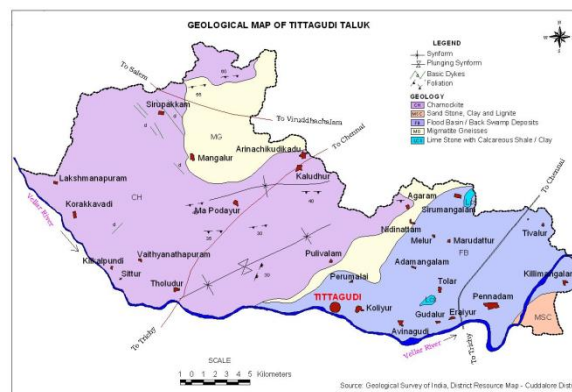


Fig.2 Geology map of the study area.

III. MATERIAL AND METHODS

1. Field Technique

Of all the surface geophysical methods, the electrical resistivity method has been applied most widely in groundwater exploration studies by Todd [7]. The electrical resistivity method can be best employed to estimate the thickness of overburden and also the thickness of weathered/fractured zones with considerable accuracy. Both Wenner and Schlumberger electrode configurations are popular and extensively employed (Srinivasa Gowd) [2]. The Schlumberger electrode configuration is applied for data acquisition and it is best suited for all terrains. In this arrangement, A and B denote the current electrodes while M and N denote the potential electrodes. Cooper [8] proposed that the current electrodes A and B are set as outer electrodes and the two potential electrodes M and N are placed as inner electrodes. This arrangement has the advantage of avoiding long potential cables in depth soundings. The factor K is called geometric factor and depends only on electrode intervals. Obviously R corresponds to the resistance of the volume of ground between the potential electrodes.

2. Field survey

The study area comprises both crystalline and sedimentary formations. The intermediate contact zone lies between these two terrains. The electrical vertical sounding was conducted in thirty locations in the study area using electronic compensator, microprocessor based signal stacking digital resistivity meter Model–SSR-MP-AT-S. The maximum

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current electrode separation (AB/2) was 100 m. The expression for the apparent resistivity is shown in Equation (1). The study area VES locations are shown in Figure 3.

$$\rho_a = \pi \times \frac{(AB/2)^2}{MN} - \frac{(MN/2)^2}{MN} \Delta V/I \tag{1}$$

- AB = Current electrode spacing in meter,
- $\Delta(V)$ = Potential differences in volts,
- MN = Potential electrodes spacing in meter
- I = Electric current in Amperes, ($\pi = 22/7$).

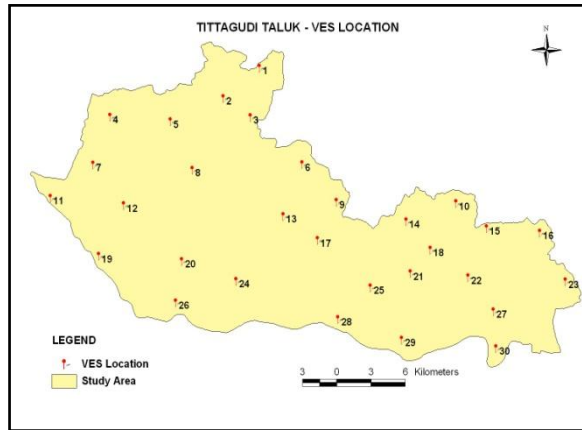


Fig.3 Study area VES locations.

3. Data Interpretation

There are two types of interpretation methods to analyse the resistivity data. One such method is qualitative method, which includes resistivity profiling, iso-resistivity contour and different resistivity curve patterns. Another method is quantitative method based on curve matching method and computerised interpretation method. The geoelectrical data of the area show that the layer system has minimum two layers to maximum eight layers. The observed lowest resistivity is 0.5 ohm.m and the highest resistivity is 2775.5 ohm.m (Table 1).

Table 1 Geoelectrical data of Tittagudi Taluk

VES No.	VES Location	Resistivity (ohm.m)					Apparent Resistivity (ohm.m)				
		ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	-10m	-20m	-40m	-60m	-80m
1	Ja. Endal	24	90.4	517.7	517.4		68.05	136.5	243	349.5	406.94
2	Rettakuruchi	22.6	125.1	1711.3	326.1		50.45	72.28	91.54	113.46	142.5
3	Adari	7.8	385.8	2775.5	93.3		1.5	2.25	3.64	3.86	4.78
4	S. Naraiyur	13.3	188.5	456	813.9		51.06	87.82	176.17	261.06	294.9
5	Sirupakkam	10.4	178.8	309.5	319.5		37.33	79.64	124.31	159.2	244.2
6	Kaluthur	18.2	387	1012.4	117.5		145.33	175.62	236.95	250.37	286.08
7	Paniyandur	75.2	154.2	38.6	371.5		55.4	100	135.5	158.2	168.5

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8	Mangalore	75.9	471.9	714.6	1908.2		20	39.62	74.59	88.48	110.1
9	Pullur	99.3	347.9	214			28	38.45	68.31	108.85	142.66
10	Sirumangalam	0.8	28.3	6.2	18.3	30.7	15.6	38.3	79.2	83.4	186.54
11	Lakshmanapuram	45.5	76.5	97.8	281	408.1	140	142.76	158.25	175.1	192.24
12	Orangur	14	232.8	41.1			81.17	76.04	113.9	157.79	199.25
13	Avatti	8.9	264.5	226.8	339.9	355.2	119.27	175	205.75	250	236
14	Agaram	12	98.2	202.5	468.3	1084.9	17.05	33.28	65.1	99.26	129.86
15	Narasingamangalam	0.8	25.3	194.6	4.5	73.1	7.8	16.4	34.8	73.25	76.8
16	Tivalur	1.2	3.9	8.4			1.5	1.7	2.5	2.9	3.35
17	Mel Aathanur	4.7	112.2	183.3	594.5	183.3	114.63	169.24	265.49	274.04	265.16
18	Melur	1.4	28.1	2591.7			2	3	5.74	7.8	12
19	Vadakarampundi	118.9	38.3	146.5	378.3	2591	53.5	64.9	93.5	123.2	162.2
20	Thachchur	2.4	82.3	929.3	101.8	675.8	56.8	75.7	112.9	99.24	93.7
21	Adamangalam	12.9	3.9	228	7.1		8.26	8.85	16.94	25	30.05
22	Kilnemili	4.9	36.1	10.3	67.7	13.9	5.63	5.82	6.18	6.9	7.9
23	Mosatti	7.6	72.9	0.5	23.4	1.0	10.2	17.2	19	12.7	8.0
24	T.Endal	12	251				18.43	33.56	68.88	95	124.5
25	Sirumalai	8.4	18.5	2370.8	68.3	198.6	5.5	12.22	19.35	27.74	32.7
26	Tholudur	17.2	62.8	114.6	489.2	45.4	98.52	72.6	95	125.02	140.71
27	Pennadam	11.1	151.5	10.6			20.96	33.97	55.68	55.3	56.05
28	Tittagudi	17.9	99.4	2712.8	44.2		12.31	19.63	33.27	42.9	55.79
29	Neyvasal	17.9	89.4	712.8	44.2		30.01	49.05	80	134.2	157.2
30	Semberi	19.3	4.7	4.1	80.8	17.3	20.99	12.99	9	11.15	12.73

Bhattacharya and Patra [9] and Keller and Frischnecht [10] explained the practical use of the principle of equivalence in the interpretation of depth sounding data for Schlumberger arrangement. Different sets of resistivity and thickness of layers give sounding curves within 5% deviation. These sets of conditions are set to be equivalent. The two intermediate layers of different thickness and resistivity can yield curves, which are normally indistinguishable from each other. This led to the formulation of the principle of equivalence. The principle of equivalence of layers containing different layers having different resistivity and thickness may produce the same electrical field distribution on the surface. For example, in the type section, a thin and highly resistive second layer may produce some effect as a layer on thickness and resistivity, or sometimes the effect of two or three layers together may be equivalent. For this reason, a perfect match of data plots with the type curves does not necessarily mean that the parameters determined are unique. However, despite these complexities, interpretation can be improved by correlation of various sounding curves with different arrays, application of the knowledge of the geological setup, and recognition of the electrical properties of the rocks.

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From a hydrogeological point of view, the crystalline rocks can be distinguished broadly into four different types (Verma et al. [11]; Natesan [12]) as below:

- *Type A* possesses intergranular porosity with clay content. The weathered rock, which contains clay/highly, decomposed formations fall under this category. When saturated with fresh water, they have low resistivity value.
- *Type B* possesses intergranular porosity without clay content and when saturated with fresh water shows intermediate resistivity values. Disintegrated zone falls in this category.
- *Type C* possesses fracture porosity. These are fractured/fissured but unweathered (fresh) rocks, have no clay content and when saturated with fresh water show relatively moderate to high resistivity values.
- *Type D* possesses hard massive formations devoid of joints/fissures which act as an impervious layer. These rocks show high to very high resistivity depending on the mineral assemblage.

The resistivity of the study area is broadly divided into two groups: 1) crystalline hard rock area and 2) sedimentary rock area and they are further divided into groups based on the values of resistivity.

IV. RESULTS AND DISCUSSION

The resistivity curve pattern depends upon the electrical conductivity of sub-surface formations. The whole set of three-layer sounding curves can be assigned to four groups, depending on the relative values of ρ_1 , ρ_2 and ρ_3 .

- ✓ Minimum type: when $\rho_1 > \rho_2 < \rho_3$ High – low – high, referred to as H - type
- ✓ Double ascending type: when $\rho_1 < \rho_2 < \rho_3$ Low – low – high, known as A – type
- ✓ Maximum type: $\rho_1 < \rho_2 < \rho_3$ Low – high – low, known as K – type
- ✓ Double descending type: when $\rho_1 > \rho_2 > \rho_3$ high – low – low, known as Q – type.

Orellana and Mooney [13] presented master tables and curves representing 76 three-layer sets (25 each of H- and K-type and 13 each of Q- and A-type) with a total of 912 curves. The VES resistivity curve types for the study area are studied and it is found that majority of the resistivity curves belong to 'A' type. The curve types of the study area are presented in Table 2.

Table 2 Study area VES curve types

VES No.	VES Location	Curve type		VES No.	VES Location	Curve type
1	Ja. Endal	AQ		16	Tivalur	A
2	Rettakuruchi	A		17	Mel Aathanur	A
3	Adari	A		18	Melur	A
4	S. Naraiyur	AQ		19	Vadakaranpundi	A
5	Sirupakkam	A		20	Thachchur	AQ
6	Kaluthur	A		21	Adamangalam	A
7	Paniyandur	AQ		22	Kilnemili	A
8	Mangalore	A		23	Mosatti	AQ
9	Pullur	AQ		24	T.Endal	A
10	Sirumangalam	A		25	Sirumalai	A
11	Lakshmanapuram	K		26	Tholudur	QA
12	Orangur	A		27	Pennadam	K
13	Avatti	A		28	Tittagudi	A
14	Agaram	A		29	Neyvasal	AQ
15	Narasingamangalam	A		30	Semberi	H

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1. Crystalline rocks

The crystalline rock formations occupy two third portions of the study area. The main rock types present are charnockite, migmatite gneisses, and basic dykes. The following are the different types of formations traversing in the VES locations (Table 3).

Table 3 Habitation, VES location and crystallinerock types

Sl. No.	Habitation	VES Location No. No.	Rock types
1.	Sirumalai	25	Migmatite gneiss
2.	Rettakurichchi	02	
3.	Adari	03	
4.	Tittagudi	28	Contact of migmatite gneiss with charnockite
5.	Ja.Endal	01	
6.	Agaram	14	
7.	Mel Aathanur	17	Migmatite gneiss
8.	Pullur	09	
9.	Kaludur	06	
10.	Avatti	13	
11.	T.Endal	24	
12.	Tachchur	20	
13.	Tholudur	26	Contact of migmatite gneiss with charnockite
14.	Vadakarampundi	19	
15.	Lakshmanapuram	11	
16.	Panaiyandur	07	
17.	Orangur	12	
18.	Mangalore	08	
19.	Sirupakkam	05	
20.	S.Naraiyur	04	

2. Sedimentary rocks

Almost one third of the area is covered by sedimentary rock types and located on the eastern part of the study area. They lie in northeast-southwest direction and are unconformable with the migmatite formation, near Sirumalai and Sirumangalam areas. The sedimentary terrain is represented by the flood plains. Back swamp deposits are common. Within these sedimentary rocks, intercalated limestone and calcareous shale are noticed near Narasingamangalam and Pennadam habitations. In the study area, the following habitations come under the sedimentary rock terrain (Table 4).

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Table 4 Habitation, VES location and sedimentary rock types

Sl.No.	Habitation	VES Location No.	Rock types
1.	Sirumangalam	10	Alluvium, coarse medium and fine sand, clay, sandstone, etc.
2.	Mosattai	23	
3.	Tivalur	16	
4.	Narasingamangalam	15	
5.	Melur	18	
6.	Adamangalam	21	
7.	Kilnemeli	22	
8.	Pennadam	27	
9.	Semberi	30	
10.	Neyvasal	29	

3. Geo-electric sections

The geo-electric sections are of special significance since they reveal the lateral and sub-surface configuration of the area. The general foliation of the area is NE to SW direction. The area is moderately undulating and sloping towards East and SE directions. The sedimentary terrain is lower in elevation than the crystalline terrain and the sandwiched contact zone is also undulating with no uniform slope.

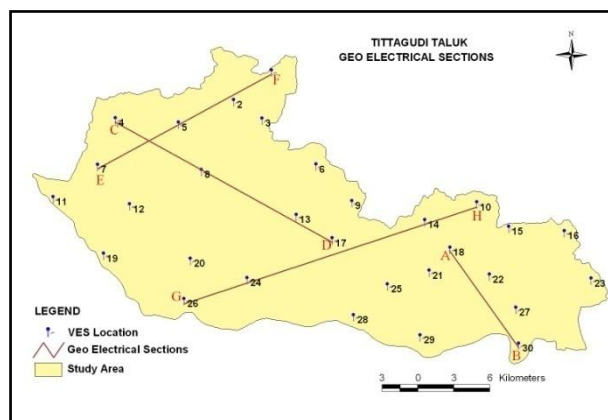


Fig. 4. Geo-electrical sections (AB, CD, EF and GH) of the study area.

There are four sets of cross-section constructed along the major structural direction viz., NW to SE direction as well as NE to SW direction, shown in Figure 4. The AB cross-section depicts the disposition of sedimentary rocks, and CD and EF sections portray the disposition of crystalline rock areas. The GH section illustrates the crystalline and sedimentary rocks as well as contact zones. The geo-electric parameters are plotted with special reference to the ground level elevation and the true resistivity is obtained from the curve matching interpretation.

Geo-electric section along AB

This section (Melur-Kilnemeli-Pennadam-Semberi) trending NW-SE direction falls within the sedimentary rock area (Fig. 5). The geoelectric section along this trend is multilayered. The lithology of Maruthathur Colony (near Kilnemeli) indicates the presence of clay, fine sand, and medium-grained sandstone upto a depth of 48 m. In the same trend when we go further southwest, it is noticed that the medium-grained sandstone occurs upto a depth of 5 m followed by clay. The thickness of the sand layer is almost 22m and low resistivity clay layer underlies this sand. In the same south-

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eastern direction at Semberi, multilayered resistivity curve is obtained. The resistivity curve indicates that good conductive low resistivity clay layer alternates with medium and coarse-grained sand throughout the depth of the investigation of 100m. The quality of groundwater and the yield from the aquifer in this section are moderate due to the intercalation of sand with clay layer.

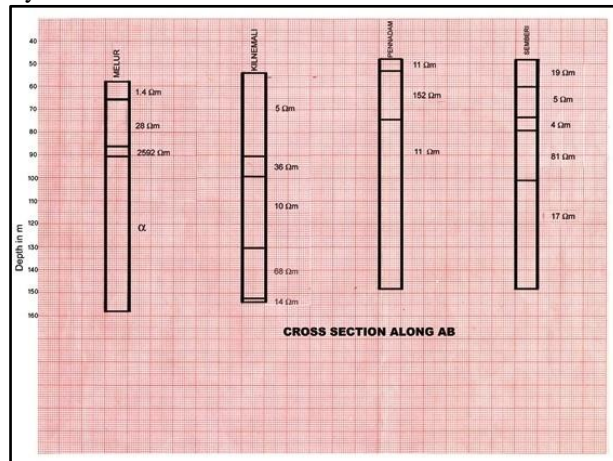


Fig.5 Geo-electrical cross section along AB.

Geo-electric section along CD

This section represents the crystalline hard rock portion of the study area. The axis of S.Naraiyur-Mangalore-Avatti and Mel Aathanur (Figure 6) merges with the direction of NNW to SSE. This section forms a typical three and four-layered earth. The resistivity ranges from 10 Ωm to 1711 Ωm. In S. Naraiyur, Mangalore and Mel Aathanur, there are four layered sections, whereas at Mangalore, it is of an ascending type of curve. At S. Naraiyur and Mel Aathanur, the curve is ascending and descending type. At Avatti, it is of simple two layer ascending type. It is ascertained from these curves that the general succession is top layer of soil followed by weathered formation, and fractured and hard massive formations at different depths. But, in certain cases, one more fractured zone appears below the hard rock as fourth layer (Mel Aathanur and S. Naraiyur). The top layer of soil is immediately followed by the massive hard formation of charnockite in Avatti. In this particular cross-section along CD, a fracture zone is invariably encountered at the depth of 50 to 60m.

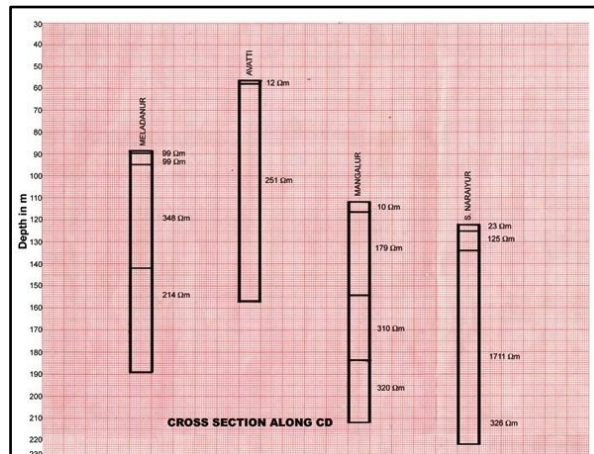


Fig.6 Geo-electrical cross section along CD.

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Geo-electrical section along EF

This section represents crystalline hard rock portion of the study area. This forms an axis along the Panaiyandur-Sirupakkam-Rettakurichi-Ja.Endal stretches in the northeast–southwest direction. This section (Figure 7) significantly represents the typical crystalline hard rock zones of three-layer pattern and when it is extended towards Sirupakkam, Rettakurichi and Ja.Endal, the section forms a four-layer set. In the three-layer set of Panaiyandur, the true resistivity gradually increases from first layer to second layer and finally decreases in the third layer, which may be a fractured charnockite formation. On the other hand, in Sirupakkam and Rettakurichi, a four-layer set of top soil, weathered kankar, fractured charnockite, and fresh rock is inferred. The curves are of the ascending type. In Ja.Endal, it is equivalent to that of Panaiyandur cross-section of three-layer framework, wherein the bottom-most layer is moderately conductive, which may be due to the presence of sizeable and adequate fractures and a groundwater-bearing zone.

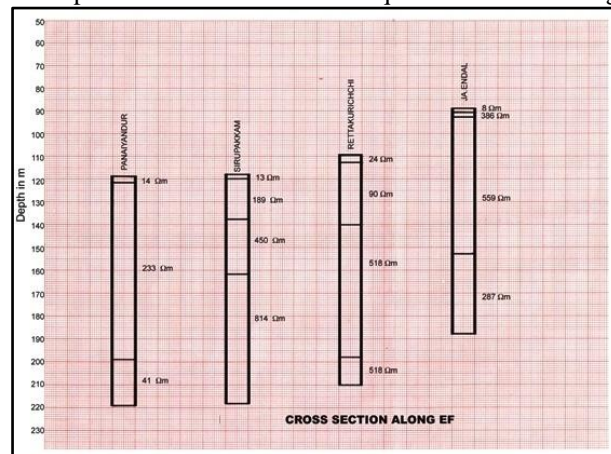


Fig.7 Geo-electrical cross section along EF.

Geo-electric section along GH

This forms the central portion of the study area stretching from T.Endal through Tholudur, Mel Aathanur and Agaram to Sirumangalam and lies in the same orientation of NE to SW (shown in Figure 8). This cross section traverses both the crystalline hard rocks and sedimentary rocks. This contact zone is prominently present in between Mel Aathanur and Agaram. As we move from west to east, it is noticed that the western portion of the study area is a typical crystalline hard rock (Ja. Endal, Tholudur and Mel Aathanur) terrain and the eastern portion comprises sedimentary rocks (Agaram and Sirumangalam). The transition contact zone bears the orientation of northeast to southwest direction (Agaram, Sirumangalam, and Tittagudi). At T.Endal, the low and high conducting formations alternate with each other and this is an example of multilayer framework. In Tholudur, the curve is typically of ascending type, comprising weathered, fissured and hard massive charnockites. The three-layer curve of Mel Aathanur indicates that the curve is a combination of ascending and descending sections, confirming the presence of medium conductive weathered formations followed by less conductive fractured gneissic formations.

The Agaram section shows a multilayer setup consisting of sedimentary and crystalline rocks (contact zone). The sedimentary formations are represented by clay, and medium to fine sand. These are followed by hard massive formations occurring at a depth of 63m. In Sirumangalam, the sand and clay alternate with each other and no hard rock is present at deeper horizons.

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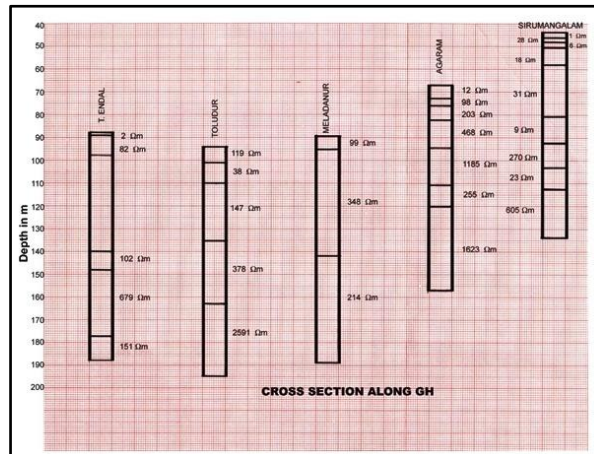


Fig.8 Geo-electrical cross section along GH.

V. CONCLUSION

- ✓ The geoelectrical section along AB reveals that the quality of groundwater and yield from the aquifers are moderate due to the intercalation of sand with clay layer.
- ✓ The geoelectrical section along CD exhibits that a fracture zone is invariably encountered at a depth of 50 to 60m.
- ✓ The section EF indicates sizeable and adequate fractures; hence it is a better groundwater-bearing zone.
- ✓ The geoelectrical section along GH represents the contact zone. The transition contact zone bears the orientation of northeast to southwest direction (Agaram, Sirumangalam and Tittagudi).
- ✓ The geoelectrical section along profile AB falls under the sedimentary rock formations, CD and EF fall under the crystalline rock formations and GH section represents the contact zone between crystalline and sedimentary rock formations.

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