Geoelectrical Schlumberger Investigation for Characterizing the Hydrogeological Conditions Using GIS in Kadavanar Sub-basin, Cauvery River, Tamil Nadu, India

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Abstract- The increasing demand for fresh water has necessitated the exploration for new sources of groundwater, particularly in hard rock terrain, where groundwater is a vital source of fresh water. A fast, cost effective and economical way of exploration is to study and analyze geophysical resistivity survey data. The present study area Kadavanar sub-basin, Cauvery River, Tamil Nadu, India, is overlain by Archaean crystalline metamorphic complex. The study area is a characteristic region of unconfined aquifer system. The potential for occurrence of groundwater in the study areas was classified as very good, good, moderate and poor by interpreting the sub-surface geophysical investigations, namely vertical electrical soundings, were carried out to delineate potential water bearing zones. The studies reveal that the groundwater potential of shallow aquifers is due to weathered zone very low resistivity and very high thickness and the potential of deeper aquifers is determined by fracture zone very low resistivity and very high thickness area. By using conventional GIS method, the spatial distribution maps for different layer (Top soil, weathered zone, first fracture zone and second fracture zone) thicknesses were prepared. The geoelectrical approach was successfully applied in the study area and can be therefore easily adopted for similar environments.

Keywords: Aquifer; Vertical Electrical Sounding (VES); spatial distribution map; hard rock terrain.

I. INTRODUCTION

Groundwater is a primary source of fresh water in this region. There has been a growing demand for fresh water for various purposes, such as domestic, agricultural and industrial use. In order to meet the demand, the delineation of potential groundwater zones is essential. There have been several methods such as geophysical and geological methods to delineate groundwater potential zones.

The resistivity survey is cost effective while studying geophysical data. In order to assess the groundwater conditions in the area, electrical resistivity surveys were carried out with Schlumberger electrode configuration to pinpoint the most favorable locations in the area. Geophysical investigations, Teeuw (1999), Shahid and Nath (2002), and Srivastava and Bhattacharya (2006) have evolved a simple and rapid approach for demarcation of groundwater potential.

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The study area covered by hard rock (Archaean crystalline metamorphic complex) formations, faces water scarcity problems for irrigation as well for drinking purposes. As such, the formations hold and yield water. However, there is spatial variation in the occurrence of groundwater. Therefore, demarcation of different groundwater potential zones is essential for water resources development and management. If the fractures are saturated with groundwater, a good contrast is observed between the resistivity and fractured rocks showing lower resistivity than hard rocks (Karous and Mares, 1988).

Geophysical methods may provide a relatively low-cost approach to hydrogeologic characterization. Numerous papers illustrate the utility of geophysical methods in defining subsurface heterogeneity in aquifer properties (Kelly and Mares, 1993). Schlumberger resistivity method is most suitable for groundwater investigations in hard rock area compared to other geophysical methods. Delineation of fracture zones in low permeability hard rock is still a very challenging task in few hundred meters. Recently, geophysical surveys for groundwater exploration in hard rock areas have been attempted by Bernard and Valla, 1991; Ronning et al. 1995; Kaikkonen and Sharma, 1997; Ramteke et al. 2001; Krishnamurthy et al. 2003; Sharma and Baranwal, 2005; and Porsani et al. 2005); Flathe (1955), Zohdy (1969) and Fitterman and Stewart (1986).

Geophysicists have realised that the integration of aquifer parameters calculated from the existed boreholes locations and surface resistivity parameters extracted from surface resistivity measurements can be highly effective, since a correlation between hydraulic and electrical aquifer properties can be possible, as both properties are related to the pore space structure and heterogeneity (Kelly, 1977; Mazac et al., 1985; Huntley, 1986; Mazac et al., 1988; Boerner et al., 1996; Christensen and Sorensen, 1998; Rubin and Hubbard, 2005; De Lima et al., 2005; Niwas et al., 2006).

GIS has emerged as a powerful technology for instruction, for research, and for building the stature of programs (Openshaw 1991; Longley 2000; Sui and Morrill 2004). GIS is an important technology for geologists (Baker and Case 2000).

II. STUDY AREA AND LOCAL HYDROGEOLOGY

Kadavanar sub-basin, Cauvery River, major part of the study area fall in Dindigul District and small portion of the Karur District is an interior part of Tamil Nadu with an total area of 2254.65 km^2. The plain area 1857.58 km^2 and Hill and forest area is an area about

397.07 km^2 is bounded (Fig. 1) by Madurai district in the south, Theni district in the northwest, Sivaganga in the Southeast, Thiruchirapalli in the West, Namakkal in the north and Erode northwest side of the study area. The Kadavanar sub-basin lies between latitudes N 10°09'56.70" and 10°52'31.5", longitudes E 77°37'29.29" and 78°13'14.21". The major source for recharge in the area is rainfall during monsoon, but average annual rainfall is medium about 838.96 mm. As the study area is underlain by the Archaean crystalline rock, groundwater may occur in the weathered zone and fractured rocks, provided the zones are connected with recharging sources. It is well known that fractures play an important and crucial role in fluid flow, especially for the movement and accumulation of groundwater in hard rock areas. Minor fractures present in the rock, if interconnected, can give copious supply of groundwater. The resistivity surveys were conducted only at the locations where ground surface is plain and suitable for laying out the array. Thus the entire area could not be mapped through the resistivity survey.

III. METHODOLOGY

The study area base map was prepared from Toposheet were registered in GIS environment. The toposheets No. 58 F/11, 13, 14, 15, 16, 58J/1, 2, 3 and 4 of 1:50,000 scale. Schlumberger vertical electrical soundings (VES) survey was carried out at 50 locations (Fig.1), with the maximum electrode spacing of 300 m. The current electrode (AB/2) spacing varied from 1 to 150 m and the potential electrode (MN/2) spacing varied from 0.5 to 15 m. Each datum was plotted in the field to check the quality and to avoid mistakes. The field data was interpreted by curve matching techniques. For this work, the computer software IPI2WIN Software was also used. The degree of uncertainty of the computed model parameters and the goodness of fit in the curve fitting algorithm are expressed in terms of curve fitting error (less than 10). The resistivity of different layers and the corresponding thickness are reproduced by a number of inversions until the model parameters of all the VES curves are totally resolved with the fitting error. These results are taken into GIS platform, their attributes are added and analyzed in ArcGIS version 9.3 software. Spatial analysis tools were used for the preparation of interpolation map. The maps were interpolated by using inverse distance methods to arrive the spatial distribution map. The methodology adopted in the present study is given in the flow chart (Fig. 2).

IV. RESULTS AND DISCUSSION

The interpretation of different VES (Vertical electrical Sounding) data (Table 1) revealed that the first layer resistivity varied from 0.02 Ohm-m to 8133 Ohm-m with 4.6 m thickness. The next layer resistivity varied from 0.83 Ohm-m to 97639 Ohm-m with 42.20 m thickness. Third layer resistivity varied from 0.19 Ohm-m to 59459 Ohm-m with 57.30 m thickness. Fourth layer resistivity varied from 0.027 Ohm-m to 96130 Ohm-m with 109 m thickness.

A. Types of Curves

Resistivity curves in to different types like nine types of curves are observed viz. three layers of KQ-type (type I), HQ-type (type II), QH-type (type III), HA-type (type IV), AA-type (type V), AK-type (type VI) HK-type (type VII), KH-type (type VIII) and QQ-type (type IX). The complete data has been interpreted by curve matching technique in IPI2WIN software (Table 2). The boundary of each layer was marked at its appropriate depth on the electrode separation (abscissa) axis and the resistivity values were given for each layer. The resistivity of the surface layer varies from place to place depending upon the surface conditions of the area, i.e., low value due to moisture content and high value due to dry rock (depth to basement). This can be considered to have four layers, with the first one as thin surface soil, the second as weathered zone (weathered rock bed), the third as primary fracture zone and the fourth as a secondary fracture zone and depth to basement (Massive rock).

B. Geohydrologic Interpretation

Table 1 shows the apparent resistivity and thickness of different layers. With the help of result and data, GIS classified spatial distribution maps that were generated on topsoil, weathered zone, first fracture zone, second fracture zone and depth to basement rock themes.

C. Top Soil

The top soil GIS spatial distribution map reveals that 22 (VES) locations have less than 0.29m thickness and were classified as Low thickness. 16 (VES) locations were covered by the thickness ranging from 0.29m to 0.55m and were classified as medium thickness. 6 locations were covered by the thickness ranging from 0.55m to 1.36m and were classified as high thickness and only 6 locations have more than 1.36m topsoil thickness and were classified as very high thickness (Table 3). Spatially 844.79 km^2 area falls in the medium thickness class (Fig. 3). The maximum resistivity value was observed in Palanatham location (VES No.9) as 7065 Ohm-m and the highest topsoil thickness was observed in Karunkalpatti (VES No.5) 2.1m. Due to large amount of recharge they are considered as favorable groundwater zones. The groundwater yield depends on the thickness of the material deposited. It indicates that drastic changes were observed over the study area. The result is given in (Table 4).

D. Weathered Zone

The weathered zone GIS spatial distribution map reveals that 27 (VES) locations having less than 0.31m were classified as low thickness. Sixteen (VES) locations covered by the thickness ranging from 0.31m to 2.77m were classified as medium thickness. Five (VES) locations covered by thickness ranging from 2.77m to 17.91m were classified as high thickness. Only 2 locations having more than 17.91m were classified as very high thickness (Table 5). Spatially 985.25km^2 area falls in the medium thickness class and 363.98km^2 area falls in low thickness class. The rest of the area 454.94 km^2 and 53.40km^2 falls under high and very high thickness class (Fig. 4). The maximum resistivity values were observed in Pallapatty location (VES No.37) as 5711Ohm-m and the highest weathered zone thickness was observed in Kappiliyappatty (VES No.30), 47m. These regions are seen almost everywhere in the area having smooth surface with 0.31–2.77m thick weathered material and covered with red soil. The groundwater prospects are good to very good. This indicates that there were drastic changes observed over the study area. The result is given in (Table 6).

E. Fracture Zones

(Table 7) shows that the first fracture zone-1 results has the maximum resistivity value and was observed in Malavarapatti (VES No.18) as 7647 Ohm-m and the highest fracture zone thickness was observed in Vallaiyappampatti (VES No.50) 128m. This indicates that drastic changes were observed over the study area.

The (Table 8) shows that the fracture zone 2 results had given the maximum resistivity value was observed in Sengalathupatty (VES No.31) as 5284ohm-m and the highest fracture zone thickness were observed in Puthipuram (VES No.17) 75.7 m. It is because of the lithological variation at highest fracture zone gneissic rock noticed on the field survey, that such drastic changes were observed over the study area.

Spatial distribution map of first layer thickness (Fig. 5) was prepared using GIS which is given in Table 7. The first layer thickness can also be classified in to four classes, such as First layer Low Thickness, First layer Medium Thickness, First layer High Thickness and First layer Very High Thickness out of which the best groundwater potential area is indicated by VHT (Very High Thickness). Very high thickness zones cover an area of about 27.24km^2. Such a region is seen in the northern part of the area and consists of charnockite in downstream part near to the kadavanar with Cauvery river confluent point area. The groundwater prospects are good to very good, as these features comprise of high weathering materials cover. Very good yields are expected along fractures/lineaments.

Similarly spatial distribution map of second layer thickness (Fig. 6) was prepared using GIS which is given in the Table 8. The second layer thickness can also be classified into four classes, such as Second layer Very Low Thickness, Second layer Low Thickness, Second layer Medium Thickness and Second layer High Thickness. The possibility of the best groundwater potential areas is related to VHT zones that cover an area of about 51.07km^2. Such a region is seen only in one patch in the northern (bottom) part of the area. This region is having almost plain area with 3.79–26.61m thick deep fracture zone covered with hornblend biotite gneiss that region present in downstream portion of the Kadavanar river. The groundwater prospects in this region are very good more yield.

V. CONCLUSION

The geoelectrical investigations, coupled with geological and hydrogeological studies, revealed several characteristics. The bottom-most layer is compact basement crystallines (predominantly charnockite rock) having mostly high resistivity. Groundwater is mainly confined in the intermediate weathered and fracture zone (fractured basement), forming an unconfined aquifer system. VES findings unearth a few promising groundwater-bearing zones of appreciably high thickness that was noticed at Karunkalpatti (VES No.5), Kappiliyappatty (VES No.30), Vallaiyappampatti (VES No.50), and Puthipuram (VES No.17). These zones can be trapped for sufficient water supply to combat acute water scarcity in the area. Spatially interpreted results gives Topsoil thickness as follows: good category of 5.51%, weathered zone thickness of good category 2.87%, first fracture zone thickness of good category 1.47% and second fracture zone thickness of good category 2.75%. It clearly shows that the water residing zone is very less. This area needs the construction of more artificial recharge zones to improve the quantity. The VES sounding results of water bearing zones also fall in this favorable zone. Schlumbergr's resistivity vertical electrical surveys one can achieve better results for future groundwater prospects in hard rock terrains. Similarly, comparative study of geology and aquifer thickness facilitates delineation of areas of potential groundwater region, which can be demarcated in the form of maps.

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VES Location	Resistivity Ohm-m /Thickness m				Total Thickness 'h' m	Curve Types
	h_1-ρ_1	h_2-ρ_2	h_3-ρ_3	h_4-ρ_4		
Ontampatty	0.61 / 125	0.57 / 6.12	0.12 / 23.8	2.55 / 1.55	3.85	HA
Pethaiyankottai	0.5 / 473	0.03 / 4.38	32.2 / 2336	45 / 547	77.73	KH
Ayyamptty	0.5 / 182	0.015 / 0.612	1.44 / 413	3.87 / 10.4	5.83	AK
Sempekkanom	1.5 / 472	2.34 / 72	2.63 / 144	3.42 / 9.24	9.89	AK
Karunkalpatty	0.02 / 325	0.007 / 885	0.14 / 29.7	0.3 / 2053	0.47	KH
Alampatty	0.64 / 95.2	0.75 / 29.3	0.07 / 2690	10.1 / 200	11.56	AK
Kadipatty	0.07 / 1044	0.03 / 34.3	0.23 / 37.4	0.22 / 1011	0.55	AK
Oothupatty	0.5 / 289	0.57 / 20.7	0.23 / 0.27	0.29 / 205	1.59	HK
Palanatham	0.17 / 7065	0.024 / 212	0.54 / 418	1.11 / 52.3	1.84	HA
Phillamanayakkanpatty	0.07 / 0.506	0.013 / 0.321	0.16 / 0.217	0.114 / 0.7911	0.36	HK
Vellaiyakoundanur	0.05 / 0.356	0.05 / 0.287	0.116 / 0.387	0.135 / 0.903	0.35	HK
Thannakanampatty	0.16 / 0.09	0.06 / 0.182	0.124 / 0.426	2.71 / 419	3.05	KH
Kolakoundampatty	0.11 / 0.233	0.015 / 0.242	0.086 / 0.342	0.104 / 0.921	0.32	KH
Kasipalayam	0.85 / 11.1	0.012 / 2.78	0.01 / 4.12	0.044 / 3.06	0.92	HK
Guruvanur	2.06 / 108	1.15 / 9.96	1.53 / 3211	1.51 / 3200	6.25	AK
Thoppur	0.18 / 0.38	0.05 / 0.456	0.159 / 2.49	50.7 / 4034	51.09	KQ
Puthipuram	0.17 / 0.299	0.048 / 0.31	0.106 / 0.988	755 / 3146	75.82	KH
Malavarapatty	0.53 / 75.5	0.03 / 7.1	1.59 / 7647	1.3 / 29.5	3.45	AK
Kamatchipuram	0.5 / 3.48	0.01 / 0.02	1.74 / 0.113	0.646 / 1.7	2.90	HK
Ottakampatty	0.23 / 0.281	0.162 / 0.57	1.03 / 592	1.54 / 500	2.96	KH
Pallappatty	2.7 / 75.1	0.98 / 3.76	1.43 / 1852	1.9 / 1800	7.01	HK
Mullampatty	0.5 / 5.88	0.015 / 319	0.213 / 0.304	0.274 / 0.479	1.00	KH
Alagupatty	0.5 / 19.1	0.082 / 0.103	0.023 / 0.089	0.021 / 0.103	0.63	QH
Kalladippatty	0.02 / 0.155	0.43 / 0.301	0.84 / 0.105	0.1 / 0.136	1.39	KH
Lakkampatty	0.18 / 0.167	0.17 / 0.19	0.105 / 0.825	0.329 / 0.14	0.78	AK
Kunkampatty	0.16 / 52.5	0.02 / 50.5	0.06 / 176	0.71 / 269	0.95	HA
Pannaipatty	1.9 / 446.1	3.14 / 16.7	4.64 / 17.8	0.12 / 18.92	9.84	HA
Reddiyarsatram	1.66 / 15.4	1.65 / 106	1 / 16.9	1.5 / 26.9	5.81	KH
Koppampatty	1.68 / 19.4	1.698 / 6.98	1.245 / 19.87	6.68 / 2454	11.30	HA
Kappiliyappatty	0.5 / 0.158	47 / 0.24	0.015 / 20.8	0.022 / 20.64	47.54	AK
Sengalathupatty	1.13 / 47.3	32.8 / 144	8.12 / 5381	12.2 / 5284	54.25	AA
Panjappatty	0.66 / 0.778	0.537 / 4300	0.33 / 4380	1.06 / 4073	2.59	AK
Dindukal	0.22 / 0.197	0.029 / 0.206	0.102 / 0.621	0.64 / 176	0.99	AA
Phillamanayakkanpatty	0.24 / 0.267	0.015 / 5.01	0.259 / 17.4	0.64 / 0.534	1.15	AK
Kambiliyampatty	0.14 / 6.08	0.077 / 7.96	0.291 / 11	0.67 / 0.203	1.18	AK
Parappatty	0.5 / 0.487	5.68 / 134	7.43 / 126	25.7 / 292	39.31	KH
Palappatty	0.5 / 907	0.57 / 5711	11.1 / 512	10.1 / 4285	22.27	KH
Thomiyapuram	0.5 / 0.382	0.07 / 6.65	14.8 / 2.35	21.6 / 55.5	36.97	KH
Reddiyappatty	0.08 / 273	0.12 / 83.5	0.317 / 44.3	0.487 / 0.078	1.00	QQ
Mettupatty	0.54 / 39.4	0.142 / 0.22	0.212 / 0.434	0.159 / 0.898	1.05	HQ
Mutthani	0.17 / 0.42	0.149 / 0.499	0.11 / 1.2	38.6 / 3969	39.03	AA
Killai	0.29 / 0.992	0.15 / 0.144	16.7 / 687	25.1 / 700	42.24	HA
Semmpatty	0.21 / 0.316	0.0267 / 0.333	0.11 / 0.861	49.5 / 2756	49.85	HQ
Vellaiyampatty	0.18 / 0.283	0.123 / 0.338	0.112 / 0.763	14.8 / 4594	15.22	QQ
Ellaipatty	0.36 / 67	0.113 / 237	2.87 / 3.06	0.63 / 38	3.97	KH
Virallipatty	0.19 / 0.297	16.8 / 2.38	23.8 / 57.1	38 / 2656	78.79	AA
Kannaiyapuram	0.91 / 0.297	16.8 / 1556	4.26 / 1981	6.38 / 1900	28.35	AK
Maniyakkaranpatty	0.37 / 1.99	0.131 / 2.23	0.69 / 1.83	0.646 / 360	1.84	KH
Elappatty	0.5 / 9.73	0.052 / 649	1.33 / 3.24	0.49 / 19.4	2.37	KH
Vellaiyappampatty	0.5 / 0.37	3.18 / 0.524	12.8 / 1570	19.1 / 1500	35.58	AK

Table 1. Geophysical Investigations Results

Table 2. Curve types and its occurrence

S.No.	Curve Types	Number of locations	Total Number of Locations
1	KQ	16	1
2	HQ	40,43	2
3	QH	23	1
4	HA	1,9,26,27,29,42	6
5	AA	31,33,41,46	4
6	AK	3,4,6,7,15,18,25,30,32,34,35,47,50	13
7	HK	8,10,11,14,19,21	6
8	KH	2,5,12,13,17,20,22,24,28,36,37,38,45,48,49	15
9	QQ	39,44	2

Table 3. GIS Spatial distribution – Top soil Thickness

Top Soil Thickness m	Number of Location	Class	Area Km^2
Less Than 0.29 m	22	Low Thickness	259.09
0.29 to 0.55 m	16	Medium Thickness	844.79
0.55 to 1.36 m	6	High Thickness	651.37
More than 1.36 m	6	Very High Thickness	102.34

Table 4. Results of curve match interpretation - Top Soil Thickness

Max./Min.	Village Name	ρ1 Ohm-m	Village Name	Topsoil Thickness m
Maximum	Palanatham (9)	7065 Ohm-m (0.17m)	Karunkalpatti (5)	2.1m (75.10 Ohm-m)
Minimum	Thannakanampatty	0.09 Ohm-m (0.16m)	Pallappatty (37)	0.02m (325 Ohm-m)

Table 5. GIS Spatial distribution – Weathered Zone Thickness

Weathered Zone Thickness m	Number of Villages	Class	Area Km^2
Less Than 0.31m	27	Low Thickness	363.98
0.31 to 2.77m	16	Medium Thickness	985.25
2.77 to 17.91m	5	High Thickness	454.94
More than 17.91m	2	Very High Thickness	53.40

Table 6. Results of curve match interpretation - Weathered Zone Thickness

Max./Min.	Village Name	(ρ2) Ohm-m	Name of the Village	Weathered Zone Thickness
Maximum	Palappatty (37)	5711 Ωm. (0.57 m)	Kappiliyappatty(30)	47.0 m.(0.24 Ωm)
Minimum	Kamatchipuram (19)	0.02 Ωm. (0.01 m)	karunkalipatti (5)	0.01m. (885.00 Ωm)

Table 7. Results of curve match interpretation - Fracture Zone 1 Thickness

Max./Min.	Village Name	(ρ3) Ohm-m	Village Name	Fracture zone 1 Thickness m
Maximum	Malavarapatti (18)	7647 Ωm. (1.59 m)	Vallaiyappampatti (50)	128. m.(1570 Ωm)
Minimum	Alagupatti (23)	0.09 Ωm. (0.02 m)	Kasipalayam(14)	0.01 m. (4.12 Ωm)

Table 8. Results of curve match interpretation - Fracture Zone 2 Thickness

Max,/Min,	Village Name	(ρ4) Ohm-m	Village Name	Fracture zone 2 Thickness m
Maximum	Sengalathupatty(31)	5284 Ωm. (12.20 m.)	Puthipuram (17)	75.5 m. (3146 Ωm.)
Minimum	Reddiyappatty(39)	0.08 Ωm. (0.49 m)	Alagupatty (23)	0.02m. (0.10 Ωm)

Table 9. GIS Spatial distribution – Fracture Zone 1 Thickness

Fracture Zone Thickness m	Number of Villages	Class	Area Km^2
Less Than 0.78m	28	Low Thickness	287.55
0.78 to 5.49m	14	Medium Thickness	1078.35
5.49 to 30.27m	7	High Thickness	464.45
More than 30.27 m	1	Very High Thickness	27.24

Table 10. GIS Spatial distribution – Fracture Zone 2 Thickness

Fracture Zone Thickness m	Number of Villages	Class	Area Km^2
Less Than 3.79 m	33	Low Thickness	341.22
3.79 to 26.61m	11	Medium Thickness	1045.60
26.61 to 166.83m	5	High Thickness	419.66
More than 166.83m	1	Very High Thickness	51.07

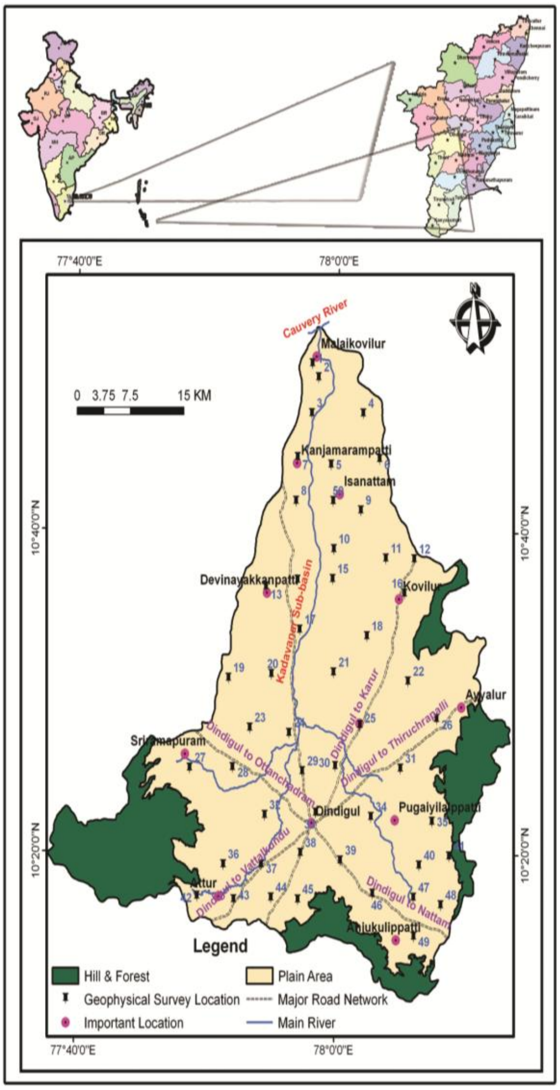

Fig.1 Key map of Study Area with Geophysical Survey Location

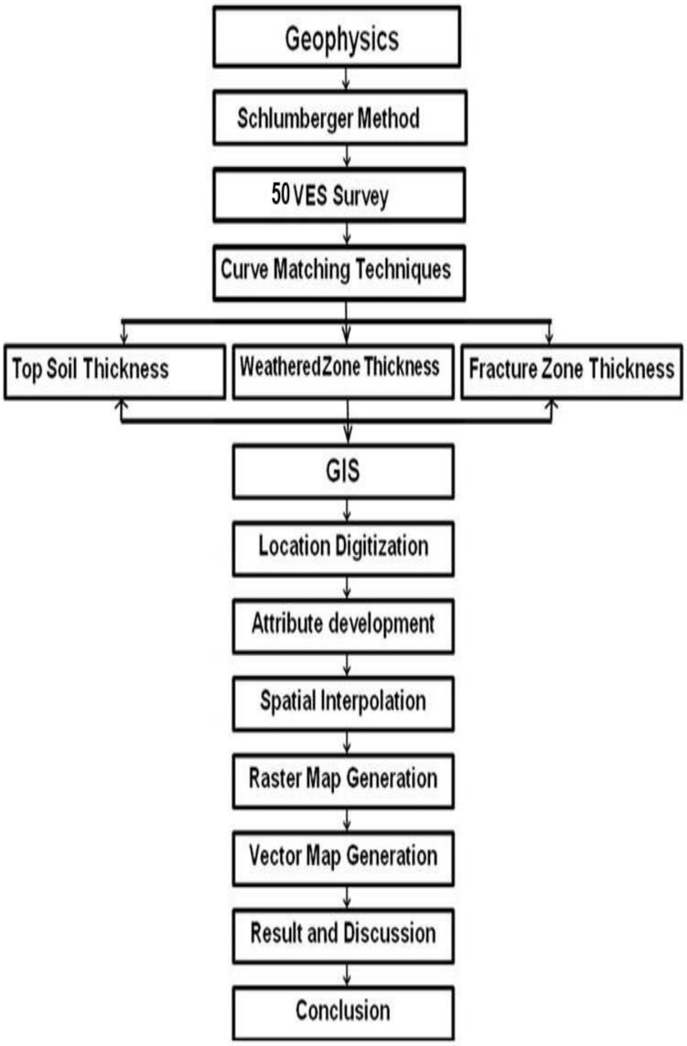

Fig.2. Flow Chart Methodology Followed

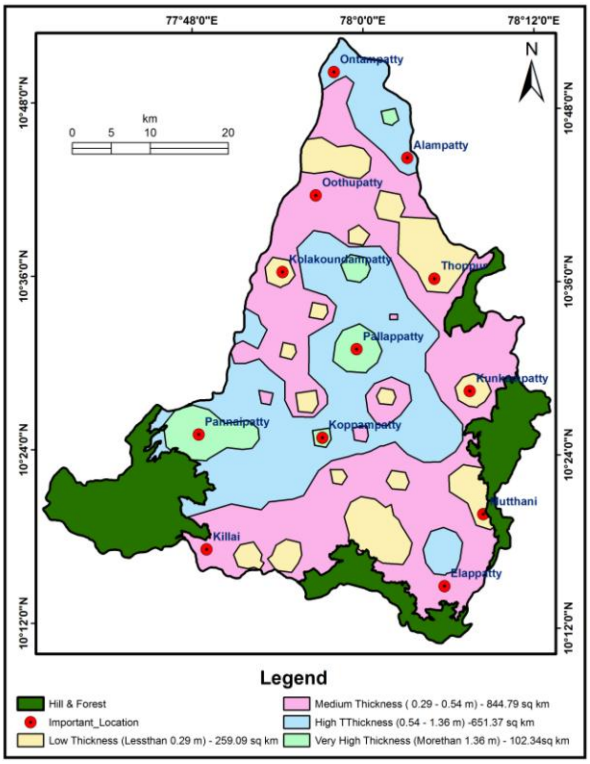

Fig. 3 Topsoil Thickness Spatial Distribution Map

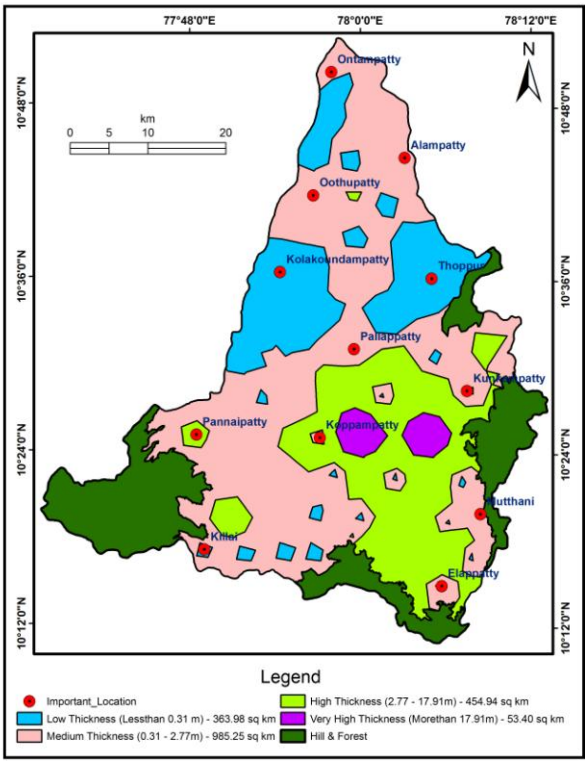

Fig. 4 Weathered Zone Thicknesses Spatial Distribution Map

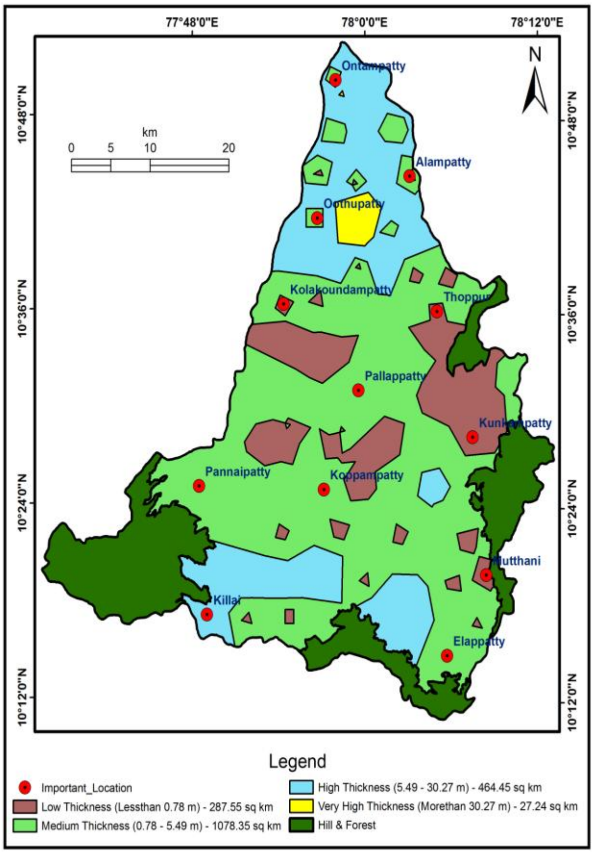

Fig. 5 First Fracture Zone Thicknesses Spatial Distribution Map

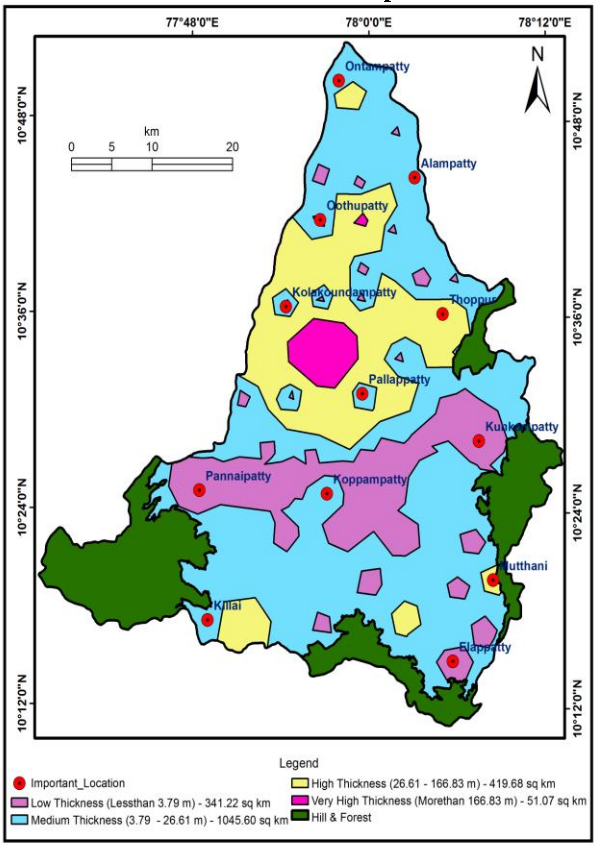

Fig. 6 Second Fracture Zone Thickness Spatial Distribution Map