IDENTIFICATION OF GROUNDWATER POTENTIAL ZONE BY USING GIS AND ELECTRICAL RESISTIVITY TECHNIQUES IN AND AROUND THE WELLINGTON RESERVOIR, CUDDALORE DISTRICT, TAMILNADU, INDIA

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Abstract

We have attempted to investigate groundwater for irrigation purpose at the time of monsoon failure which would serve as a key element in both short and long-term perspective in and around the Wellington reservoir of Vellar basin by assessing the subsurface geology and groundwater potential zones. An attempt had been made to identify the subsurface lithology and aquifer zones by geoelectrical resistivity method in part of Tittagudi, Nallur and Vriddhachalam block of Cuddalore District. This method is useful to delineate the subsurface formations, weathered zone and fracture pattern, etc. The study area consists of major subsurface litho units like sand, Silt, Clay, Charnockite, Migmatite rocks and Fissile hornblende biotite gneiss. In order to explore the groundwater resources of the study area with an aerial extent of 495.3 km^2. Electrical soundings have been conducted at every 5 Km intervals in grid pattern by adopting Schlumberger technique in 30 locations. Each location measuring 100m extent with an electrode spacing of 10m,20m, 30m, 40m, 50m, 60m, 80m, 100m spacing. Which have been qualitatively and quantitatively interpreted using software. Pseudo sections have been generated by IPI2 WIN ver.3.1 and isoresistivity maps were prepared by using software MapInfo 8.5 Considering the geological, geomorphology and hydrogeological conditions the VES interpretation was done. From the interpretation result the VES no. 4 (Alambadi) and VES no 30 (Devangudi) is found to be prospective for groundwater. This information not only helps to understand the hydrogeology of the area but also provides improved task for groundwater exploration and management as well.

Keyword: GIS, Isoresistivity maps, Pseudo sections, qualitatively and quantitatively, MapInfo 8.5 and VES

Introduction

Water is essential for development of different seasons irrigation, industry and domestic purpose. Groundwater is the main source for potable water supply, domestic, industrial and agricultural uses. The scarcity of groundwater increases day by day due to rapid population, urbanization, industrial and agricultural related activities, failure of monsoon natural calamities. Groundwater is more advantageous than the surface water due to its lesser extent of evaporation. Water scarcity problem affects the human chain and other living things. To meet out the demand of water, people are depending more on aquifers. There are two end members in spectrum of types of aquifers; confined and unconfined (with semi confined aquifer being in between them) (3). The study area is covered by sedimentary and hard rock formations, and faces acute water scarcity problem both with respect to irrigation as well as drinking purposes (1). Occurrence of groundwater in this type of area is limited to fractured and weathered horizons and upper unconsolidated materials. For identifying the groundwater potential in the hard rock terrain, the main target is fractured zone (11). The concept of integrated Remote sensing and GIS has proved to be an efficient tool in groundwater studies and the inclusion of subsurface information inferred from geoelectrical survey can give more realistic picture of groundwater potential of an area, (4), (5) and (6). Surface electrical resistivity surveys were conducted at different locations to obtain subsurface lithological information, identification of horizontal and vertical disposition of aquifer system (12). The rapid rural development in and around the study area and the associated activities have resulted in the increase of population demands leading so excesses utilization of groundwater. Because of the over exploitation of groundwater, the groundwater level has been declined in recent times (13). Warrants groundwater assessment for sustainable utilization within the study area. The main objective of the investigation is to delineate the subsurface lithology and to assess the groundwater resources of the sub watershed. Its also aim to focus on the identification of fracture zone and its thickness by using VES (Vertical Electrical Sounding) method (14), (15).

Study Area

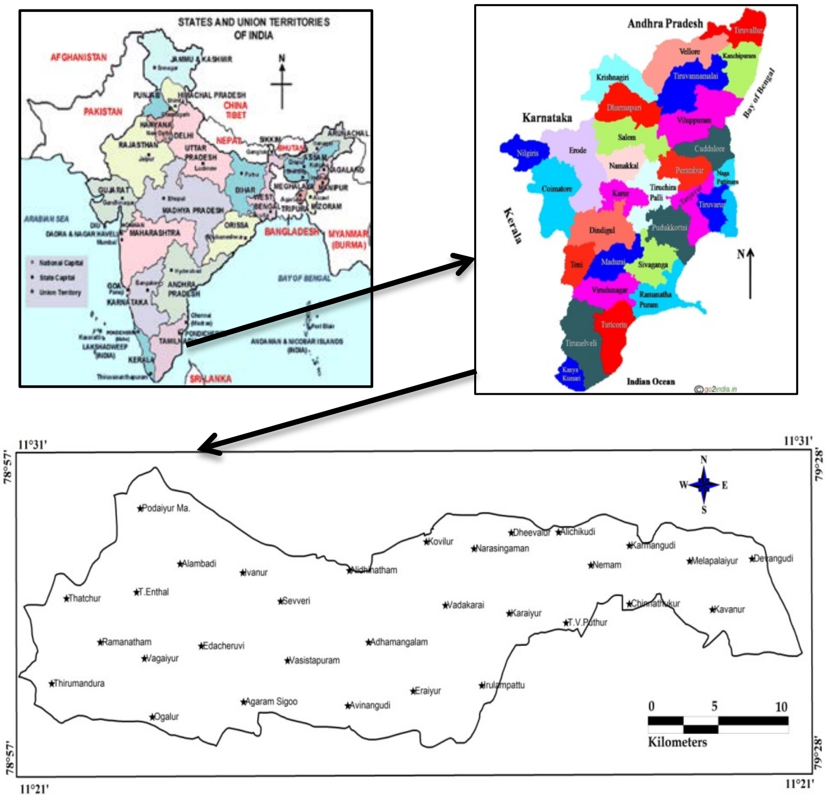

Fig: 1. Location map of the Study area

The study area considered is Wellington reservoir watershed which is located in the Tittakudi taluk (Fig 1). It lies between the longitudes of 11°21' to 11°31' E and latitudes of 78°57' to 79°28'N. The present study area occupies an aerial extent of 100 sq.km and the relief ranges from 62 m to 121 m above MSL. As of 2001 India Census, Tittagudi had a population of 20,734. In this taluk, agriculture area is 823.74 km^2. The study area receives an average rainfall of 1100 mm with more than 80% of the rainfall received during the NE monsoon. The minimum and maximum temperature ranges between 20°C and 34°C in the month of January and May respectively. River Vellar flows in the southern part of the study area. Geomorphologically the area consists of old flood plains, pediments, duricrust and pediments covered by forest land (7). Black soil is predominant soil type in this area and main occupation of the area is agriculture. The groundwater level of the study area ranges from 2m to 8m bgl (below ground level). The Wellington Reservoir is located in Vellar Basin across a tributary stream Periya Odai of Vellar River. The Reservoir was constructed during 1913-1923 and irrigates an ayacut of 11,200 Hectare. It receives regulated supply diverted from Vellar River at Tholudur regulator and an additional catchment area of 129 $(Km)^2$ of its own during North East Monsoon. Paddy, Sugarcane is the major crops grown in and around wellington ayacut.

Geology and Hydrogeology

Western pediplains of entire area (fig. 1b) covered by Mangalur and Nallur blocks. This area is occupied by denudational landforms like shallow buried pediment, deep buried pediment and pediments. Central part of the district is characterized by sedimentary high grounds, with an elevation of >80m AMSL (Above Mean Sea Level) representing Cuddalore sandstone of Tertiary age. This zone occupies part of Virudhachalam, Kammapuram, Kurinjipadi, Cuddalore and Kattumannarkoil taluks. The study area rock types (fig 1a) belong to the hard consolidated and crystalline rocks of Archaean age represent the fissured and fractured formations and occur in the western part of the district covering major part of Tittagudi and western part of Virudhachalam taluks and consists mainly of Charnockite and associated rocks of Archaean age (10). The Charnockites are intermediate to acid is in composition, coarse to medium grained and form the high land topography. In the study area groundwater occurs under water table conditions in the joints, fractures and weathered rocks. Generally, the charnockite of the study area is massive and compact and devoid of joints and fractures making it impervious, which in turn result in poor potential. The open wells give better yield than bore wells (9).

Materials And Methods

Geophysical prospecting of groundwater comes under both surface and subsurface exploration. Under geophysical prospecting, one of the electrical methods is schlumberger array of electrical resistivity method. The schlumberger array was used to ensure deep penetration and for logistics of limited man power in the field (3). Schlumberger configuration using Microprocessor based signal stacking digital resistivity meter (IGIS, Hyderabad, Model – SSR-MP-AT-S). Both the survey procedures resistivity profiling and resistivity sounding (VES) have been carried out. Resistivity profiling has been conducted in a grid pattern. The total study area of 495.3 Sq.Km. has been divided into square grids of 5.0 km and 5 resistivity profiles were conducted with a station interval of 5 Km resistivity profiling with AB/2 (10, 20, 30, 40, 50, 50, 60, 80 & 100 m) and MN/2 (2, 2, 2, 2, 2, 10, 10, 10 & 10m) have been carried out. VES has been conducted at all 30 locations with AB/2 of 100 m. The resistivity data have been qualitatively and quantitatively interpreted and analyzed by software packages.

Resistivity Method

The electrical resistivity is the resistance offered by the opposite faces of a unit cube of material to direct current is called as resistivity. In geophysical literature the unit of resistivity is taken as the ohm. m. The resistance (R) of the material having a resistivity (ρ) over a length (L) and surface area of current flow (A) is given by $R = \rho L/A$ This is governed by ohms law. The inverse of resistance is termed as conductance (8). The resistivity of the geological formation is generally very high under dry conditions and decreases in clayey rock. The presence of water containing salt even in minor amounts, geological formations makes them relatively conductive and as the moisture increases the resistivity falls deeply. As the salinity of water increases the resistivity of the rock formation decreases internally.

Measurement of Resistivity

In general for measuring the resistivity of the sub surface formation four electrodes are required. The current of electrical intensity (I) is introduced between one pair of electrodes called current electrodes which can be identified as A & B. The potential difference produced as a result of current flow is measured with help of another pair of electrodes called potential electrodes represented as M&N. Let δ^r represent the potential difference. The apparent resistivity measure is $K*D^v/I$, where K represents geometrical constant, which can be calculated if we know the electrode arrangements. The basic needs for the resistivity survey are the power source, meter to measure current and potential, electrodes and cables.

Schlumberger Configuration

In schlumberger configuration all the four electrodes are kept in a line similar to that of Wenner but the outer electrode spacing is kept large compared to inner electrode spacing usually more than five times. For each measurement only the current electrodes are moved keeping the potential electrodes at the same locations. The potential electrodes are moved only when the signal become too week to be measured. The apparent resistivity for this configuration is computed with the formula;

$$\rho = \{[(AB/2)^2 - (MN/2)^2)/MN]* \pi R\}$$

Vertical Electrical Sounding (VES)

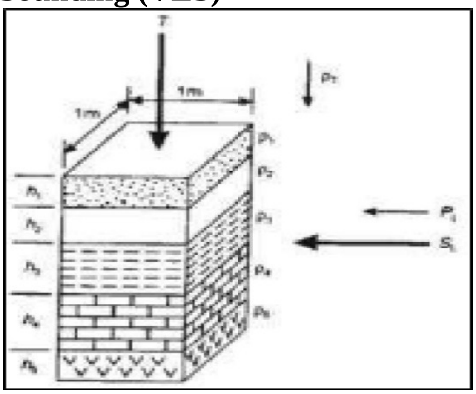

Fig.2. Columnar prism defining geoelectrical parameter

A series of measurements of resistivity are made by increasing the electrode spacing in successive steps about a fixed point. This method of vertical exploration is known as the expanding electrode method, "Resistivity sounding" or "Depth probing" or vertical electrical sounding (VES). The apparent resistivity values obtained with increasing values of electrode separation are used to estimate the thickness and resistivities of the subsurface formations. VES mainly employed in groundwater exploration to determine the disposition of the aquifers.

Geoelectrical Parameters

The main objective of the quantitative interpretation of VES curve is to obtain the geoelectrical parameters. A geoelectric layer is called by its fundamental characters, resistivity 'ρ' and thickness 'h'. These two parameters are called the primary geoelectrical parameters. The secondary geoelctrical are also important to describe the geoelectric section consisting of several layers. The longitudinal (S) and the total transverse (T), transverse resistivity (T/h) an – isotropy (λ) are called the secondary geoelectrical parameters. The (Fig.2) Shows columnar prism used in defining geoelectric parameters.

Result And Discussion

The field data were interpreted and processed qualitatively and quantitatively by using partial curve matching techniques and computer to obtain the resistivity values of different subsurface layers and their corresponding thickness (Table 1).

Interpretation of Resistivity Data

The interpretation of resistivity data is done in two stages, 1. Processing of data to get the geoelectric parameters in s of apparent resistivities, depth/thickness and 2. These parameters are used to infer the nature of surface lithology on the basis of the local geological knowledge and correlation studies.

Quantitative Approach

The quantitative approach is to get the geoelectric parameters i.e., the true resistivity, layer thickness/ depth etc. The VES data of the study area have been qualitatively and quantitatively analyzed and interpreted using software MapInfo 8.5 and IPI2 WIN version 3.1.0, a Russian software package of Moscow University. By using Surfer, resistivity contour maps have been generated for different depth ranges to identify and demarcate the anomaly zones. The IPI2 WIN software (8) is used to prepare the VES curves, Pseudo sections, Geoelectric profiles and Geoelectric sections. The 5 nos. of Pseudo sections along 5 profiles (Fig 7 - 11) in different directions and have prepared by considering geoelectrical parameters for all the 30 VES curves.

Table 1: Summary of VES data interpretations with positions

VES No	1st Layer Resistivity ρ1 (Ohm meter)	2nd Layer Resistivity ρ2 (Ohm meter)	3rd Layer Resistivity ρ3 (Ohm meter)	h1 (meter)	h2 (meter)	Error %	Fig No
1	4.204	47.82	2076	5.469	32.72	0.67	3
2	7.59	6006	6.79	4.2	2.87	9.41	3
3	19.4	90.9	250	6	11.3	2.31	3
4	26.9	943.1	75.66	6	47.08	0.864	3
5	15.4	3242	215	5.13	1.8	4.85	3
6	11.41	38.93	729.9	6	11.32	1.88	3
7	74.3	202.6	-	10.54	-	1.29	3a
8	63.04	119.4	591.2	6	44.1	0.89	3a
9	6.28	277	-	4.04	-	3.05	3a
10	7.49	82.2	668	3.67	97.1	3.66	3a
11	6.676	60.86	516.1	6	44.37	1.08	3a
12	60.5	12.4	0.271	16.9	43.5	5.25	3a
13	3.87	4.74	6.65	6	44.1	2.86	3b
14	1.545	4.906	12.7	6	11.32	0.796	3b
15	5.49	6.73	13.7	6	44	2.07	3b
16	4.401	8.941	3.727	6	11.32	0.76	3b
17	4.125	104.2	1125	6	45.23	1.41	3b
18	3.945	13.18	202	6	11.32	0.617	3b
19	14.3	66	88.1	6	11.3	2.3	3c
20	46.6	488.3	833.7	6	11.32	1.41	3c
21	2.414	17.74	6.07	6	11.32	1.05	3c
22	17.8	102	8.24	3.61	6.57	2.11	3c
23	3.123	40.08	8.713	5.168	3.992	0.98	3c
24	1.98	18.8	10.41	17.32	32.68	1.57	3c
25	29.1	33.4	94.6	6	44	1.58	3d
26	282	8.24	23.4	3.49	6.36	4.89	3d
27	2.876	4.403	28.16	5.878	7.462	0.437	3d
28	4.236	5.529	17.11	6	11.32	1.59	3d
29	11.9	518	3.27	6	11.3	2.08	3d
30	3.8	7.03	134	3.21	13.5	5.66	3d

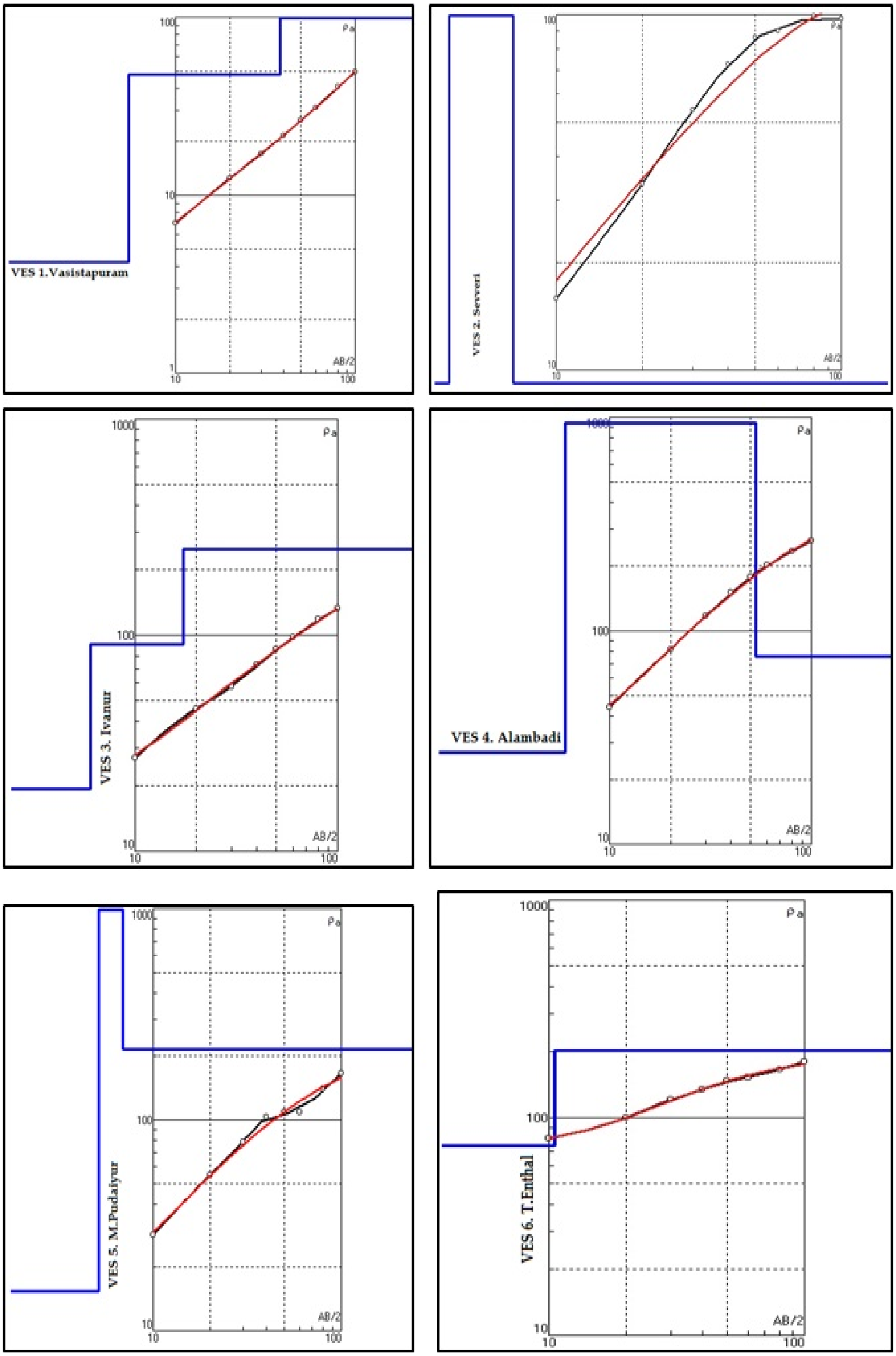

Figure: 3. Interpretations of Vertical Electrical Sounding Field Curves

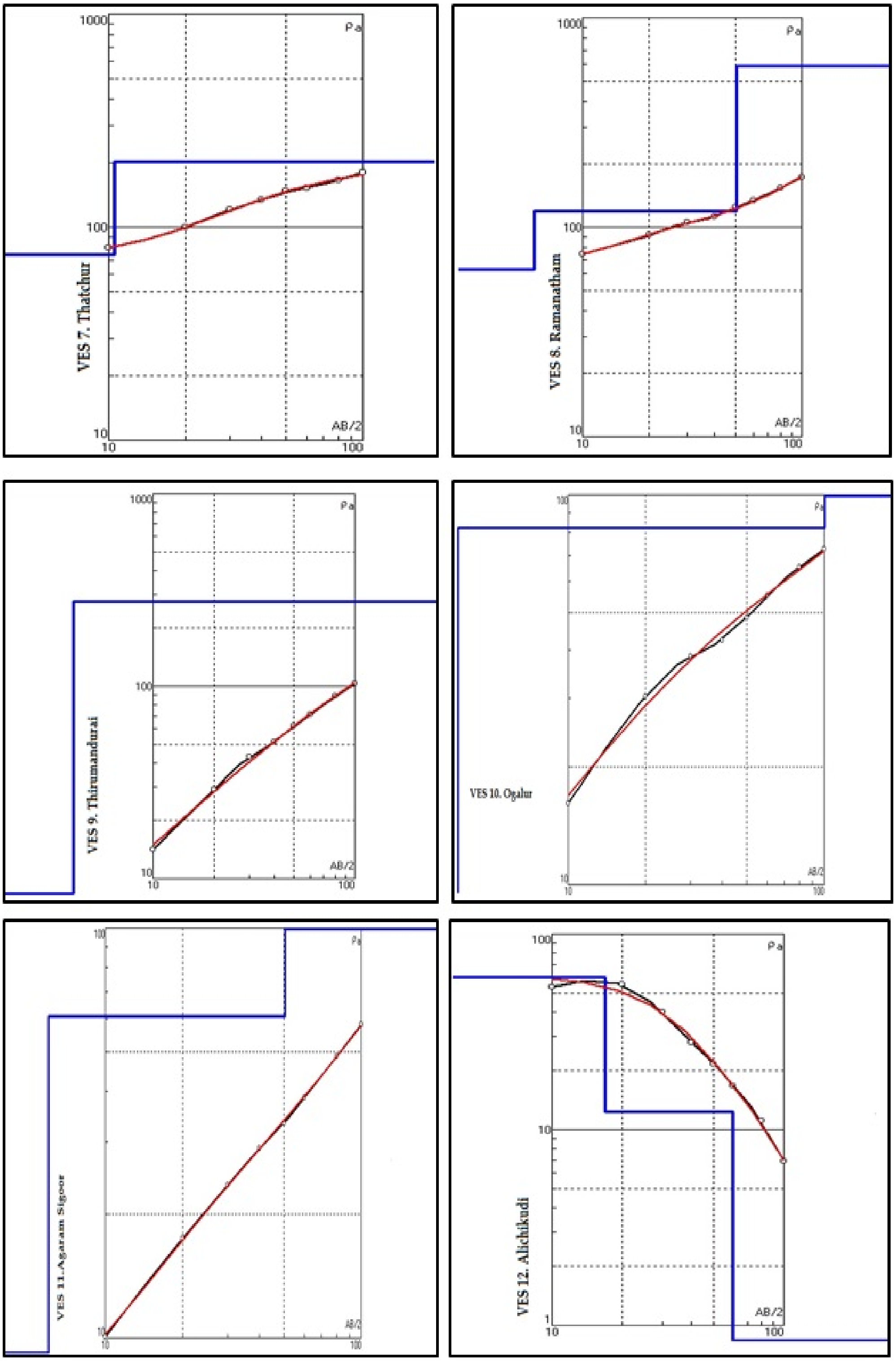

Figure: 3a. Interpretations of Vertical Electrical Sounding Field Curves

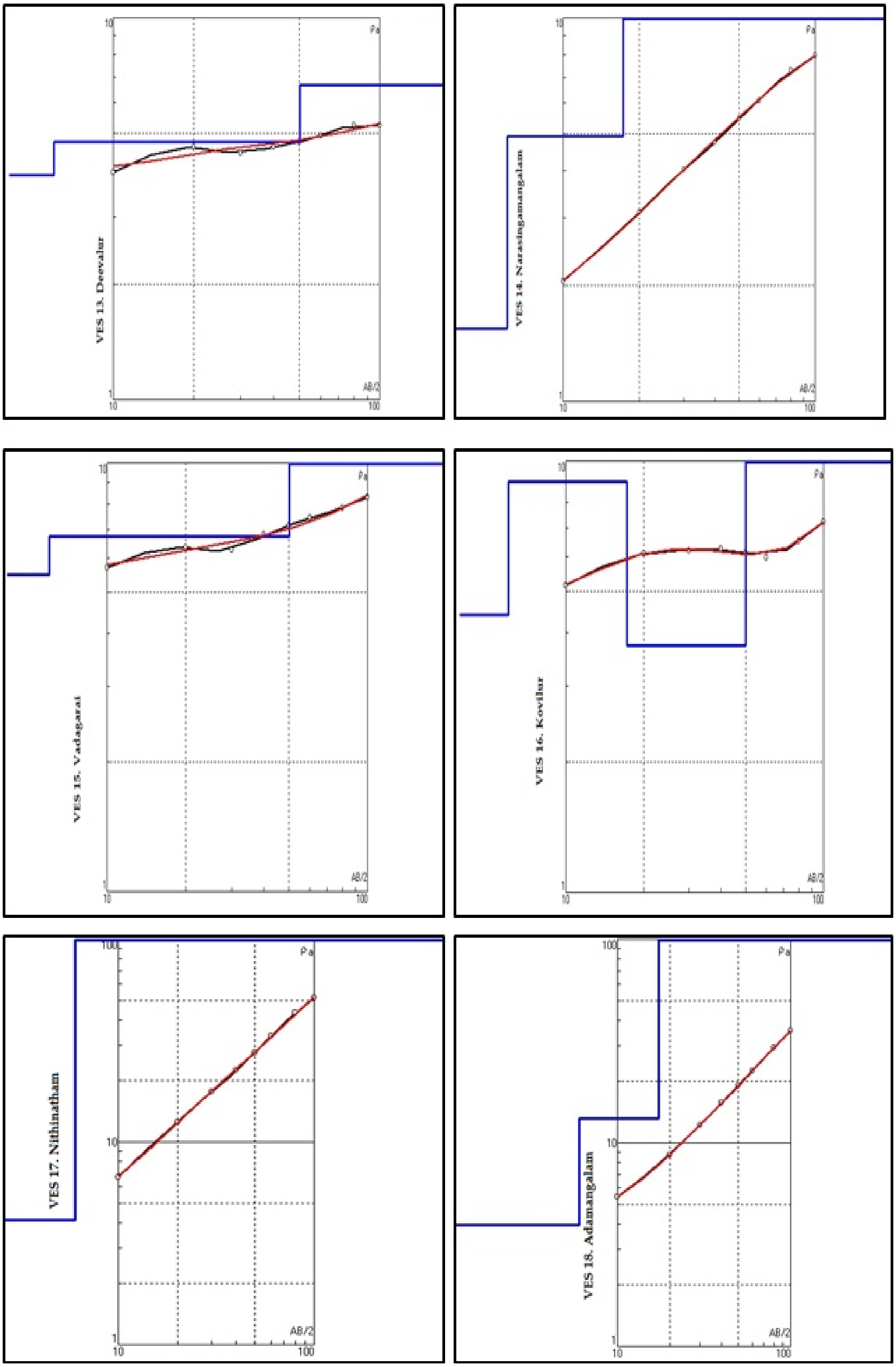

Figure: 3b. Interpretations of Vertical Electrical Sounding Field Curves

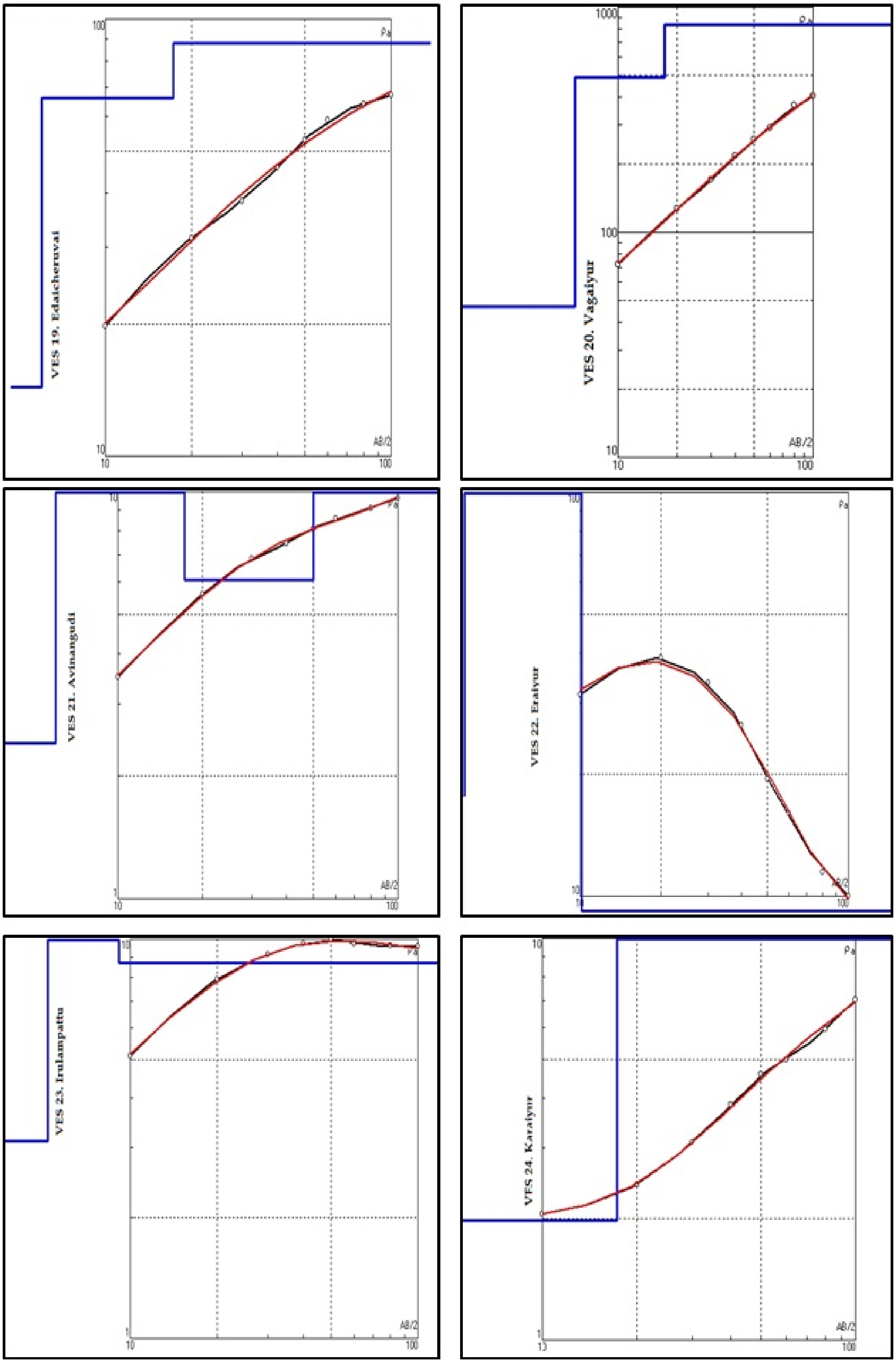

Figure: 3c. Interpretations of Vertical Electrical Sounding Field Curves

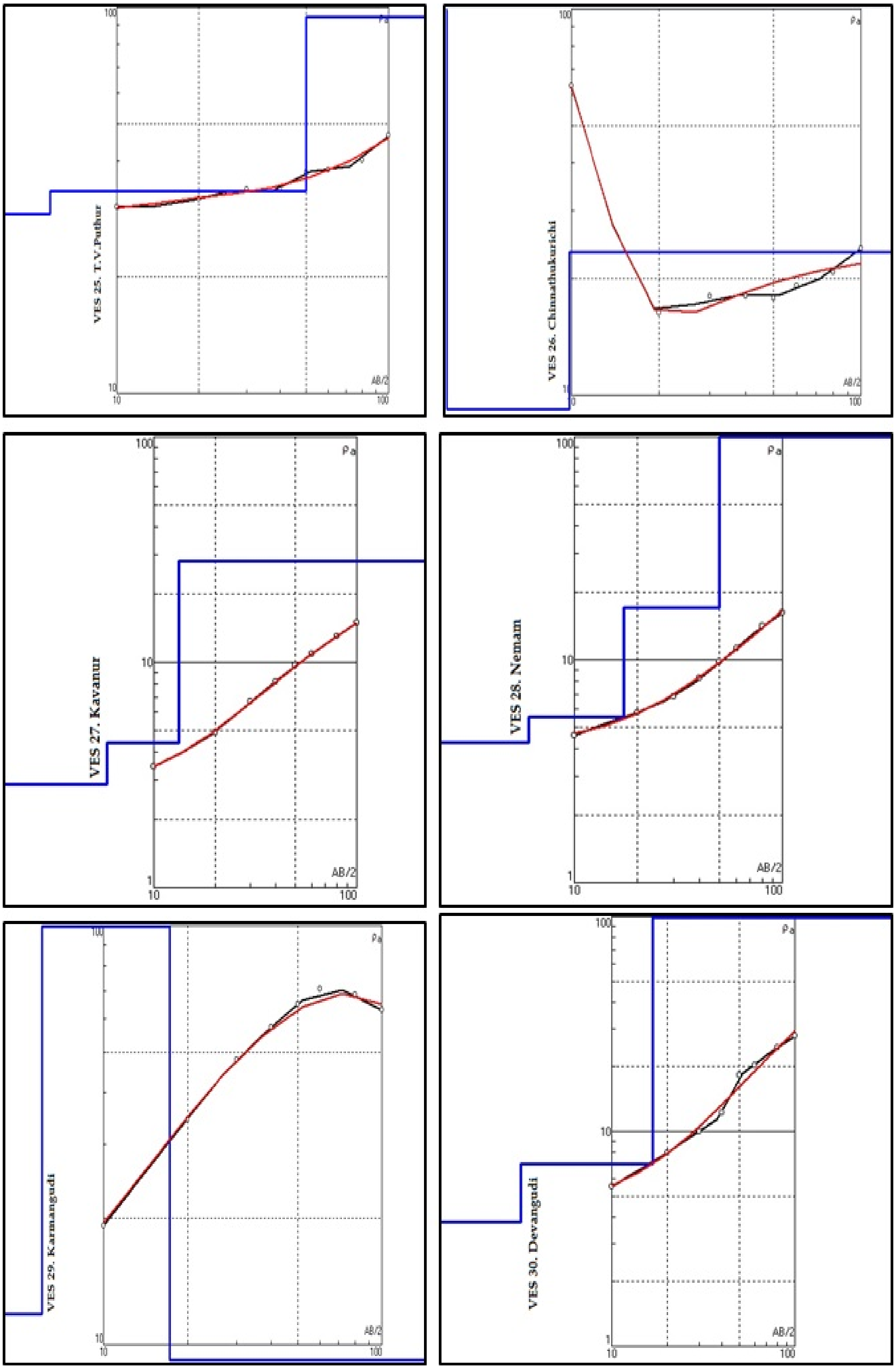

Figure: 3d. Interpretations of Vertical Electrical Sounding Field Curves

Table 2: Qualitative analysis of curve types where ρ represents resistivity of the layer

VES	Curve type	Curve Characteristics	No. of Geo-electric Layer
VES 9, 10, 11, 21, 22, 23	AK	$\rho1 < \rho2 < \rho3 > \rho4$	4
VES 8, 20, 19, 1, 25	A	$\rho1 < \rho2 < \rho3$	3
VES 7, 6, 3, 18, 15, 24,	K	$\rho1 < \rho2 > \rho3$	3
VES 5, 4, 2, 17, 14, 28, 1,	A	$\rho1 < \rho2 < \rho3$	3
VES 16, 13, 12, 29	KH	$\rho1 < \rho2 > \rho3 < \rho4$	4

Isoresistivity Maps

The Iso resistivity maps are the resistivity contour maps and Iso is a Greek word meaning ‘equal’ and contours are imaginary lines on map connecting equal value. The values may be of any parameter, like elevation, TDS, layer thickness and so on. Accordingly the layer thickness contour maps of the study area have been generated incorporating all the 30 VES data for different formation with their co-ordinates, joining equal layer thickness of the depth of investigation. The layer thickness contour map for first layer, second layer, third layer were prepared (Fig: 4, 5, 6). The difference between two consecutive contour lines is termed the contour interval. The contour maps can be generated using MapInfo 8.5 software packages. The Iso resistivity maps can be used for qualitative interpretation of the groundwater and by quantity by demarcating the low and high layer thickness anomalous zones. This also further helps to delineate the granular and clayey zones in weathered, fractured and massive rock zones in crystalline terrains. The method of Qualitative and Quantitative interpretations helps us identify good ground water potential zones. There are different curve types inferred during the geophysical interpretations. The general trend of the aquifer is expected to be K where in the resistivity values keep on decreasing with depth or decreases in the deeper aquifer. Where the first layer has low resistivity values than the under laying layers. All these locations with A & K type curve (14), (15).

Geoelectircal Profiles

All the 30 VES locations studied were made into 5 profiles covering the entire study area (Fig 7, 8, 9, 10 and 11) with definite orientations, traversing different geological formations to project a two dimensional subsurface geoelectric section along that profile. All these geoelectric profiles have been generated by IPI2 WIN software package. The geoelectric profiles are nothing but the geoelectrical section of each VES locations united into one profile with a definite directional orientation. Each geoelectric profile has two profiles namely Pseudo section displaying the apparent resistivities at different depths below ground level from surface to 100 m depth and the other section with thickness of different geoelectric layers below ground level. The resistivity sections only reflect the interpreted subsurface lithology. The ordinate ‘X axis’ represent the distance of traverse and the abscissa ‘Y axis’ represent the depth in meters below ground level.

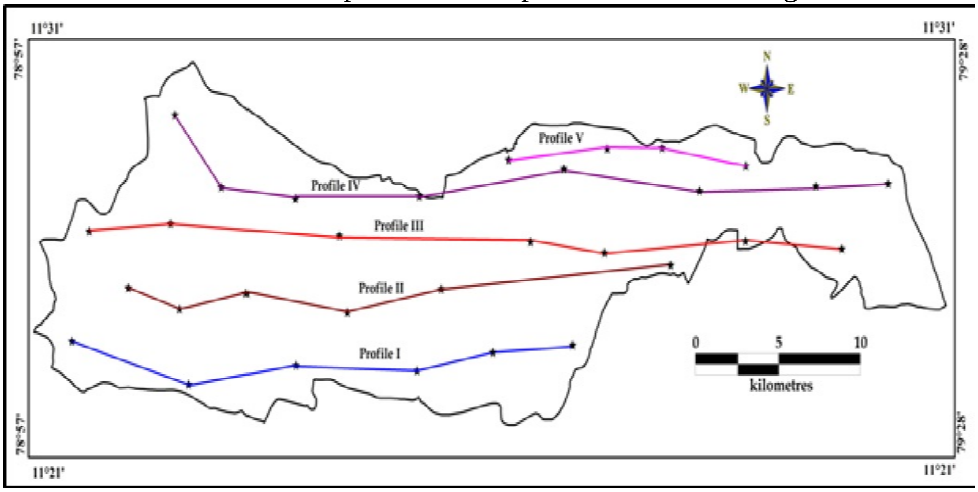

Fig: 3e. VES profile map of the Study area

Profile -I

The profile I located in southern bank of upstream side of Vellar River. The river flows from the west to eastern parts of the study area. The location considered in this profile Thirumandurai, Ogalur, Agaram Sigoor, Avinangudi and Eraiyur are the upstream side and Irulampattu in downstream side of the study area. The traverse of the profile is from west to eastern part of the study area (fig.7).

Profile -II

The profile II located in north bank of upstream side of Vellar River. The location of this profile include Ramanatham, Vagaiyur, Edaicheruvai and Vasistapuram are on the upstream side and T.V.Puthur on the downstream side of the study area. The traverse of the profile is west to eastern part of the study area (fig.8).

Profile -III

The profile III located in middle side of the Wellington reservoir and north side of Vellar River. The location considered for this profile are Thatchur, Enthal, Ivanur, Adamangalam on upper reaches of Wellington reservoir and Vadagarai, Karaiyur, Chinnathukurichi and Kavanur on the of the Wellington reservoir. The traverse of the profile is west to eastern side of the study area (fig.9).

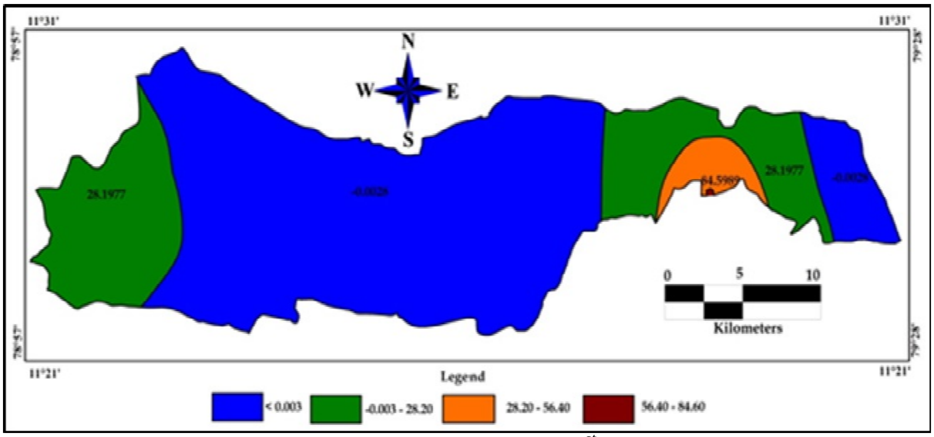

Fig: 4. Isoresistivity map of 1st Layer

Pseudo Section with Resistivity Section

The central part of the profile figure exhibits low resistivity clay from the central part to eastern sides. Since the profile is along the river course, the low resistivity anomalies may be due to the presence of alluvium, clay and weathered bed rock (11). The higher resistivity [30 to 140 Ωm] may be due to the presence of sand or massive.

The minimum and maximum apparent resistivity is 4Ωm and 140Ωm (Fig 7 - 11) and all the VES are multilayered geoelectrical sections. The minimum and maximum numbers of layers are 3 and 4. The central portion of the profile shows the least resistivity in the range of 2.87 Ωm to 23.5 Ωm, indicating highly conducting formations like clay, clayey sands or formations with high conductive water. Based on the geological, hydrogeological and geoelectrical investigations, the entire profile is a hard rock formations (consolidated) represented by minor lithological units of alluvium, clay, sand which are resulted by weathering and gneiss with good ground water potential.

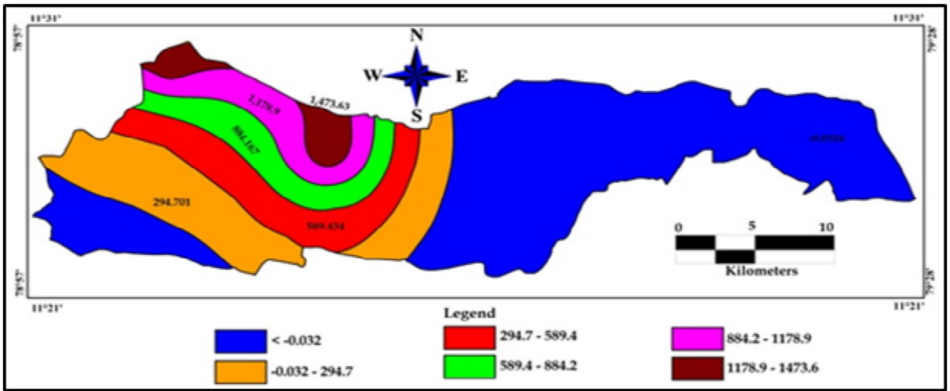

Fig: 5. Isoresistivity map of 2nd Layer

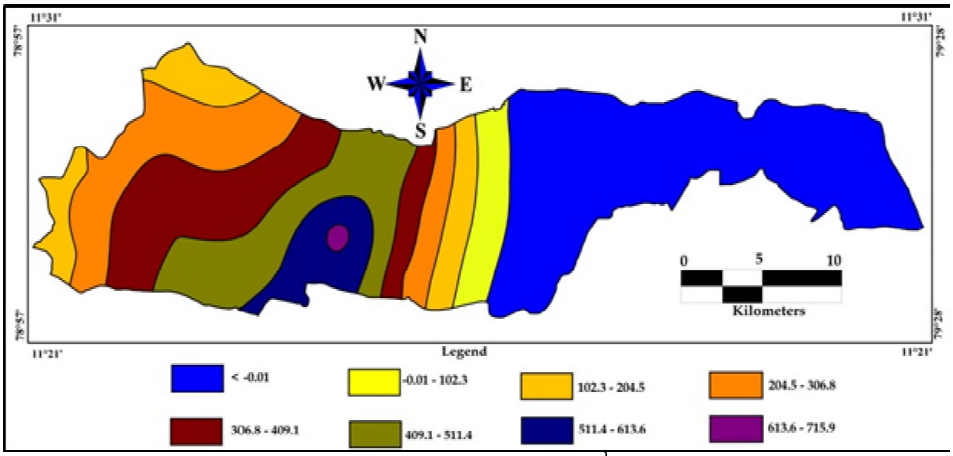

Fig: 6. Isoresistivity map of 3rd Layer

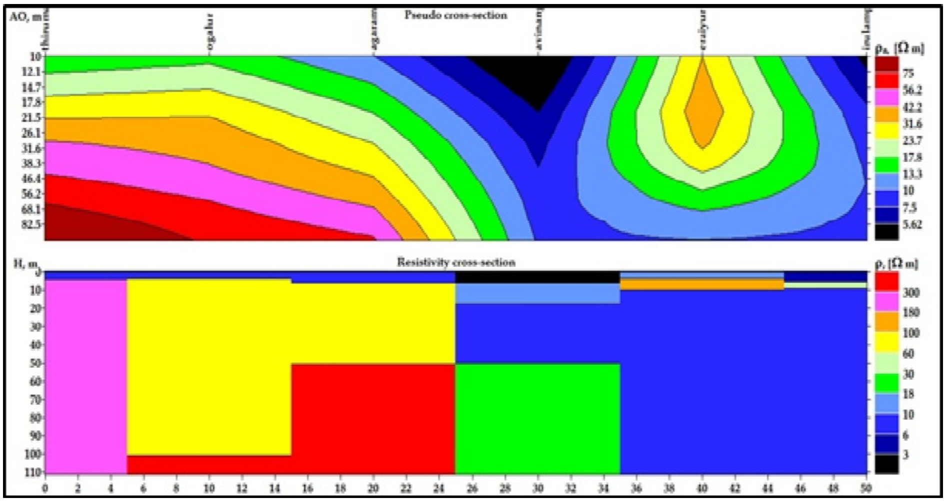

Figure 7: Resistivity pseudo section and 2D inverse model (Profile 1)

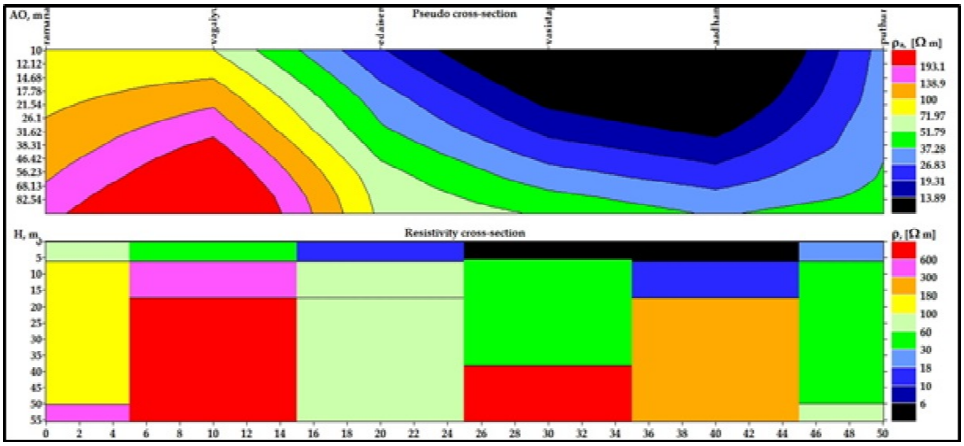

Figure 8: Resistivity pseudo section and 2D inverse model (Profile 2)

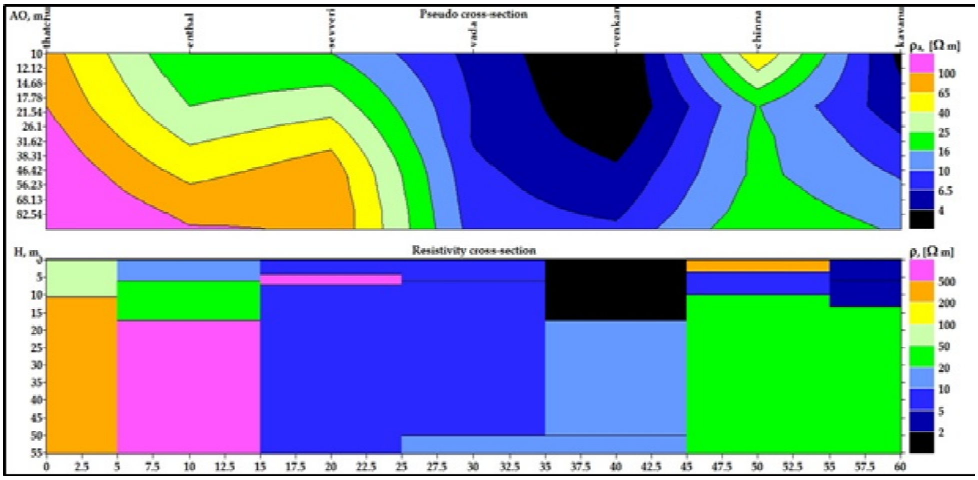

Figure 9: Resistivity pseudo section and 2D inverse model (Profile 3)

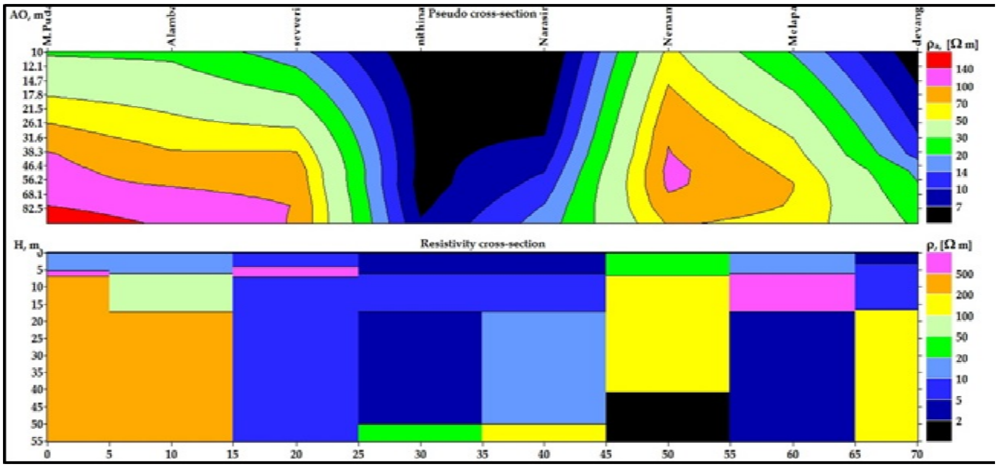

Figure 10: Resistivity pseudo section and 2D inverse model (Profile 4)

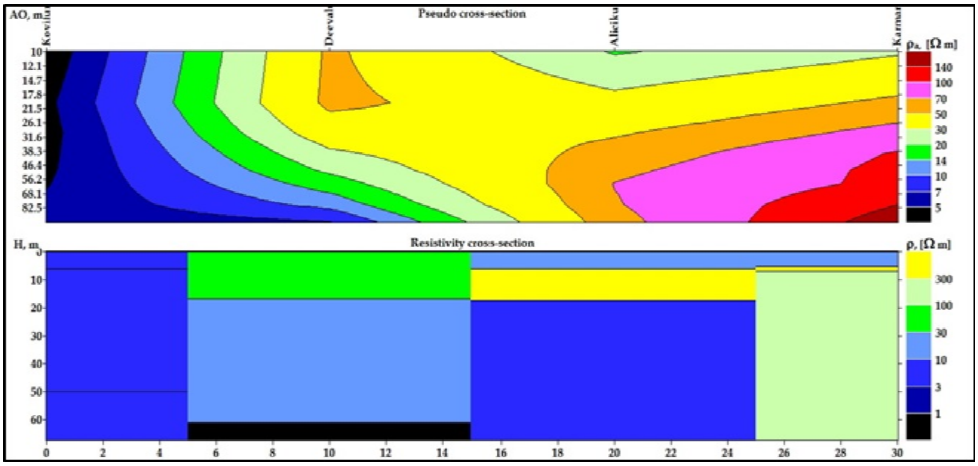

Figure 11: Resistivity pseudo section and 2D inverse model (Profile 5)

Profile -IV

The profile IV located in north side of the Wellington reservoir and north side of Vellar River. The elevations of this profile include Ma.Pudaiyur, Alambadi and Nithinatham on upper side of the Wellington reservoir and Narasingamangalam, Nemam, Melapalaiyur and Devangudi on the lower side of the Wellington reservoir. The traverse of the profile is west to eastern side of the study area (fig 10).

Profile –V

The profile V located in north side of the Wellington reservoir and north side of Vellar River. The location in the profile are Kovilur, Alichigudi and Karmangudi. The traverse of the profile is west to eastern side of the study area (fig 11).

Table: 3. Assigned features for the groundwater potential zoning.

Sl.No	VES ID	Groundwater potential zone
1	21, 22, 25, 27, 28, 29, 30.	Very good
2	11, 17, 23, 24.	Good
3	1, 12, 14, 15, 16, 18, 26.	Moderate
4	2, 3, 4, 5, 6, 7, 8, 9, 10, 13, 15, 19, 20.	Poor

Conclusion

Vertical Electrical Sounding using Schlumberger electrode configuration was conducted in and around Wellington reservoir to determine the underground water potential and the lithological setting in terms of aquifer distribution. The study has shown that the region is underlain by 3 to 4 geoelectric layers within the depth penetrated. The groundwater potential of in and around Wellington reservoir (Table 3) reveals four distinct classes (zones) representing ‘Very good’, ‘good’, ‘moderate’ and ‘poor’ groundwater potential in the area. The Very good groundwater potential zone mainly encompasses good be recharged along the River alluvium. The good groundwater potential zone mainly covered by regions with groundwater in joints & some quantity of ground water will be recharged held in the weathered zone subsequently fractured planes. It’s also identified that Groundwater occurs under water table conditions the depth of water table ranges from 10 to 13 m. Groundwater recharge takes place through precipitation of rain water aided by morphological features of ground surface around the major river systems. It’s also demarcate that the areas in the upper part of the study area is not suitable for groundwater storage and also indicates the deep availability of water very below the ground. The poor groundwater potential is due to the higher slope and unfavorable geology and geomorphology in this zone. These prospective groundwater zones can provide a basis for the detailed hydrogeologic and/or geophysical investigations needed for well sitting and proper management of scarce groundwater resources.

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