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Geophysical Techniques for Aquifer Characteristic Studies - A Case Study of Tavanur Grama Panchayat, Malappuram, Kerala

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A study on the aquifer characteristics of Tavanur Grama Panchayat, Malappuram, Keralawas conducted across 23 VES locations by vertical electrical sounding technique. The study aimed to analyse the hydro-geological characteristics of the geological formations of Tavanur Panchayat using an electrical resistivity meter. The data obtained from the vertical electrical sounding was interpreted using IPI2WIN software andsounding curves were generated which depict how the apparent resistivity changes with the distance between electrodes or with depth. From the sounding curves obtained from IPI2WIN software, it was found that among 23 locations, seventeen locations showed three layered substrata and four locations showed four layered substrata. A total of 7 types of sounding curves were obtained viz H, K, A, Q, HA, HK and QH.Out of the 23 locations, 8 locations showed the H type and 3 locations showed A type sounding curves. The resistivity and pseudo cross sections of 6 sections including 3 to 7 VES locations were also prepared and analysed. From this study, it could be concluded that the majority of the study area has lateritic soil to hard laterite with medium to high groundwater potential and the areas were found suitable for the construction of open wells.

(***Key words:*** *Aquifer, Electrical resistivity survey, IPI2WIN software,Vertical electrical sounding*)

Geophysical surveys yield dependable delineations of groundwater potential zones through the integration of surface and subsurface data pertaining to hydrogeological characteristics (Sainato *et al.,* 2003). The electrical resistivity method is a commonly used geophysical method for groundwater exploration throughout the world (El-Qady and Ushijima 2001; Loke *et al.,* 2014).This method helps address various hydrogeological challenges viz., assessing the spatial extent of aquifers (Greggio *et al.,* 2018), determining the hydraulic parameters of aquifers (De Clercq *et al.,* 2020), monitoring seawater intrusions into coastal aquifers (Niculescu and Andrei, 2021), etc. The convenience in field application, ability to provide information on the subsurface strata ranging from a few meters to several hundred meters and software interpretation of data in both 2D and 3D formats are considered the major advantages of this method.

Profiling and vertical electrical sounding are the most extensively utilized electrical resistivity approaches for assessing aquifer systems globally (Nagaraj *et al.,* 2021).

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The vertical electrical sounding (VES) technique, due to its simple implementation and cost-effectiveness in comparison to alternative methods, has shown substantial effectiveness in mapping aquifer systems, delineating geological layers and identifying structural anomalies indicative of faults and fractures (Hamzah *et al.,* 2007). The VESis a depth-sounding galvanic method and has proved very useful in groundwater studies due to the simplicity and reliability of the method. The electrical resistivity data can be interpreted to calculate the accurate depths and resistivities for each VES curve using computerized methods (IPI2win-1D Program, 2000).

The major sources of groundwater in Malappuram, a northern district in the state of Kerala, are open wells and bore wells. Tavanur panchayat in Malappuram district is located on the southern bank of Bharathapuzha. According to a report by the Central Ground Water Board (CGWB), the groundwater level in Tavanur Panchayat is generally in the range of 2 to 8 meters below ground level. Tavanur Panchayat may experience changes in water demand due to population growth, changes in land use, or other factors. Therefore, it is necessary to study the characteristics of the geological formations in the study area for assessing the groundwater potential zones in the area.

The present study aimed to analyse the hydrogeological characteristics of the geological formations of Tavanur Panchayat using an electrical resistivity meter and to prepare the resistivity and pseudo-cross-section of the aquifer formation using IPI2Win software.

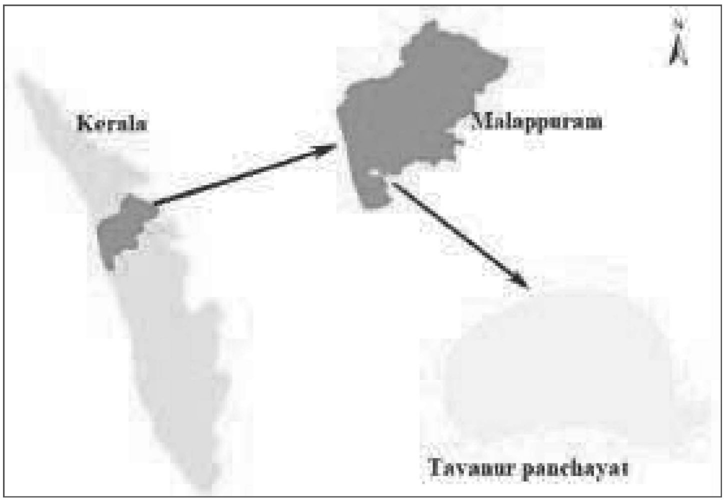

Fig.1. *Location map of the study area*

MATERIALS AND METHODS

Study area

The study area accommodating an aerial extent of 42.37 km2 lies between 10°51′47″ to 10°49′40″ N latitudes and 75°57′39″ to 76°01′25″ E longitudes. The location map of the study area is shown in Fig.1. The mean maximum and minimum temperatures of the area range from 28.9 to 36.2°C and 17.0 to 23.4°C, respectively. The average relative humidity of the area ranges from 84 to 94% during morning hours. Tavanur receives an average annual rainfall of 2200 mm.

Electrical Resistivity Meter

An electrical resistivity meter is a geophysical tool used to investigate the subsurface properties of the earth. It works by measuring the electrical resistivity of the ground, whichcan provide information about the distribution of water, minerals, and other subsurfacefeatures.The basic components of an electrical resistivity meter for groundwater exploration include:

Current source

Batteries are commonly used as the power source for current in shallow surveys. The current used is either direct current, commutated direct current (i.e., a square-wave alternating current), or AC of low frequency (typically about 20 Hz). In survey data analysis, the usual assumption revolves around employing direct current (DC), yet in real-world applications, it's common to utilize a low-frequency square-wave alternating current (AC).

Electrodes

The electrodes are the part of the device that comes in contact with the ground and conducts the electric current to the soil. There are typically four electrodes, two for passing the current into the ground and two for measuring the voltage difference.

Data acquisition unit

The data acquisition unit is responsible for recording thevoltage measurements from the electrodes and storing the data for later analysis. Itmay also include signal processing and filtering units to remove noise and interference.

Display unit

The display unit is used to visualize the resistivity data. It may include software for data analysisand interpretation.

Cables

The cables are used to connect the electrodes, current source and dataacquisition unit. They are typically shielded to minimize interference fromexternal electrical sources.

Calibration of electrical resistivity meter

Fig.2. *Calibration of electrical resistivity meter*

The Test Resistance Box was used to calibrate the resistivity meter(MODEL-SSR-MP-ATS). It has two rows, the first row has 0.1 and 0.4 Ohms and the second row has 1 and 4 Ohms. To test the low values of resistance, connect the current terminals to the C1& C2 ports of the top row and connect the potential terminals across 0.1 or 0.4 Ohms. The measured value of resistance should tally within 1%. To check the second row of resistance, connect the current terminals to the C1 & C2 ports of the second row and connect the potential terminals across 1 or 4 Ohms and the measurements are taken. Fig.2. shows the calibration procedure of the electrical resistivity meter.

Methodology

The study was conducted in April-May, 2023. The map of the study area was downloaded from Google Earth as a KML file and created the grid map (1000 x 1000 m) using ArcGIS 10.7. The grid map was then exported to GoogleEarth for marking the locations in the real field to check the possibility of conducting the VES survey. Further 24 possible sites were located (Fig.3) and a reconnaissance survey was conducted to find the suitability of the selected locations.

The vertical electrical sounding method was carried out to analyse the groundwater potentiality of different locations in the study area using Resistivity Meter (MODEL-SSR-MP-ATS). Wennerelectrode configuration was used to determine the resistivity of the underground substrata.The current electrode spacing (AB) ranged from 6 m to 120 m (AB/2 = 3 to 60 m) andpotential electrode spacing (MN) ranged from 2 to 40 m (MN/2-1 to 20 m) was selected for the study. At each VES station, electrodes were placed in a straight line and the inter-electrode spreads were gradually increased about a fixed centre. The current was passed into the ground and the potential difference (V) due to this current was measured and recorded against the electrode spacing. As the electrode spacing increases, the penetration of current also increases. The penetration of current below the surface is proportional to half of

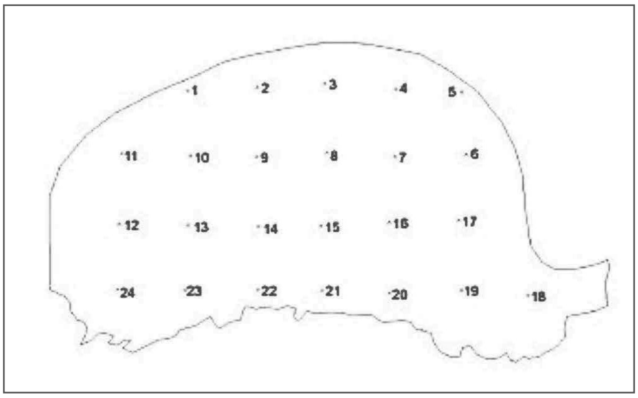

Fig.3. *VES locations in the study area*

the distance between two current electrodes. With the available values of the current and potential difference of the electrode configuration adopted, one can get the apparent resistivity (ρ). A decrease in the resistivity value indicates the presence of fractures, joints, water content etc. in the formation.

RESuLTS AND DISCuSSION

The vertical electrical sounding (VES) was carried out at different spacings using the Wenner arrangement of electrodes. The depth of investigation varies based on the electrode spacing, and the current study considered a maximum depth of 30 meters from the ground surface.The field data collected from the VES survey were interpreted using IP12WIN software to obtain the resistivity values of different subsurface layers and the thickness of each layer which are tabulated in Table 1.

Interpretation of VES data

The field data obtained from the electrical resistivity meter are represented as sounding curves using IPI2WIN software. The software gives an output thatdisplays the resistivity, thickness and depth of different soil layers from the ground surface (Shishaye and Abdi, 2016). The graphical representations of apparent resistivity versus electrode spacing or depth are referred to as the sounding curves. These curves depict how the apparent resistivity changes with the distance between electrodes or with depth.The simplest soundingcurves are ascending and descending types of curves with two-layered cases. If the ground has a two-layered structure, with loose topsoil or a weathered and compact basement, the curve will beascending type. A descending curve is created if the top layer is highly resistive and the bottomlayer is conductive due to saline water or some other saturated conditions (Brijesh andBalasubramanian, 2014).

By the interpretation of sounding curves, 2 to 4 subsurface layers were identified within the study area with the sounding curves H, K, A, Q, HA, HK and QH. The H, K, A and Q sounding curvesrepresenta three-layered substratum, while the combination curves HK, QH and HA represent four-layered substrata. Out of the 23 locations of the VES survey, one location showed two-layered substrata, seventeen locations showed three-layered substrata and four locations showed four-layered substrata.

A resistivity range of 0 to 15 Ωm indicates the presence of clay, while 15 to 25 Ωm indicates the presence of weathered stone, and 25 to 35 Ωm points to semi-weathered to fractured stone (Sudhakar *et al.,* 2018). The range of resistivity extending from 35 to 120 Ωm is indicative of fractured rock, and resistivities exceeding 150 Ωm are associated with the hard bedrock.

H type curve

The sounding curves from Kuzhunjodi (G4), Muvankara (G9), Muradavilpadi (G10), Kakkasserykunnu (G11), Tavanur Central jail (G17), MES college (G18), Kadanchery (G22) and Mathoorpalli (G24) showed 'H' type curve having three-layered substrata ($\rho 1>\rho 2<\rho 3$)with the middle layer having the lower resistivity. The locations G4, G11 and G22 showed the same soil formation. The first and third layers of all three locations were found to have resistivity ranging from 33.8 to 80.3 Ωm which indicated that the soil

Table 1. *Resistivity and thickness of the various layers of substrata*

Grid point	Locations	ρ1 (Ωm)	ρ2 (Ωm)	ρ3 (Ωm)	ρ4 (Ωm)	h1 (m)	h2 (m)	h3 (m)	Depth to bedrock (m)
G1	Coconut orchard near Nila (KCAET)	188.00	10.50	162.00	5030.00	1.00	3.04	12.30	16.30
G2	Coconut orchard near lab (KCAET)	2258.00	1139.00	-	-	2.68	-	-	2.68
G3	Nambram	21.40	402.00	0.46	-	3.63	5.07	-	8.70
G4	Kuzhunjodi	42.50	8.02	56.00	-	2.57	1.21	-	3.78
G6	Madirassery	124.00	15.20	10.80	2571.00	1.00	3.66	17.10	21.80
G7	Vellanchery	175.00	84.70	23.70	-	1.00	1.62	-	2.62
G8	Kadakassery	1076.00	535.00	104.00	-	3.66	7.93	-	11.60
G9	Muvankara	13.30	7.61	348.00	-	1.00	3.36	-	4.36
G10	Muradavil-padi	182.00	8.88	1785.00	-	1.87	8.69	-	10.60
G11	Kak-kasserykunnu	33.80	5.41	80.30	-	2.02	2.24	-	4.26
G12	Nadet	354.00	26.50	60.80	0.72	1.00	3.52	15.90	20.40
G13	Athaloor	17.70	57.00	140.00	-	1.00	23.60	-	24.60
G14	Anthyalam-kulam	95.10	48.90	21.70	65.90	1.00	3.95	19.50	24.50
G15	Kallur	102.00	200.00	1178.00	-	4.52	15.90	-	20.40
G16	Ayankalam	241.00	614.00	1474.00	-	4.52	15.90	-	20.40
G17	Tavanur Cen-tral jail	1269.00	48.20	15500.00	-	6.87	8.63	-	15.50
G18	MES college	679.00	34.10	402.00	-	1.00	0.80	-	1.80
G19	Pattaparambu	395.00	1644.00	169.00	-	1.00	1.70	-	2.70
G20	Kachery-parambu	755.00	7692.00	4.60	-	1.02	3.78	-	4.80
G22	Kadanchery	58.60	18.50	54.20	-	4.36	13.80	-	18.20
G23	Athaloor	43.60	44.70	18.00	-	1.00	3.48	-	4.48
G24	Mathoorpalli	64.70	30.10	142.00	-	1.00	14.00	-	15.00

formation is lateritic. The second layer had resistivity ranging from 5.41 to 18.5 Ωm indicating the presence of lateritic clay or clayey formation. The sounding curves for the locations G4, G11 and G22 are shown in Fig.4.

The sounding curve for the first layer of the locations G17 and G18 showed resistivities of 679 and 1269 Ωm respectively, which indicated the presence of hard laterite and the second layer had resistivities of 48.2 and 34.1 Ωm respectively, which indicated the presence of lateritic soil or loose soil. The sounding curve of location G17 depicted a third layer witha resistivity of 15500 Ωm, which indicated the presence of hard rock

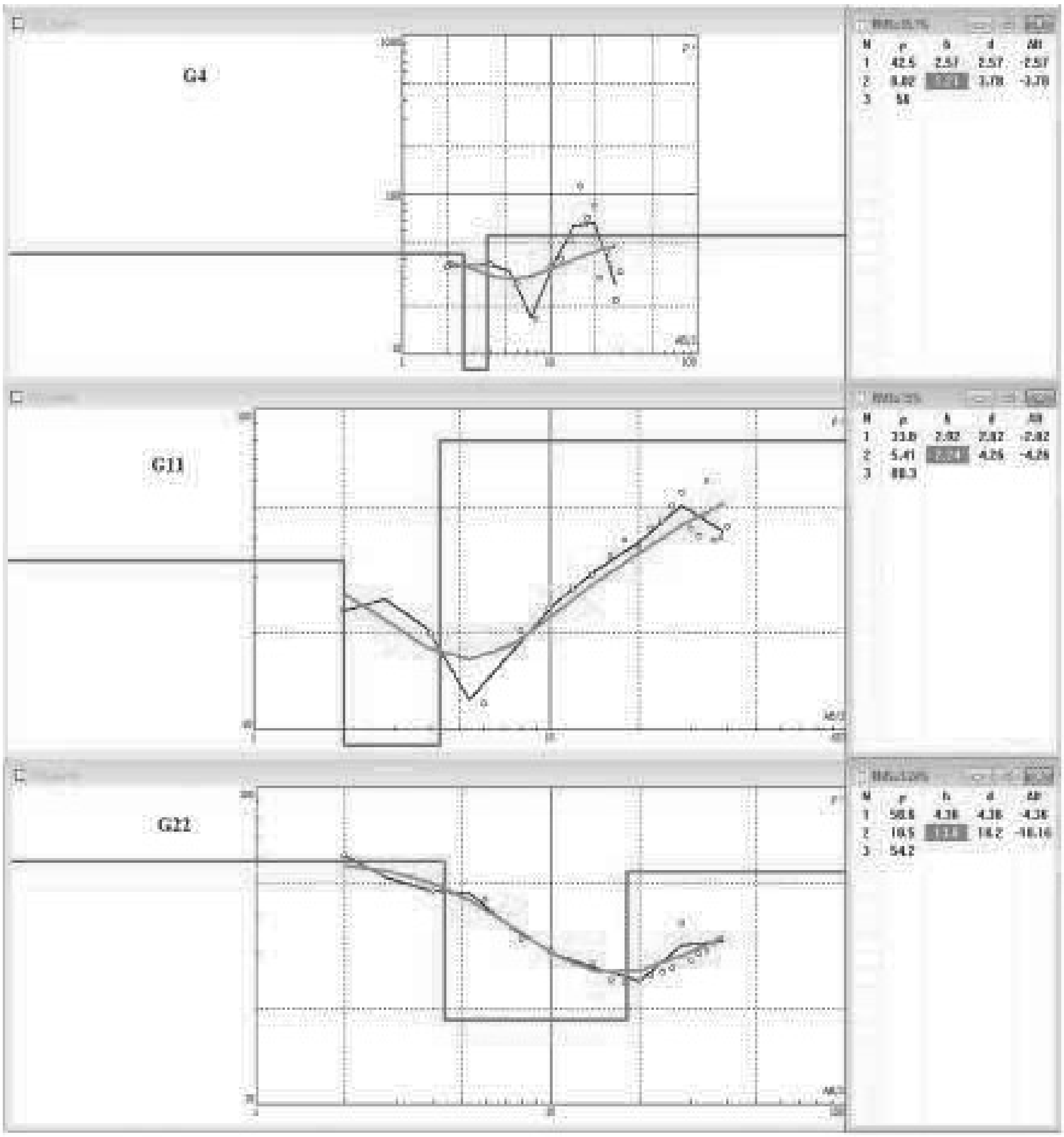

Fig.4. *Sounding curves of the location G4, G11and G22 (H-Type)*

(Metamorphic/Gneiss). This was the location near the Central Jail, Tavanur. The sounding curve of the location G18 had a third layer of hard laterite formation or weathered rock with a resistivity of 482 Ωm. Fig.5. shows the sounding curves for the locations G17, G18 and G10.

The sounding curve data of the location G10 indicated the presence of a thin layer of top soil for a depth of 1.87 m followed by lateritic clay of thickness 8.69 m along with a bottom layer of hard lateritic rock formation.The sounding curve of the site G24 (Fig. 6) showed low resistivity ranges which indicated the presence of lateritic soil or loose soil.

The sounding curve for the location G9 (Fig.7a) was found to have low resistivity in the top layer which indicated the presence of clay loam formation. The

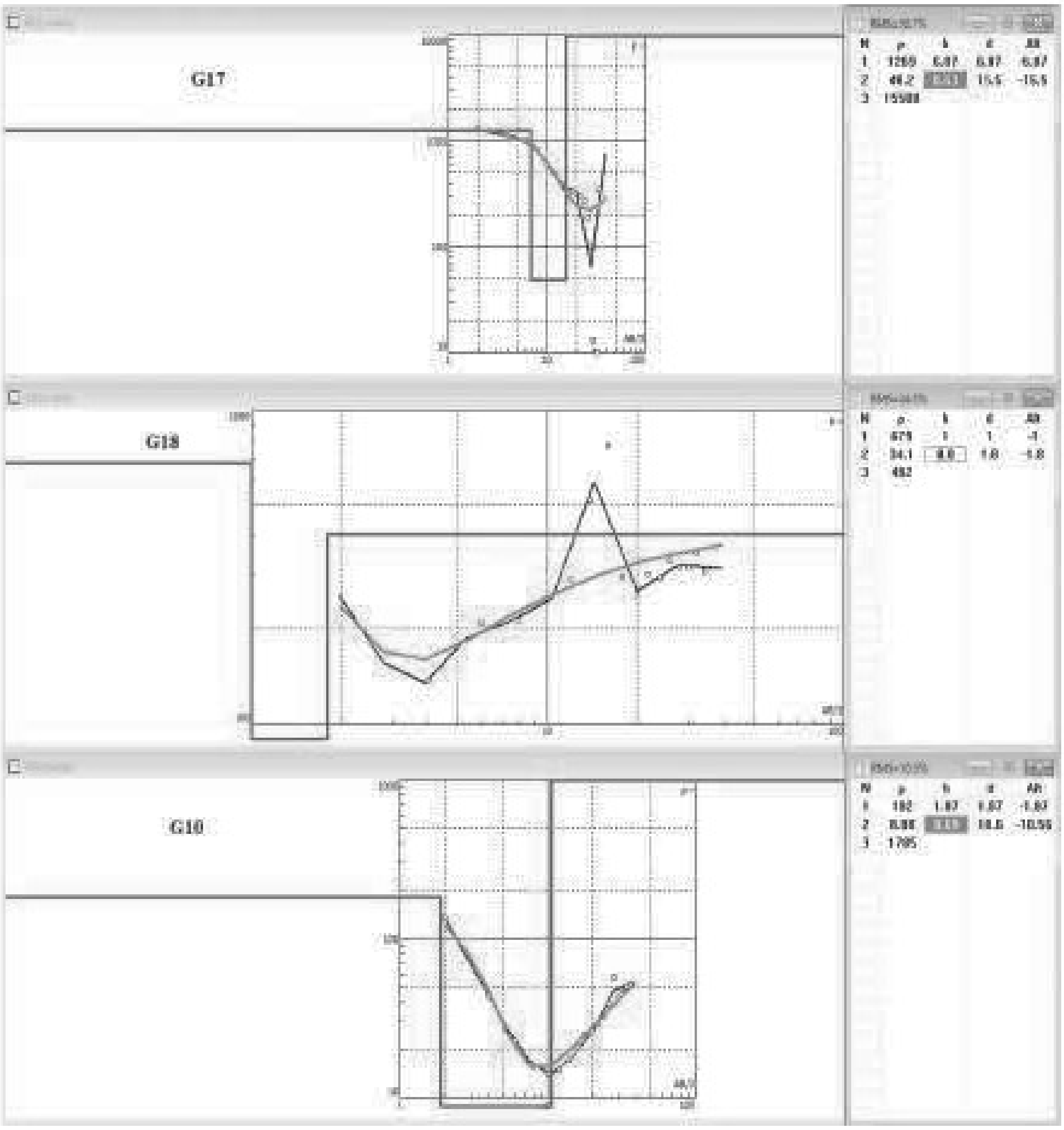

Fig.5. *Sounding curves of the location G17,G18 and G10 (H-Type)*

result from the survey was justified with the photograph taken from the location (Fig.7b).

K type curve

The soundings curves from Pattaparambu (G19),Nambram (G3), Kacheryparambu (G20) and Athaloor (G23) revealed the presence of a three-layered substrata (ρl<ρ2>ρ3) with 'K' type curve as shown in Fig.8. The resistivity of the first layer ranged from 21.4 to 755 Ωmwith a thickness of 1 to 3.63 m indicating the presence of lateritic topsoil. The second layer resistivity ranged from 44.7 to 7692 Ωmindicating the presence of hard laterite/unconsolidated sedimentary rock with a thickness range of 1.7 m to 5.07 m. The third layer was the low resistivity substrata (0.462 - 169 Ωm) such as weathered rock. These results were in good agreement with the results reported by Sajeenaet al. (2017).

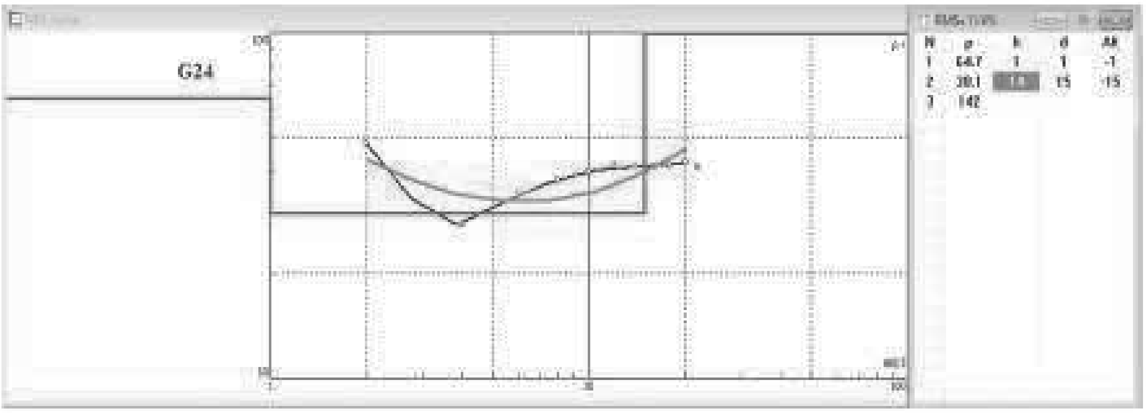

Fig. 6. *Sounding curve of the location G24 (H-Type)*

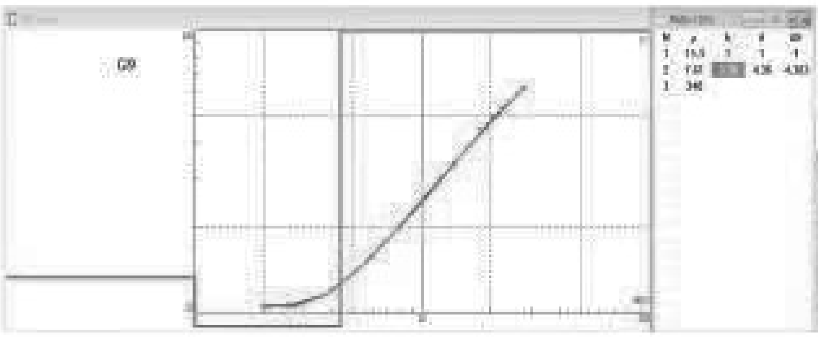

Fig.7a. *Sounding curve of the location G9 (H-Type)*

Fig.7b. *. Paddy field in Muvankara (G9)*

A type curve

The sounding curves of the locations Athaloor (G13), Kallur (G15) and Ayankalam (G16) were morphologically defined by a three-layered model with the resistivity sequence of $\rho 1<\rho 2<\rho 3$ as shown in Fig.9. This type of curves implies that the soil is having a low resistivity top layer and a high resistivity third layer with a steady increase in the resistivity with increase in the depth. The first layer had a resistivity range of 17.7 - 241 Ωm having a thickness ranging from 1 to 4.52 m. A comparatively low electrical resistivity in these areas to greater depths indicates the presence of water-bearing formations beneath the ground.Therefore, this area is highly suitable for the construction of open wells.

Q type curve

The sounding curves from the locations Vellanchery (G7) and Kadakassery (G8) could be explained by a three-layered model with a steady decrease in the soil resistivity ($\rho 1>\rho 2>\rho 3$) with an increase in depth. A low resistivity value indicates the presence of water-bearing strata (Venkateswaran *et al.,* 2014). Thesounding curve of location G7 (Fig.10) showed a resistivity of 175 Ωm in the top layer followed by a layer of resistivity 84.7 Ωm. This indicated that the topsoil is followed by a clay layer. At location G8, the top layer hada resistivity of 1076 Ωm, and was decreasing towards the bedrock (Fig. 19). This indicated the presence of a hard laterite layer at the top and its hardness decreased towards the bottom.

HK type curve

The sounding curve obtained for the location Nadet (G12) could be explained with a four-layered model with a resistivity sequence of $\rho 1>\rho 2<\rho 3>\rho 4$, 'HK' type curve as shown in Fig.11. This indicated the probability of the existence of a weathered rock as second layer, which could act as a better path for groundwater movement down to deep aquifers. The third layer showed a

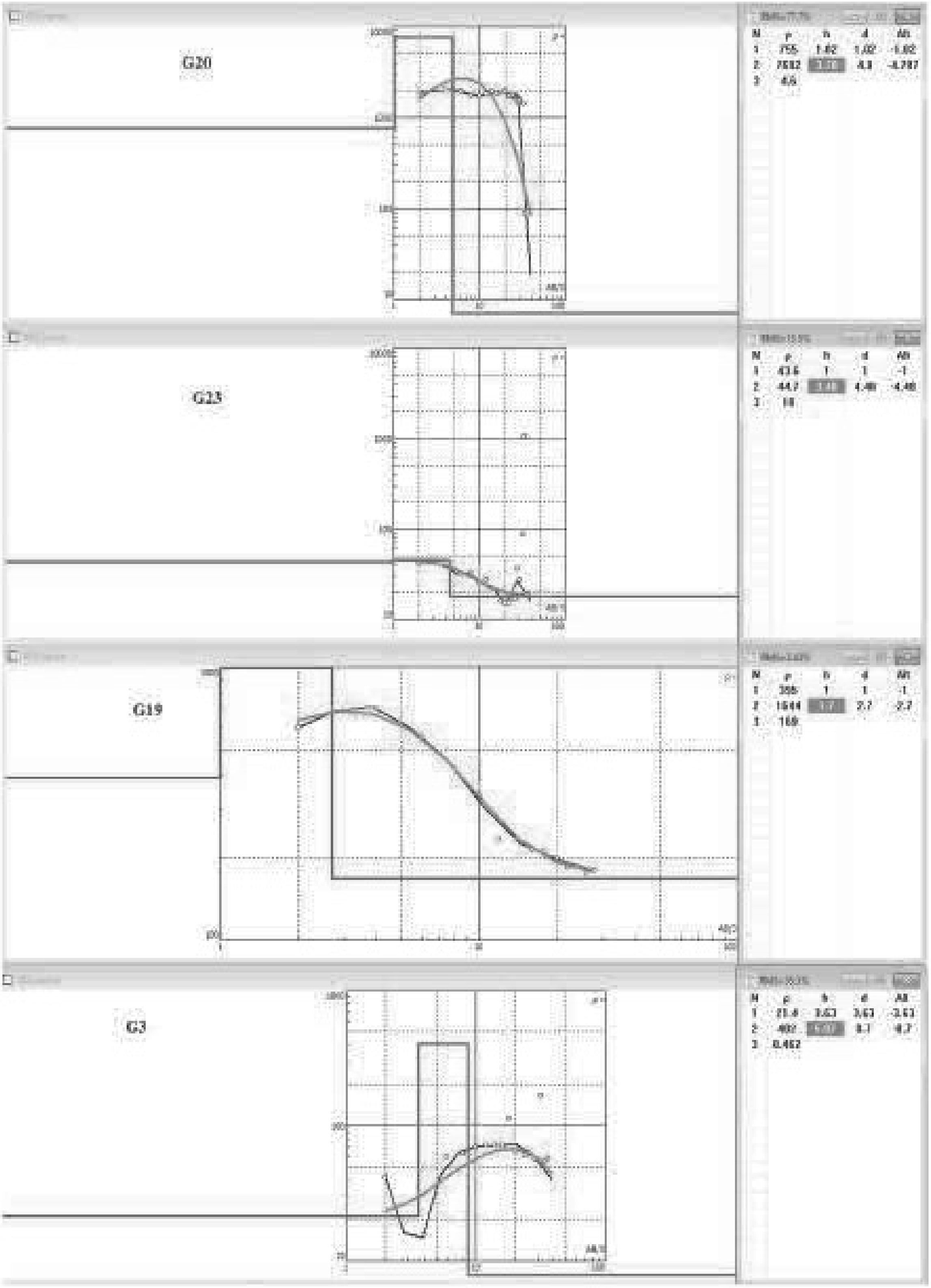

Fig.8. *Sounding curves of the location G19, G3, G20 and G23 (K-Type)*

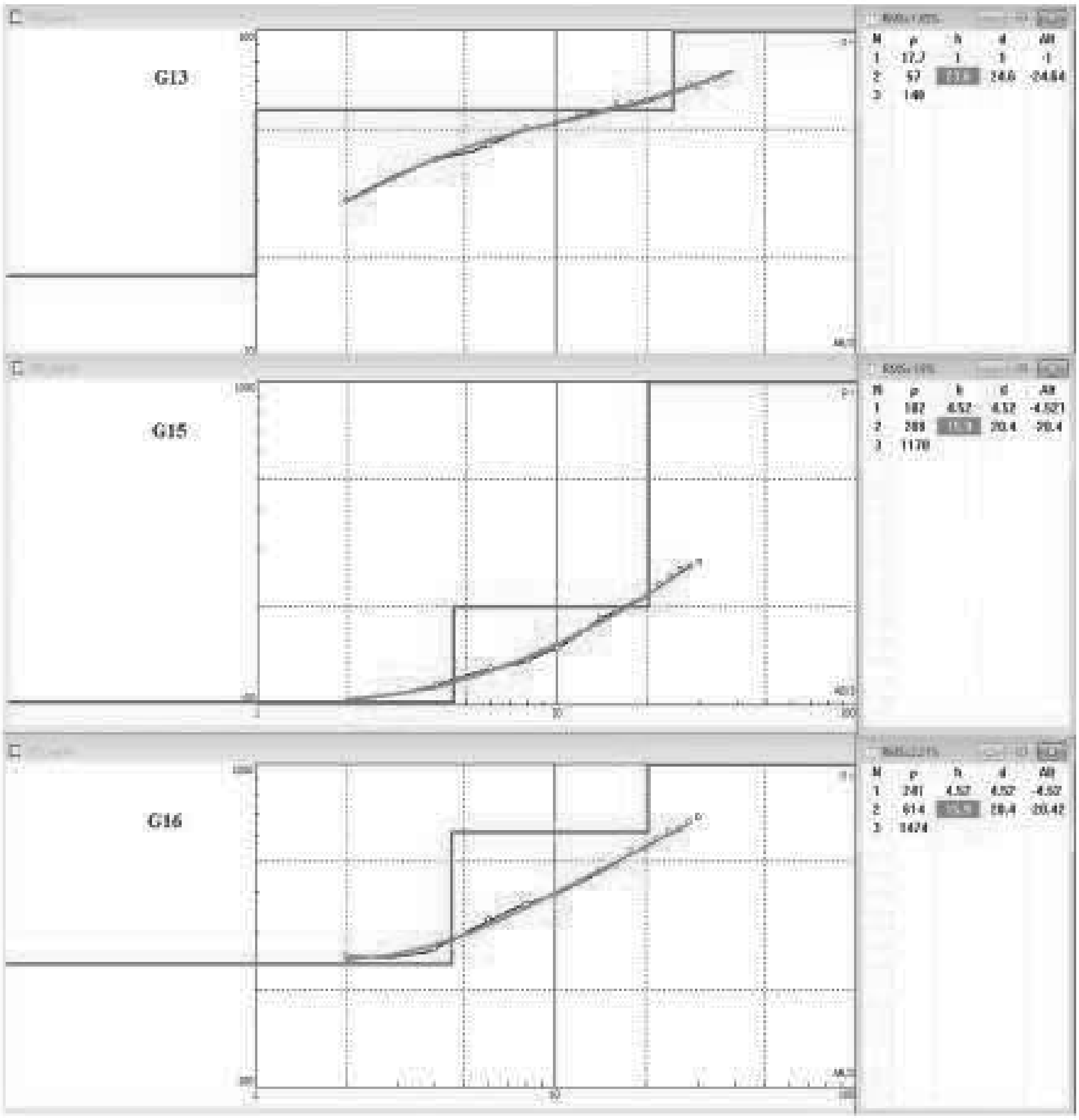

Fig.9. *Sounding curves of the location G13, G15 and G16 (A-Type)*

sudden rise in resistivity value with the indication of the absence or lack of fractured rock layers. The fourth layer indicated a slight reduction in the resistivity value due to the presence of interconnected fractures, which could be used for moderate groundwater supply.

QH type curve

The sounding curves of the locations Madirassery (G6) and Anthyalamkulam (G14) showed QH type curve representing a four-layered model which can be morphologically explained by the resistivity sequence $\rho 1>\rho 2>\rho 3<\rho 4$ as shown in Fig.12. These curves indicated the presence of lateritic soil/ moderate laterite followed by weathered rock/clay with a thickness of 3.66 and 3.95 m.

HA type curve

The sounding curves obtained from a coconut orchard near the river Nila, KCAET (G1) was morphologically defined by a four-layered model with

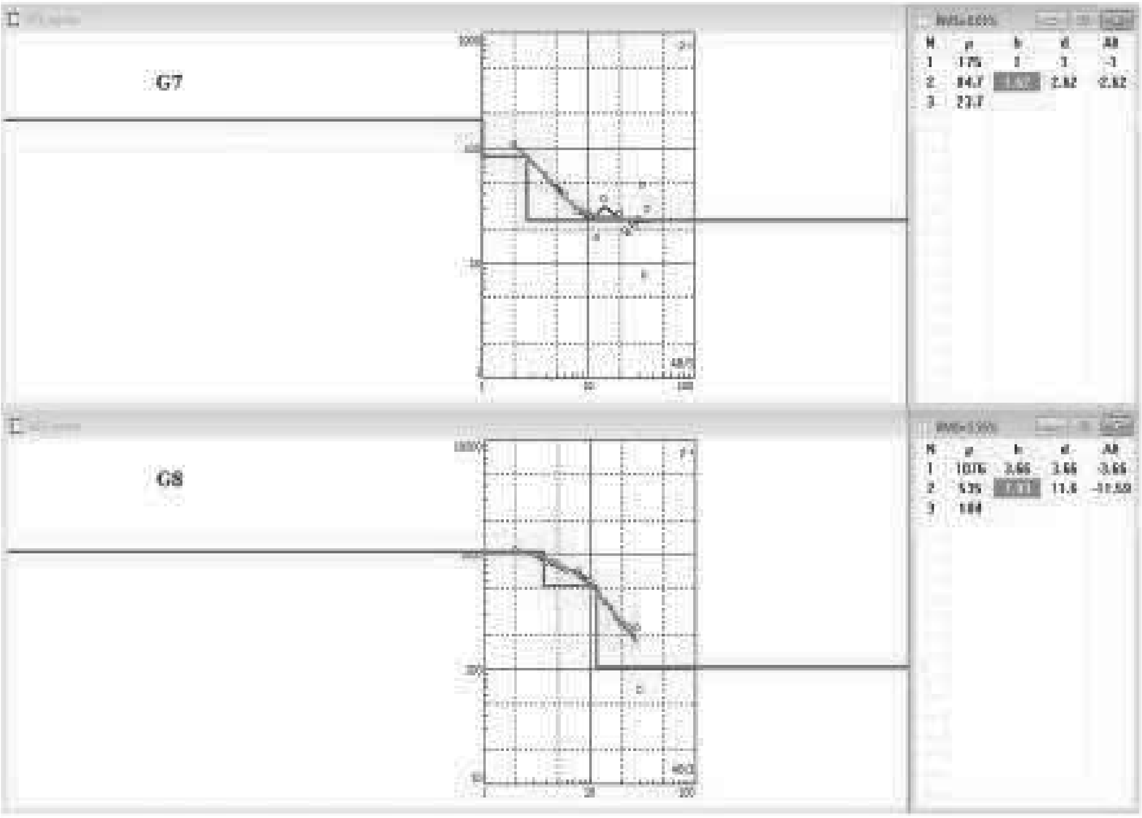

Fig.10. *Sounding curves of the location G7 and G8 (Q-Type)*

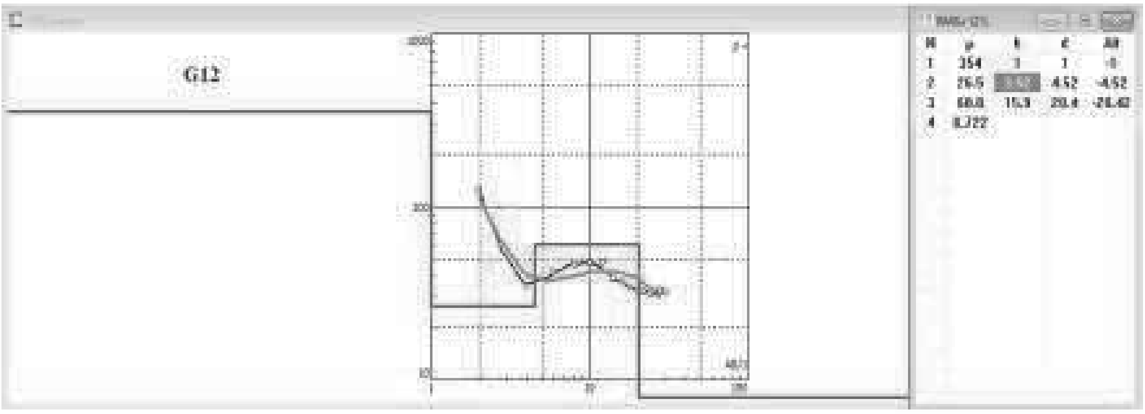

Fig.11. *Sounding curve of the location G12 (HK-Type)*

the resistivity sequence of ρl>ρ2<ρ3<ρ4 as shown in Fig.13. This was an HA type curve and it implied a layer of lateritic top soil followed by a clay layer. The fourth layer hada high resistivity of 5030 Ωm, which indicated the existence of hard rock.

Resistivity and pseudosections

The apparent resistivity data can be represented in a pseudosection, where the values are plotted based on both traverse position and depth beneath the land surface. Each apparent resistivity value is depicted at the

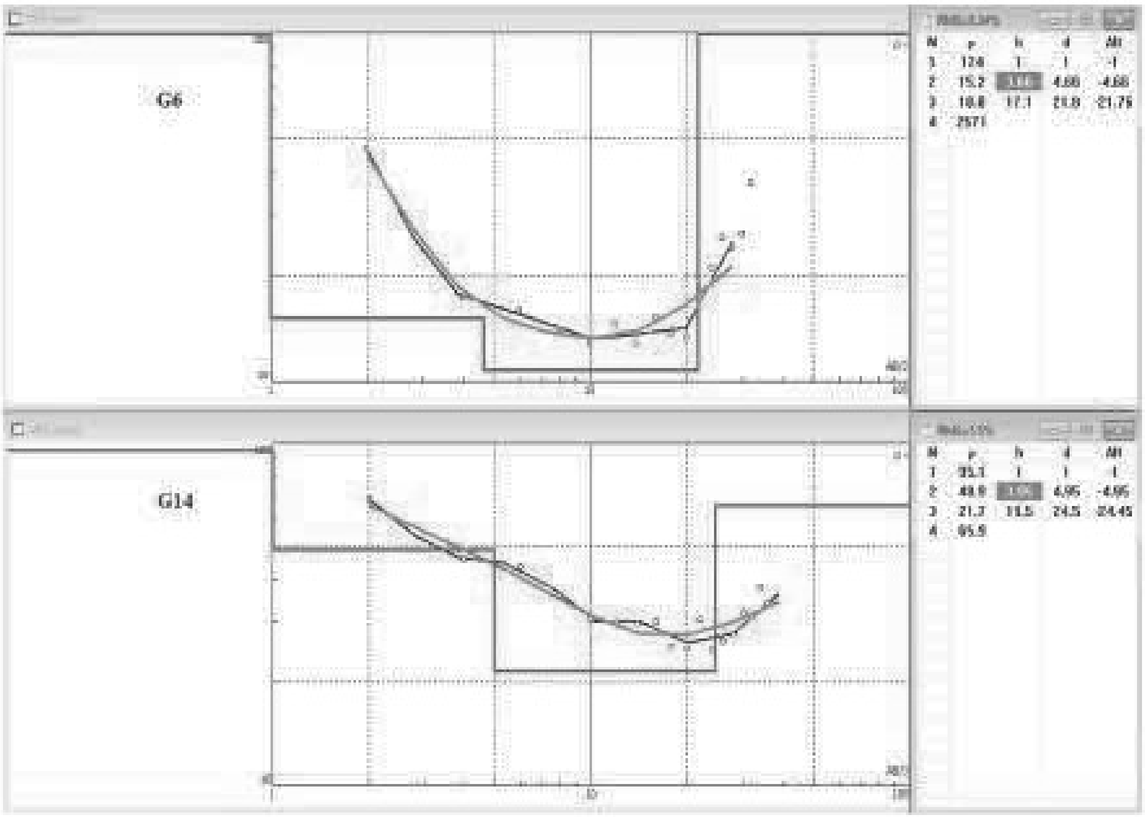

Fig.12. Sounding curves of the location G6 and G14 (QH-Type)

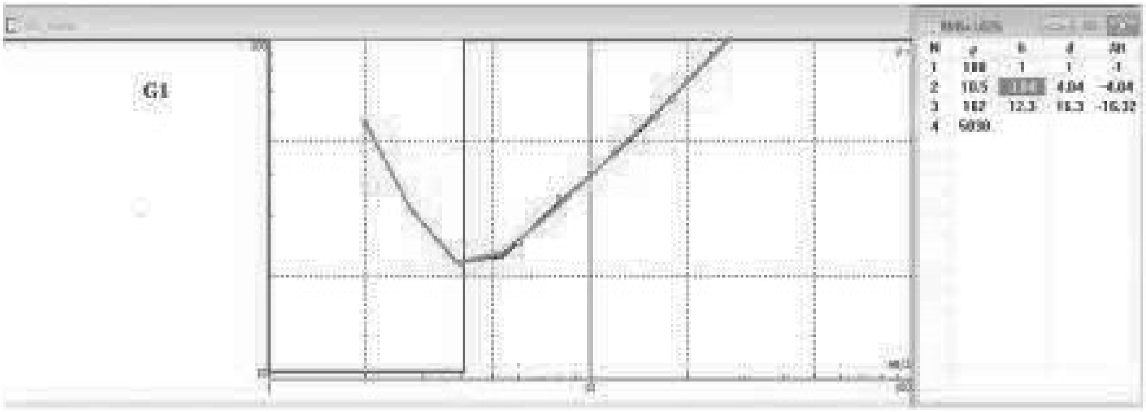

Fig.13. Sounding curve of the location G1 (HA-Type)

intersection of 45° lines originating from the midpoints of the respective current and potential electrode pairs. In order to create the resistivity and pseudo cross-sections, a section having maximum points in a straight line was selected as shown in Fig.14. The resistivity and pseudo cross sections along AA' to FF' were prepared using the true and apparent resistivity values.

AA′ represents the cross-section along the VES locations viz.Coconut orchard, KCAET (G2), Kadakassery (G8), Ayankalam (G16) and Pattaparambu (G19). BB′ represents a cross-section along the VES locationsviz., Kuzhunjodi (G4), Kadakassery

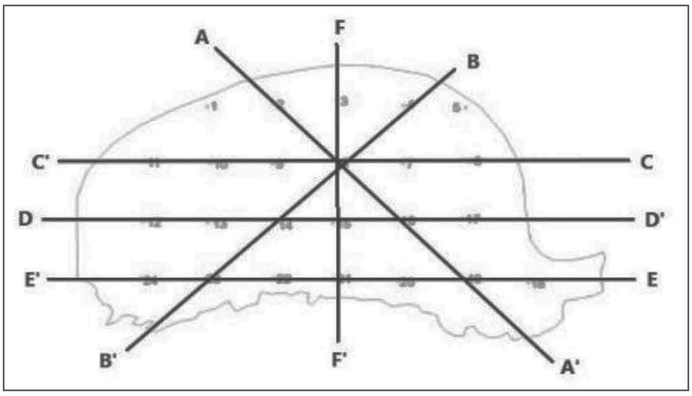

Fig.14. *Sections of resistivity and pseudo cross-sections*

(G8), Anthyalamkulam (G14) and Athaloor (G23). CC′ represents the cross sections along the VES locations viz.,Athaloor (G6), Vellanchery (G7), Kadakassery (G8), Muvankara (G9), Muradavilpadi (G10) andKakkasserykunnu (G11). DD′ represents the cross sections along the VES locations viz.,Nadet (G12),Athaloor (G13),Anthyalamkulam (G14),Kallur (G15), Ayankalam (G16) and Central jail (G17). EE′ represents the cross sections along the VES locations viz., MES College (G18), Pattaparambu (G19), Kacheryparambu (G20), Kadanchery (G22), Athaloor (G23) andMathoorpalli (G24). FF′ represents the cross sections along the VES locations viz.,Nambram (G3), Kadakassery (G8) andKallur (G15).

The resistivity and pseudo cross sections along the AA′ section are depicted in Fig. 15. The area between G2 and G8 (from Tavanur to Kadakassery) showed high resistivity values indicating the existence of unconsolidated sedimentary rock formation. The area between G8 and G19 (from Kadakassery to Pattaparambu) showed resistivity values under the range of lateritic soil formation. Fig.16. depicts the resistivity and pseudo cross-sections along section BB'. This section represents the resistivity of geological formations in the areas that lie diagonally from Kuzhinjodi to Athaloor of Tavanur panchayat. The pseudo cross-sections of the areas between G4, G8, G14 and G23 showed the existence of a lateritic soil formation.

The resistivity and pseudo cross-sections along section CC′are depicted in Fig. 17. This section formed a horizontal cross-section between Madirassery and Kakkasserykunnu in Tavanur Grama Panchayat. This section revealed the presence of a lateritic soil formation at high resistivity areas and lateritic clay formation at low resistivity areas. In low resistivity areas (between G6, G7 and G9, G11), the presence of water-bearing strata could be expected.

Fig.18. depicts the resistivity and pseudo cross-sections along section DD′. This figure included the horizontal section showing varying resistivity values from Nedat to the Central jail area of Tavanur Grama Panchayat. Here, the soil formation was found to show a gradual variation from lateritic to unconsolidated rock formation. The resistivity and pseudo cross-sections along the section EE′ (Fig.19) represent the horizontal section of the area between MES College and MathoorPalli region in Tavanur Grama Panchayat. The soil formation in this region showed a transition from lateritic soil to clay formation indicating the presence of water at low resistivity areas. The area between G10 and G19 has lateritic soil, between G19 and G20 has unconsolidated sedimentary rock, between G20 and G22 has lateritic soil and the rest of the area is clay. Fig.20. shows the resistivity and pseudo cross-section along the vertical section (FF') between Nambram and Kallur indicating the presence of both clay and lateritic soil formation. The area from G3 to G8 showed a transition from clay to lateritic soil and the area from G8 to G15 showed a transition from lateritic to clay soil.

The VES survey was conducted in the Tavanur Grama Panchayat to investigate the hydrogeological characteristics of the geological formationsof the areausing an electrical resistivity meter. Out of the 24 locations selected for the VES survey, 8 locations showed

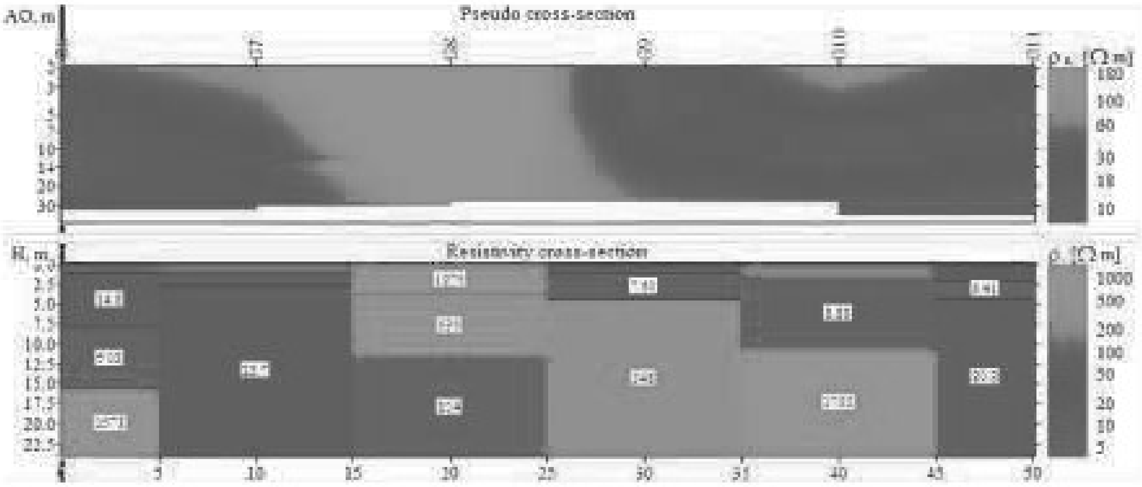

Fig.15. *Resistivity and pseudo cross-sections along section AA'*

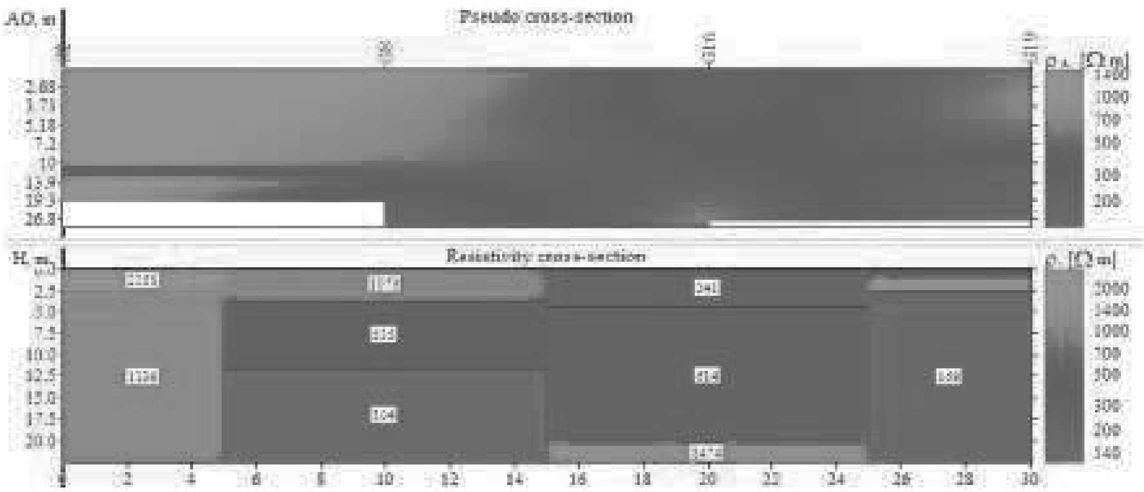

Fig. 16. *Resistivity and pseudo cross-sections along section BB'*

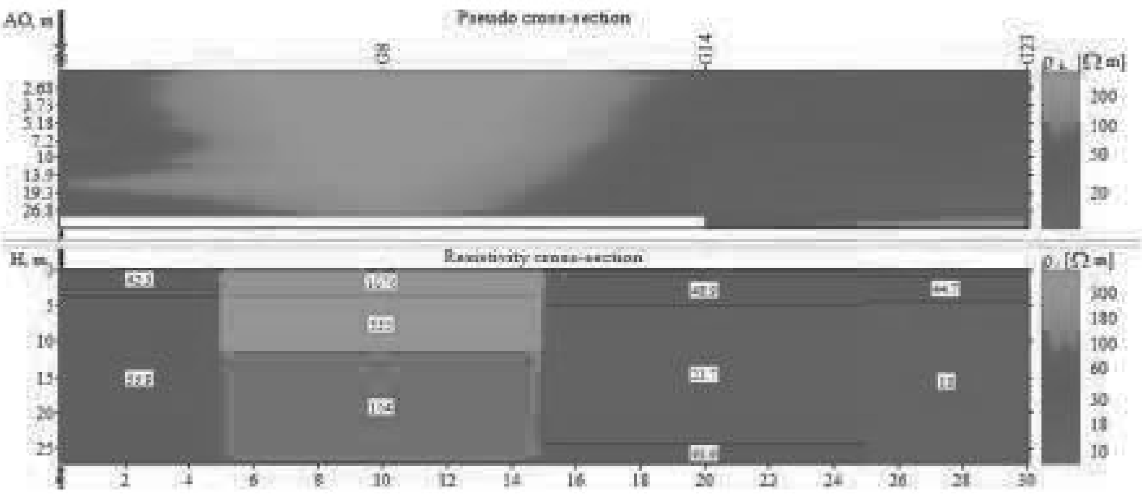

Fig. 17. *Resistivity and pseudo cross-sections along section CC'*

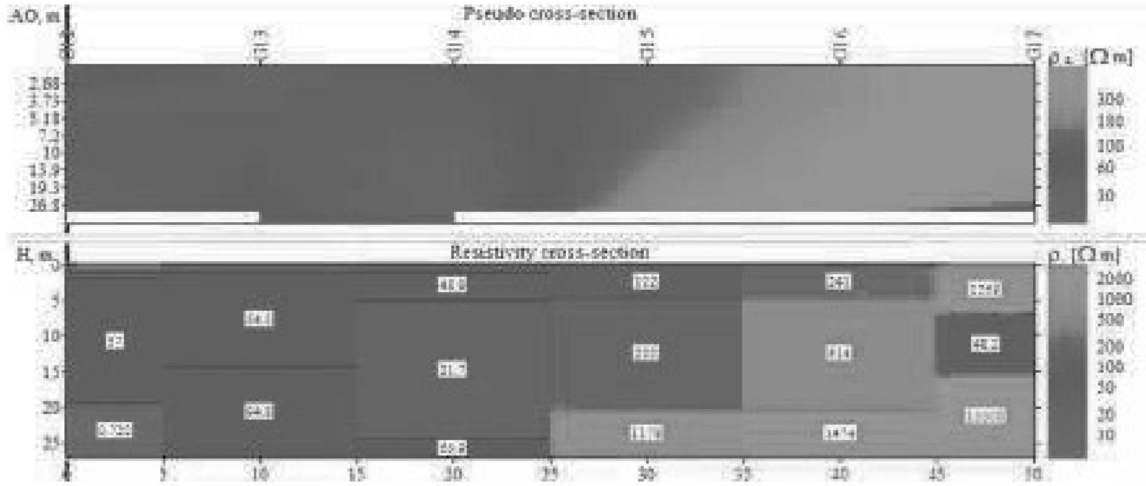

Fig.18. *Resistivity and pseudo cross-sections along section DD′*

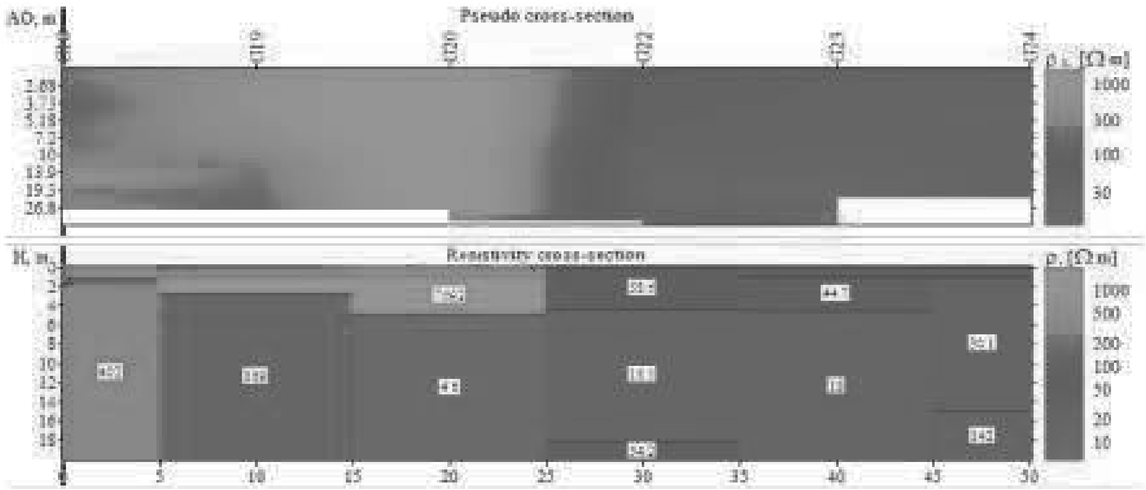

Fig.19. *Resistivity and pseudo cross-sections along section EE′*

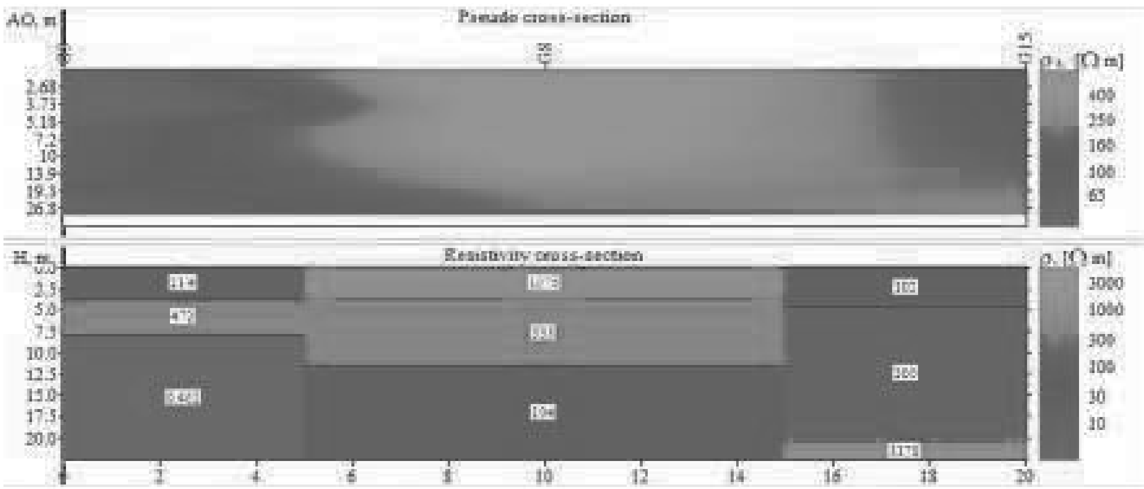

Fig.20. *Resistivity and pseudo cross-sections along section FF′*

the H type and 3 locations showed A type sounding curves in the data interpretation using IPI2WIN. The data interpretation results indicated that a majority of the study area has groundwater potential formations and was found suitable for the construction of open wells.

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