GEOPHYSICAL TECHNIQUES FOR AQUIFER CHARACTERISTIC STUDIES – A CASE STUDY OF TAVANUR GRAMA PANCHAYAT, MALAPPURAM, KERALA

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KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

TAVANUR- 679 573, MALAPPURAM, KERALA, INDIA

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PROJECT REPORT

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DEPARTMENT OF IRRIGATION AND DRAINAGE ENGINEERING
KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY
TAVANUR- 679 573, MALAPPURAM, KERALA, INDIA
2023

DECLARATION

We hereby declare that this project entitled " GEOPHYSICAL TECHNIQUES FOR AQUIFER CHARACTERISTIC STUDIES – A CASE STUDY OF TAVANUR GRAMA PANCHAYAT, MALAPPURAM, KERALA" is a bonafide record of project work done by us during the course of study and that the report has not previously formed the basis for the award to us of any degree, diploma, associateship, fellowship or other similar title of another university or society.

Place: Tavanur

Date: 30-05-2023

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CERTIFICATE

Certified that the project entitled **"GEOPHYSICAL TECHNIQUES FOR AQUIFER CHARACTERISTIC STUDIES – A CASE STUDY OF TAVANUR GRAMA PANCHAYAT, MALAPPURAM, KERALA"** is a record of project work done jointly by **Ms. APARNA (2019-02-013), Ms. HARIPRIYA S (2019-02-020), Ms. MANCHIMA S LAL (2019-02-024) and Ms. MEGHA P.P (2019-02-026)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associate ship to them.

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Dedicated to our Profession

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SYMBOLS AND ABBREVATIONS

Symbols and Abbreviations	
'	Minute
"	Seconds
°	Degree
°C	Degree Celsius
%	Percentage
Ω	Ohm
Ωm	Ohm meter
ΔV	Potential Difference
1D	One Dimensional
2 D	Two Dimensional
ρ_{aw}	Apparent resistivity
ArcGIS	Aeronautical Reconnaissance Coverage Geographic Information System
CGWB	Central Groundwater Board
E	East
EM	Electromagnetic
ERM	Electrical resistivity method
et al	And others
FDEM	Frequency Domain Electromagnetic
Fig	Figure
H	Thickness
I	Current

IGIS	Integrated Geo Instruments and Services
KCAET	Kelapajji college of Agricultural Engineering and technology
Km	Kilometer
KML	Keyhole Markup Language
M	Meter
Mm	Millimeter
N	North
Pvt. Ltd	Private Limited
R	Resistance
TDEM	Time Domain Electromagnetic
VES	Vertical Electrical Sounding

Introduction

CHAPTER I

INTRODUCTION

Groundwater is the world's largest source of freshwater. It is estimated that 30% of the world's freshwater, is stored in the aquifers beneath the earth's surface in soil pores and rock cracks. In many regions of the world, it is the only reliable source of water. It is the main source of drinking water for many people and is also used for agricultural, industrial, and commercial purposes. It is recharged by precipitation, snowmelt, and other forms of water that percolate through the soil and rocks.

The groundwater level is declining in many parts of the world due to overexploitation. Over extraction of groundwater has led to the depletion of aquifers, causing the water table to drop and making it more difficult to access groundwater resources. Climate change is also affecting the global groundwater scenario. According to the United Nations, groundwater is the world's largest freshwater resource, with over 2.5 billion people depending on it for drinking water and agricultural production. However, more than 1.7 billion people live in areas where groundwater resources are under threat due to overexploitation, pollution, and climate change.

Groundwater management involves monitoring and regulating the use of groundwater resources to ensure sustainability and protecting it against pollution. This aspect includes measures such as limiting pumping rates, implementing regulations on land use practices that could affect groundwater quality, and developing and implementing strategies for groundwater recharge. Groundwater is an essential resource that is necessary for human survival, economic development, and the health of ecosystems. It is important to manage groundwater resources sustainably to ensure that they are available for the future generations.

India is the largest user of groundwater in the world, accounting for approximately 25% of the global groundwater extraction. However, over-extraction, contamination, and inadequate recharge are major issues affecting the groundwater scenario in India. In many regions of India, the groundwater levels have been declining rapidly due to excessive pumping, leading to depletion of aquifers. In some regions, such as parts of Punjab, Haryana, and Western Uttar Pradesh, the water table has fallen by more than 1m per year, leading to severe water scarcity.

Kerala is known for its abundant rainfall and high-water availability. The state receives an average annual rainfall of around 3,000 mm, and it has a diverse range of aquifers, including hard rock, sedimentary, and coastal aquifers. Despite these advantages, the state is facing several challenges in managing its groundwater resources due to spatial and temporal non uniformity in rainfall. The indiscriminate use of groundwater for irrigation, domestic and industrial purposes, and the construction of large dams and reservoirs have led to a decline in the water table in several areas. In some regions, the groundwater extraction rate is higher than the recharge rate, which has led to a depletion of the aquifer's storage capacity and an increase in salinity levels. Effective groundwater management strategies should involve a combination of regulatory measures, conservation practices, and the promotion of alternative water sources.

Malappuram, a district in the state of Kerala is located in the foothills of the Western Ghats and is drained by several rivers and their tributaries. The district has an estimated groundwater potential of around 60 million cubic meters per year. The major sources of groundwater in the district are open wells and bore wells. Tavanur panchayat in Malappuram district is located on the southern bank of Bharathapuzha. The groundwater scenario in Tavanur Panchayat is generally good, with ample water availability in most of the areas. 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. The CGWB has identified some areas as "overexploited" meaning that the groundwater extraction rate is higher than the recharge rate. This can lead to a depletion of the groundwater resource in the long term, and may require measures such as artificial recharge to replenish the aquifers. Therefore, a thorough investigation and exploration of the groundwater levels on a spatial scale is inevitable in managing the groundwater efficiently.

The analysis of groundwater potential in Tavanur Panchayat is necessary for several reasons. Understanding the availability of groundwater is critical for developing sustainable groundwater management strategies and ensuring that the resource is used efficiently. Tavanur Panchayat may experience changes in water demand due to population growth, changes in land use, or other factors. Analysing groundwater potential can help planners anticipate these changes and develop strategies to ensure that adequate water resources are available in the future. Not all areas have the same potential for groundwater availability. By analysing groundwater potential, it is possible to identify areas where the resource is abundant and areas where it is scarce. It can also help preventing over-exploitation of groundwater resources. In this regard, the groundwater availability and depths are investigated using various traditional as well as geophysical investigation methods. Due to the inaccuracy of the traditional methods, geophysical investigations are preferred over them, to obtain more precise results.

Electrical resistivity method is a commonly used geophysical method for ground water exploration throughout the world. Vertical Electrical Sounding (VES) is a depth sounding galvanic method and has proved very useful in ground water studies due to simplicity and reliability of the method.

An electrical resistivity meter, also known as a resistivity imaging tool, is an instrument used to measure the electrical resistivity of materials or subsurface formations. By taking measurements at different locations and depths, the meter can create a resistivity profile of the subsurface. There are different types of electrical resistivity meters, ranging from handheld instruments to larger, more complex systems used for advanced geophysical surveys. The choice of meter depends on the specific application and the required level of accuracy and resolution.

IPI2WIN software can be used to analyse and visualize data related to groundwater levels and flow rates for mapping the aquifers. It can help in identifying and mapping the boundaries of aquifers and estimate their thickness, hydraulic conductivity, and storativity. The software can also be used to create cross-sectional views of the aquifer system and generate contour maps of the water table elevation. One of the key advantages of using IPI2WIN in aquifer mapping is that it allows for spatial analysis of groundwater data.

Groundwater has top priority in recent years. Identifying groundwater potential also helps to protect the quality of groundwater resources by preventing overexploitation and ensuring that water extraction is sustainable.

In this context we are selecting the topic entitled "Geophysical Techniques for Aquifer Characteristic Studies – A Case Study of Tavanur Grama Panchayat, Malappuram, Kerala" with the following objective:,

1. To study the hydrogeological characteristic of the geological formations of Tavanur Panchayat using Electrical Resistivity Meter.
2. To prepare the resistivity and pseudo cross-section of the aquifer formation of Tavanur panchayat using IPI2WIN software.

Review of Literature

CHAPTER II

REVIEW OF LITERATURE

This chapter provides an overview of prior studies on the various groundwater investigation methods and aquifer mapping.

2.1. GROUND WATER

Effective management of groundwater resources is critical to ensure their sustainability. Foster and Chilton (2003) provided an overview of the principles and practices of groundwater management, including issues such as groundwater recharge, allocation, and protection. Although global in scope, the emphasis of this paper is on groundwater-based economies in a developing nation context, where accelerated resource development has brought major social and economic benefits over the past 20 years. It is concluded that aquifer degradation is much more than a localized problem because the sustainability of the resource base for much of the rapid socio-economic development of the second half of the twentieth century is threatened on quite a widespread geographical basis.

Groundwater is widely acknowledged to be an important source of drinking water in low-income regions, and it, therefore, plays a critical role in the realization of the human right to water. However, the proportion of households using groundwater compared with other sources is rarely quantified, with national and global datasets more focused on facilities—rather than resources used. Studies conducted by Carrard *et.al.* (2019) contributed data that can be used to strengthen the integration of resource considerations within water service delivery and inform the work of development partners supporting this area. Findings support the case for governments and development agencies to strengthen engagement with groundwater resource management as foundational for achieving sustainable water services for all.

2.2. GEOPHYSICAL INVESTIGATIONS FOR GROUND WATER EXPLORATION

Geophysical investigations are performed on soil surface to explore the ground water resources by observing physical parameters such as density, conductivity, resistivity, magnetic, electromagnetic and radioactivity. These methods detect the differences, or anomalies of physical properties within the earth's crust. The main geophysical methods which are useful in solving some of the problems of hydrogeology, are the Electrical, Seismic, Gravity, and Magnetic methods.

2.2.1. Gravity method

Gravimeters are used in this method to measure the differences in density on the earth's surface that may indicate the underlying geologic structures. It is a widely used geophysical method for finding out mineral resources and groundwater in sedimentary terrain. Murthy and Raghavan (2002) had used gravity method for groundwater exploration in a peninsular granitic region in Hyderabad, India. The study revealed that the magnitude of residual gravity and well yield exhibits an inverse relation and found that the gravity method is feasible for such regions.

2.2.2. Magnetic method

It enables detecting the magnetic fields of the earth, which can be measured and mapped. Magnetometers are the equipment's used to measure the magnetic fields and variations. Major limitation of this method is magnetic contrasts are seldom associated with groundwater occurrence.

Oni *et al.* (2020) had done the investigation if groundwater using magnetic method in a basement complex terrain in Southwest Nigeria. The lineaments and overburden thicknesses derived from the magnetic method were validated with that obtained from resistivity survey and borehole log data of the area. The study concluded that the magnetic method can be used reliably for investigating the groundwater in a complex terrain.

2.2.3. Seismic method

Seismic methods are of two kinds: Seismic refraction and Seismic reflection methods. Seismic refraction method involves creation of a small shock at the earth's surface either by the impact of a heavy instrument or by a small explosive charge and measuring the time required for the resulting sound, or shock, wave to travel known distances. Seismic reflection methods provide information on geologic structure thousands of meters below the surface.

Grelle and Guadagno (2009) studied the seismic refraction profiles for identifying the groundwater levels and defined the water seismic index for southern Italian region. The researchers studied the propagational velocity of P and S waves through the saturated and unsaturated media and the groundwater levels were found to be correlated the water seismic index.

2.2.4 Electrical magnetic method

Two methods of EM survey are Time-domain (TDEM) EM surveys and Frequency-domain (FDEM) EM surveys. TDEM methods are based on the principle of using electromagnetic induction to generate measurable responses from sub-surface features. FDEM is related to the measurements at one or more frequencies.

Vargemezis *et al.* (2012) detected the presence of groundwater in Northern Greece using electrical and EM methods of geophysical investigations and suggested the promising locations to construct wells. The potential groundwater regions were proposed by exploring the water levels using very low frequency electromagnetic method.

2.2.5. Electrical resistivity method

In Electrical Resistivity methods, current sent into the ground through a pair of electrodes, called current electrodes, and resulting potential difference across the ground is measured with the help of another pair of electrodes, called potential electrodes. The ratio between the potential difference (ΔV) and the current (I) gives the apparent resistance, which depends on the electrode arrangement and on the resistivities of the subsurface formations.

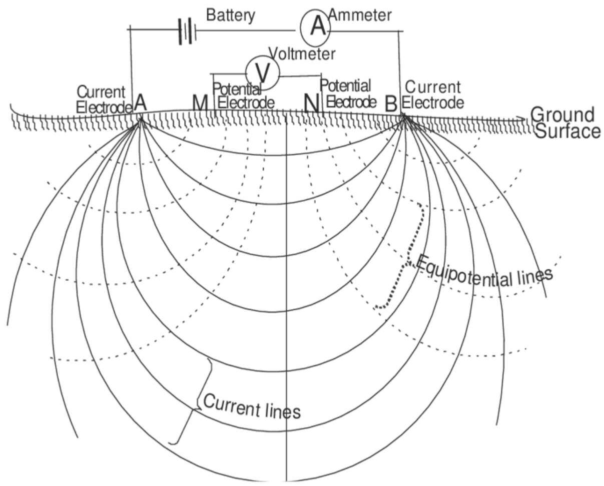

Fig. 2.1 Electrical resistivity method

Ariyo and Adeyemi (2009) studied the role of Electrical Resistivity Method for Groundwater Exploration in Hard Rock Southwestern Nigeria. In the study, the weathered or fractured rock areas and most potential groundwater zones were identified and mapped by conducting VES survey in twenty-eight sites probed in the study area. The survey revealed the presence of 3-5 geoelectric layers and the weathered and fractured bedrock was found to be the common aquifer which forms a typical Basement Complex of Nigeria.

Sajeena *et al.* (2017) reported that geophysical method is a vital tool in groundwater exploration. The geophysical techniques are intended to comprehend the hydrogeological conditions of the subsurface sufficiently and precisely. The study stated that the effectiveness of any geophysical techniques depends on its capacity to detect and resolve the subsurface hydrogeological heterogeneities or variation. The study used a Vertical Electrical Sounding (VES) approach using a Signal Resistivity Metre (MODEL-SSR-MP-ATS) for exploring the groundwater potential sites in the Kadalundi River Basin. A regional span of 1122 km^2 of the Kadalundi River Basin underwent a VES study at 22 places using nine Schlumberger electrode configurations and thirteen Wenner electrode configurations.

Riwayat *et al.* (2018) suggested that an applicable alternative technique in groundwater exploration such as ERM, which complement with existing conventional method, might produce comprehensive and convincing output thus effective in terms of cost, time, data coverage and sustainable. Excavation and test boring are the conventional methods used to obtain information of earth layer during site investigation. Major disadvantage of the conventional method is that it provides information at actual drilling point only. This study was carried out to expose the application of ERM in groundwater exploration. The study proposed that the results from ERM could be used as an additional information for solving problems on groundwater pollution, leachate, underground and sources of water supply.

2.2.5.1. Vertical Electrical Sounding (VES)

VES is used to determine the resistivity variation with depth. Apparent resistivity is measured using a resistivity meter. The calculated resistivity value is not the true resistivity of the subsurface, but an "apparent" value which is the resistivity of a homogeneous ground which will give the same resistance value for the same electrode arrangement. To determine the true subsurface resistivity, an inversion of the measured apparent resistivity values using a computer program must be carried out.

2.2.5.2 Horizontal Profiling

In this case, the spacing between the electrodes remains fixed, but the entire array is moved along a straight line. It gives information about lateral changes in the subsurface resistivity, but it cannot detect vertical changes in the resistivity.

Ozcep *et al.* (2009) used geophysical methods of vertical electrical sounding for measuring soil electrical properties and tested for different soils. Study was carried out in areas of Istanbul and Golcuk. The electrical resistivity in this area was measured by VES (Vertical Electrical Sounding) using McPHAR resistivity equipment. For geotechnical purposes, soil mechanics laboratory procedures on the soil samples from borings were carried out and soil water contents were determined.

Zawawia *et al.* (2011) conducted a study on resistivity imaging profiling. It is one of an important technique to obtain information for finding out hidden water in geophysical survey and this has been applied in the Beriah Landfill Site. Two-dimensional geo electrical imaging has been used in this study. The principal goals of the survey were to define the depth of aquifer layers from the subsoil, the water table and the depth of bedrock as well as suitable site for well. An imaging method was used in the study to map the subsurface soil and groundwater in and around the landfill area that includes six resistivity lines. Surveys were conducted using SAS4000 resistivity meter and ABEM LUND electrode and the measured resistivity profiles were interpreted with 2-D resistivity inversion programme (RES2DINV).

Gupta *et al.* (2015) conducted a study on two-dimensional (2D) resistivity survey of Chikotra basin, southern part of Kolhapur district in the Deccan Volcanic Province of Maharashtra. The work focussed on determining the aquifer zones of the study area using electrical resistivity imaging technique. The sources of groundwater appeared to be available in weathered and fractured basalt trapped between weathered overburden and hard rock. The resistivity models suggested that the northern part of the study area represented a promising aquifer zone with reasonable thickness of weathered basement. The models further indicated that there were several locations throughout the basin for possible groundwater exploration as it exhibited strong water-bearing potential in the subsurface rocks.

Shishaye and Abdi (2016) conducted a study to locate two well site locations using surface geophysical methods for water supply purposes. Hydrogeological and geological investigations were incorporated in addition to the geophysical surveying activities for the betterment of the study. The intended well site locations with their corresponding thickness and resistivity values were identified using the integrated approaches.

Jamaluddin (2017) remarked geoelectric method as one of the measurement techniques to examine the geological data of the subsurface strata. Wenner-Schlumberger array configuration was used to detect the lateral and vertical anomaly of material resistivity. The 2D profiling of the study area was done to determine the electrical resistivity of different soil layers. The data was processed using software Res2Dinv which yielded a cross section of 2D resistivity. When using a Wenner-Schlumberger arrangement with electrodes spaced 5 m apart, data were collected along a 70 m length. The data processing yielded an approximation of resistivity that ranged from 1000 to 1548 m with an iteration error of 87.9%. The research location was having alluvium and coastal precipitation with grain in the forms of gravel, sand, and small stones, according to the geological map of the Ujung Pandang sheet.

Teye (2021) conducted an electrical resistivity survey in 11 communities in Ga West Municipal city to determine the presence of water-bearing zones within the basement rocks underlying the new settlement areas of the communities. For this purpose, 1-dimensional electrical resistivity profiling and vertical electrical sounding were carried out in these communities using ABEM Terrameter SAS 300C.The Schlumberger electrode array was used for both electrical resistivity profiling and vertical electrical sounding. The 31 anomalous points identified for vertical electrical sounding were modelled and resulted in 3, 4 and 5-layer subsurface structures characterized by A, H, K, AA, KH, QH and HKH- type resistivity curves.

The electrical resistivity method uses several types of electrode arrangements (configurations) of which Wenner and Schlumberger configurations are more popular.

2.2.5.3. Wenner array

In Wenner Configuration, all the four electrodes are kept along a line at equal distances 'a' called electrode spacing. For each measurement all the electrodes are moved simultaneously keeping the inter electrode spacing same. The current is sent normally through outer electrodes and potential difference is measured across the inner electrodes. The resistance is multiplied by the configuration factor 2πa, to get the value of apparent resistivity (ρ_{aw}).

$$\rho_{aw} = 2\pi a R$$

$$\text{where } R = \frac{\Delta V}{I}$$

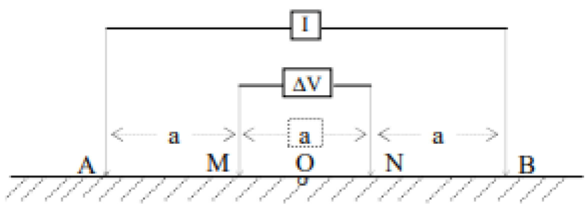

Fig. 2.2 Wenner electrode configuration

Kurien *et al.* (2013) performed a hydro geophysical investigation of groundwater using electrical resistivity method using the IGIS signal stacking resistivity metre model SSR-MP-ATS. The vertical electrical sounding (VES) was carried out using the Wenner electrode configuration. The study was carried out to identify the potential aquifer locations and to determine the pattern of local aquifer distribution. The resistivity and thickness of different subsurface layers at a certain place was determined by gradually expanding the electrode spacing. The inverse of the resistance measured 1/R was plotted against the Wenner electrode spacing on a linear graph to identify the thickness of various layers. The 2D cross-section of strip resistivity was analysed to find a location that would be ideal for a recharge structure.

Cubbage *et al.* (2017) described Wenner array as a popular measurement strategy for acquiring geoelectrical data for 1D soundings and 2D profiles. The study stated that the high signal strength of the Wenner array is advantageous as the receiving dipole expands in size proportional to the transmitting dipole. The low data acquisition efficiency was found to be the major demerit as this array can only be used in a single-channel acquisition mode. Modifications to the Wenner array by adding additional receiver dipoles was proposed as an alternative to overcome its demerits.

2.2.5.4. Schlumberger array

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 the inner electrode spacing, usually more than 5 times. For each measurement only current electrodes are moved keeping the potential electrodes at the same locations. The potential electrodes are moved only when the signal becomes too weak to be measured.

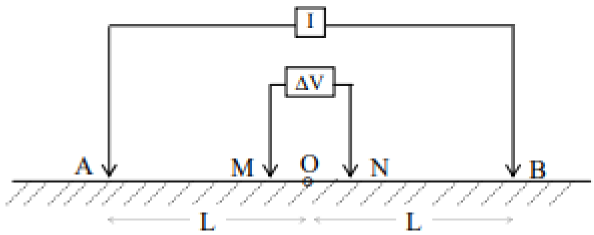

Fig. 2.3 Schlumberger electrode configuration

The apparent resistivity for this configuration is computed with the formula;

$$\rho_{as} = \pi \frac{\left(\frac{AB^2}{2} - \frac{MN^2}{2}\right)}{MN} R$$

Where, $R = \frac{\Delta V}{I}$

Ojalebi *et al.* (2002) compared the two common electrode arrays - the Wenner and Schlumberger - used in the geoelectric resistivity method for groundwater exploration within a typical area of basement complex. The results of the study indicated that Schlumberger electrode array has a high investigating depth per unit current electrode separation and is more suitable for subsurface delineation and groundwater exploration.

Arshad *et al.* (2007) carried out an electrical resistivity survey in order to study the groundwater conditions such as depth, thickness, location of the aquifer and the type of water along the Jhang Branch canal. Vertical electrical soundings were carried out at 9 locations up to a depth of 200 m using Schlumberger electrode configuration. It was inferred from the resistivity data that the aquifer was of an alluvial formation. Lithology and the groundwater quality of the aquifer were determined using the data. The increasing value of the resistivity of the aquifer indicated the existence of fresh groundwater.

In order to demonstrate the use of the vertical electrical sounding method of research in the groundwater exploration in Pachipenta Mandal and surrounding areas, Selvam (2012) conducted a study. VES survey was conducted at 9 locations up to a depth of 200 m in 4 communities that were spaced 200–300 metres away from each other. The data from the field were produced using ABEM SAS 300 C terrameter. The current electrode spacing (AB) used for the Schlumberger soundings ranged from 2-300 m (AB/2-1-150 m). Potential electrode spacing (MN) was measured throughout a range of 03–10 m (MN/2-015–5 m). Winner software was used to imitate the field data. The site VES 1 and VES 5 was found to have higher chances of accommodating groundwater.

Kumar (2013) has done geohydrological investigations on the main campus of Banaras Hindu University in Varanasi, Uttar Pradesh, India, to evaluate the groundwater characteristics for identifying suitable areas for groundwater research and resource management. Nine vertical electrical sounding (VES) sites were selected and surveys were conducted by Schlumberger configurations in different locations inside the campus premise. Both curve matching and the computer-assisted automatic iterative resistivity sounding approach had been used to interpret the sounding data. Four geoelectrical cross sections was created along the profiles based on the interpreted sounding results. Four layers were revealed by the data interpretation, with the top thin layer typically covering the other three thick levels. The borehole data supported the interpreted results well. The results depicted proper geohydrological conditions for existence of good aquifers suggesting continued supply of groundwater in the campus for an extended period.

Sahoo *et al.* (2022) conducted the Vertical Electrical Sounding in a part of Krushnaprasad Block to isolate the coastal aquifers which were affected by saltwater contamination. A total of 9 soundings with Schlumberger electrode arrangement was done and the results were analysed using IPI2WIN software. The results brought out an indication of underlying strata affected by saltwater. The higher resistivity value (more than 30 Ωm) indicated the lithology without any presence of saline water and the low resistivity value (1 Ωm) indicated aquifers with saline water presence. The resistivity cross-section separating depth of 9 to 25 metre was identified to have a clay layer with lower resistivity value (0.5 Ωm) indicating saline aquifer.

2.3. IPI2WIN

The IPI2WIN software is a program designed for automatic or semi-automatic analysis of single piece 1D geoelectrical survey data to get the smallest error (Mohammad *et al*., 2013).

Selvam and Sivasubramanian (2012) carried out a geoelectrical resistivity survey by vertical electrical soundings (VES) in the Medak District of Andhra Pradesh, India in order to evaluate the underlying geology and groundwater potential zones in the area. Schlumberger electrode arrangement was used to record 26 vertical electrical soundings, with current electrode spacing (AB/2) varying from 1 to 150 m. The curve matching and electrical imaging computer programme IPI2WIN had been used to interpret the field data. Interpretations revealed the number, thickness, and depth of underlying formation layers.

Mohammad *et al*. (2013) conducted vertical electrical sounding (VES) survey using the Schlumberger configuration at 16 VES stations. The obtained field data were analysed using computer software (IPI2WIN). The VES results showed the heterogeneity of the underground geological sequence. The geological sequence below the study area consisted of soil, weathered layer, partially weathered and fresh bedrock. The result showed that the groundwater efficiency based on the IPI2WIN method around Malang City is still high to be used not only for domestic water supply but also for irrigation.

Arunbose (2018) studied an approach to assess groundwater status near Tiruchendur, Tuticorin district, Tamil Nadu, India. A total of 12 VES were performed in the area with the Schlumberger configuration. A DDR3 resistance meter (IGIS Pvt. Ltd.) was used for data collection. The obtained field data were analysed and interpreted using the IPI2WIN software, which provides an automatic interpretation of the apparent resistance. The results of the quantitative interpretation of the geoelectrical data indicated that the study area consisted of three to five electrical layers. The resistivity of the resulting layer varies from 1.3 Ωm to 1512 Ωm. From a total of 12 vertical electric soundings, 3 VES depicted good groundwater potential and quality, and 6 VES depicted poor quality groundwater potential.

Smegha and Sajeena (2022) conducted aquifer characteristics studies at the ayacut areas of Bakkikayam regulator situated across the Kadalundi River Pandikasala, Vengara, Malappuram district using earth resistivity techniques. Vertical Electrical Sounding (VES) surveys were conducted using a Signal Stacking Resistivity Meter (MODEL-SSR-MP-ATS) at 18 locations and were interpreted using IPI2WIN software in order to analyze the aquifer characteristics of the study area. According to the VES studies, the top soil in the study area is either laterite soil or hydromorphic soil, with a thickness of 0.75 to 4 m. Laterites of varying hardness were found at depths ranging from 4 to 17 m. In some locations, there was lithomargic clay that was less than 2 m thick beneath the laterites. These layers were found to sit on top of weathered rock that ranges in thickness from 2 to 14 m, then hard rock that may or may not have fractures.

Materials and Methods

CHAPTER III

MATERIALS AND METHODS

Groundwater is a vital natural resource and its availability and quality are crucial for the existence of life. Demand for groundwater is increasing year by year, and in order to meet this increasing demand, it is extremely important to properly understand the supply and distribution of groundwater. The objective of the study was to analyse the hydrogeological characteristics of the geological formations of Tavanur Grama Panchayat using Electrical Resistivity Meter and to prepare the pseudo cross-section of the aquifer formation of the study area using IPI2WIN software. Tavanur Grama Panchayat was taken as the study area and the materials and methods chosen for carrying out the study are discussed in this chapter.

3.1 STUDY AREA

The area selected for the study was Tavanur Grama Panchayat, situated in Malappuram District of Kerala State in India. This panchayat is located on the southern bank of Bharathapuzha, second largest river in Kerala. The study area accommodating an aerial extent of 42.37 km^2 lies between 10° 51' 47" to 10° 49' 40" N latitude and 75° 57' 39" to 76° 01' 25" E longitude. The location map of the study area is shown in the figure (Fig. 4.1).

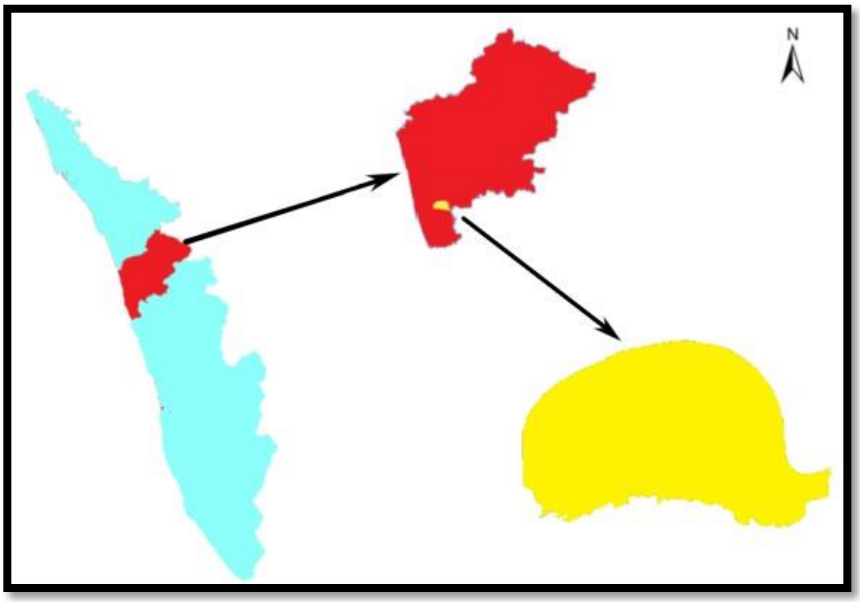

Fig. 3.1 Location map of the study area

The mean maximum and minimum temperatures of the area ranges 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.

The groundwater exploration study was done by conducting the geophysical survey in the selected 24 locations across the panchayat.

3.2 ELECTRICAL RESISTIVITY SURVEY

The vertical electrical sounding method was carried out to analyse the aquifer characteristics of different locations in the study area using Earth Resistivity Meter (MODEL-SSR-MP-ATS). 24 locations in the study area was selected for doing VES survey. Wenner electrode configuration was used to do the VES survey. The current electrode spacing (AB) ranged from 6 m to 120 m (AB/2 = 3 to 60 m) and potential 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. Current was applied 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 the distance between two current electrodes. With the available values of 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.

3.2.1 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, which can provide information about the distribution of water, minerals, and other subsurface features.

The basic components of an electrical resistivity meter for ground water exploration includes:

3.2.1.1 Electrodes

The electrodes (Plate 3.1) are the parts of the meter that encounters 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.

Plate 3.1 Electrode

3.2.1.2 Current source

A 24 V chargeable battery is used as a current source. The current is typically a low-frequency alternating current, ranging from a few milli amperes to several amperes. Plate 3.2 and Plate 3.3 shows the battery and battery charger of the electrical resistivity meter respectively.

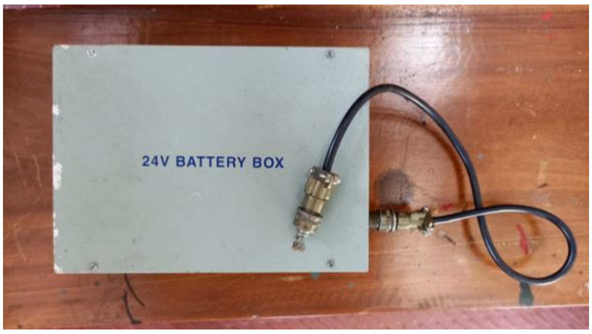

Plate 3.2 Battery

Plate 3.3 Battery charger

***3.2.1.3* Data acquisition unit**

The data acquisition unit (Plate 3.4) is responsible for recording the voltage measurements and storing the data for later analysis. It may also include signal processing.

Plate 3.4 Data Acquisition unit of Electrical resistivity meter

3.2.1.4 Display unit

The display unit (Plate 3.5) is used to visualize the resistivity data in real-time or after the measurement has been completed. It may include software for data analysis and interpretation.

Plate 3.5 Display unit

3.2.1.5 Cables

The cables (Plate 3.6) are used to connect the electrodes, current source, and the data acquisition unit together.

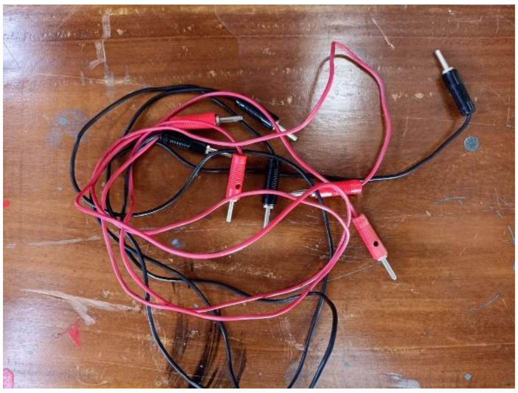

Plate 3.6 Cables

3.2.1.6 Winches

There are four winches with sufficient length of wire, two winches for current electrodes and two winches for potential electrodes. The open end of wires is equipped with a clip pin, which is used to connect the wire to the electrodes. Banana sockets are provided at both ends of the winches to connect the instrument. Plate 3.7 shows the winches.

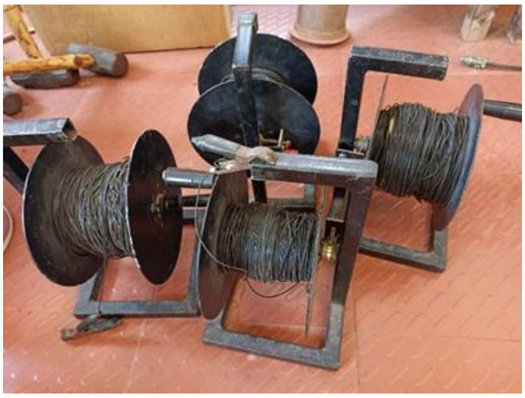

Plate 3.7 Winches

In short, an electrical resistivity meter is a complex system that requires careful calibration and operation to obtain accurate and reliable data. It is commonly used in geologic and environmental investigations, such as groundwater exploration, mineral exploration, and mapping geological structures.

3.2.2 Calibration of Electrical Resistivity Meter

The Test Resistance Box (Plate 3.8) was used to calibrate the resistivity meter and it has three rows of ports with different resisitivities. The first row has 0.1 and 0.4 Ω and the second row has 1 and 4 Ω. For this study, the first two rows were selected for the calibration. To test the low values of resistance, connect the current terminals to C1 & C2 ports of the top row and connect the potential terminals across 0.1 or 0.4 Ω. The measured value of resistance should tally within 1%. To check the second row of resistance, connect the current terminals to C1 & C2 of the second row and connect the potential terminals across 1 or 4 Ω and the measurements were taken. Plate 3.9 depicts the calibration procedure.

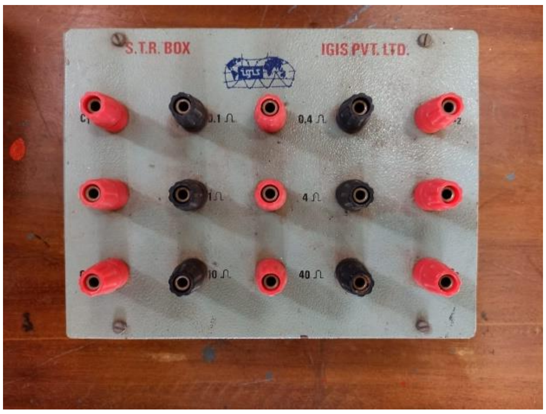

Plate 3.8 Test resistance box

Plate 3.9 Calibration of Electrical resistivity meter

3.3 SELECTION OF VES LOCATIONS

The map of the study area (Tavanur panchayat) was downloaded from Google Earth as KML file (Fig. 3.2) and it was then imported to ArcGIS. Further, the grid map of the study area was created (Fig. 3.3) using the following procedure:

Select Arctoolbox → Conversion tools → From KML → KML to Layer → The Grid map of Tavanur panchayat with an interval of 1km was created using ArcGIS → Zoom the study area → Arc toolbox → Cartography tool → Data driven pages → Grid index feature → Grid (1000 × 1000 m) → To KML.

The grid map generated from ArcGIS was then exported to google earth for marking the locations in the real field for conducting the VES as shown in Fig. 3.4. The latitude, longitude and elevation of the points were noted. The deatails of the VES locations are tabulated in Table 1.

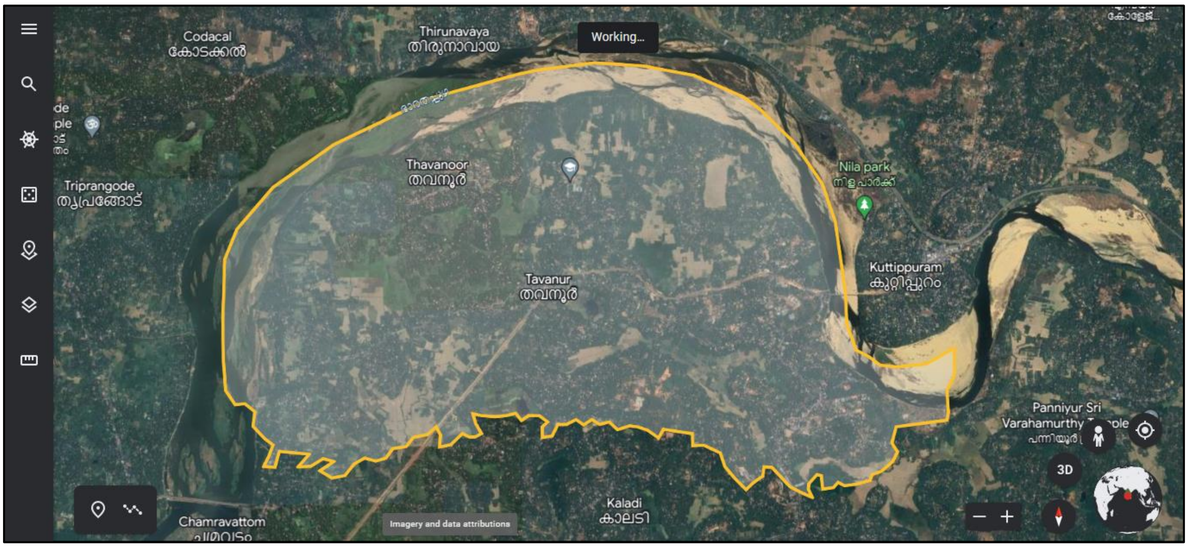

Fig. 3.2 Google earth map of Tavanur panchayat

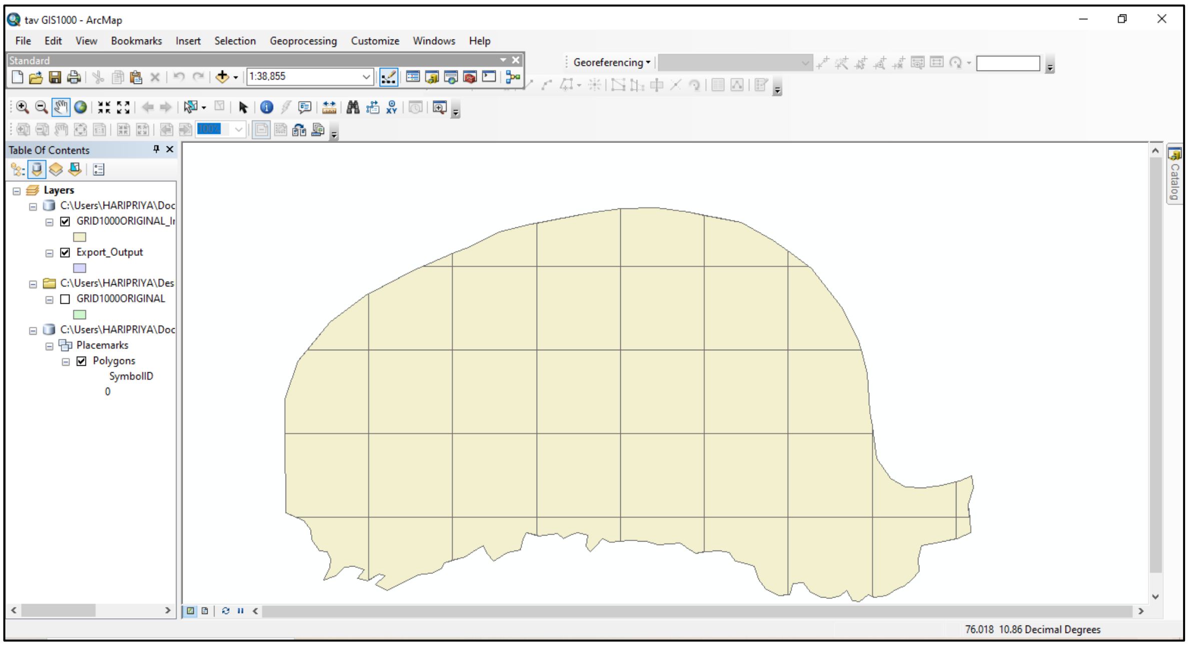

Fig. 3.3 Grid formation of the study area

Table 1: Details of VES locations

Grid point	Latitude	Longitude	Elevation	Landmark
G1	10°51'21.31"N	75°59'3.74"E	18	Coconut orchard near Nila (KCAET)
G2	10°51'9.29"N	75°59'18.44"E	26	Coconut orchard near lab (KCAET)
G3	10°51'31.50"N	75°59'42.44"E	22	Nambram
G4	10°51'26.04"N	76° 0'21.74"E	28	Kuzhunjodi
G5	10°51'25.59"N	76° 0'53.73"E	20	Avoided
G6	10°50'45.05"N	76° 0'50.80"E	40	Madirassery
G7	10°51'4.076"N	76° 0'13.05"E	34	Vellanchery
G8	10°50'56.22"N	75°59'49.84"E	38	Kadakassery
G9	10°50'52.12"N	75°59'21.54"E	36	Muvankara
G10	10°50'44.46"N	76°0'50.13"E	38	Muradavilpadi
G11	10°50'28.17"N	75°58'18.85"E	31	Kakkasserykunnu
G12	10°50'14.18"N	75°58'11.02"E	28	Nadet
G13	10°50'28"N	75°58'47"E	19	Athaloor
G14	10°50'33.30"N	75°59'16.32"E	37	Anthyalamkulam
G15	10°50'12.90"N	75°59'13.68"E	25	Kallur
G16	10°50'28.23"N	76° 0'34.67"E	42	Ayankalam
G17	10°50'9.015"N	76° 0'47.73"E	57	Tavanur Central jail
G18	10°49'48.90"N	76° 1'25.94"E	73	MES college
G19	10°49'40.12"N	76° 1'6.015"E	50	Pattaparambu
G20	10°49'32.46"N	76° 0'7.255"E	60	Kachery parambu
G21	10°49'47.71"N	75°59'50.96"E	36	Maravanchery
G22	10°49'47"N	75°59'7"E	20	Kadanchery
G23	10°49'55.62"N	75°58'38.44"E	24	Athaloor
G24	10°49'51.55"N	75°58'13.12"E	25	Mathoor palli

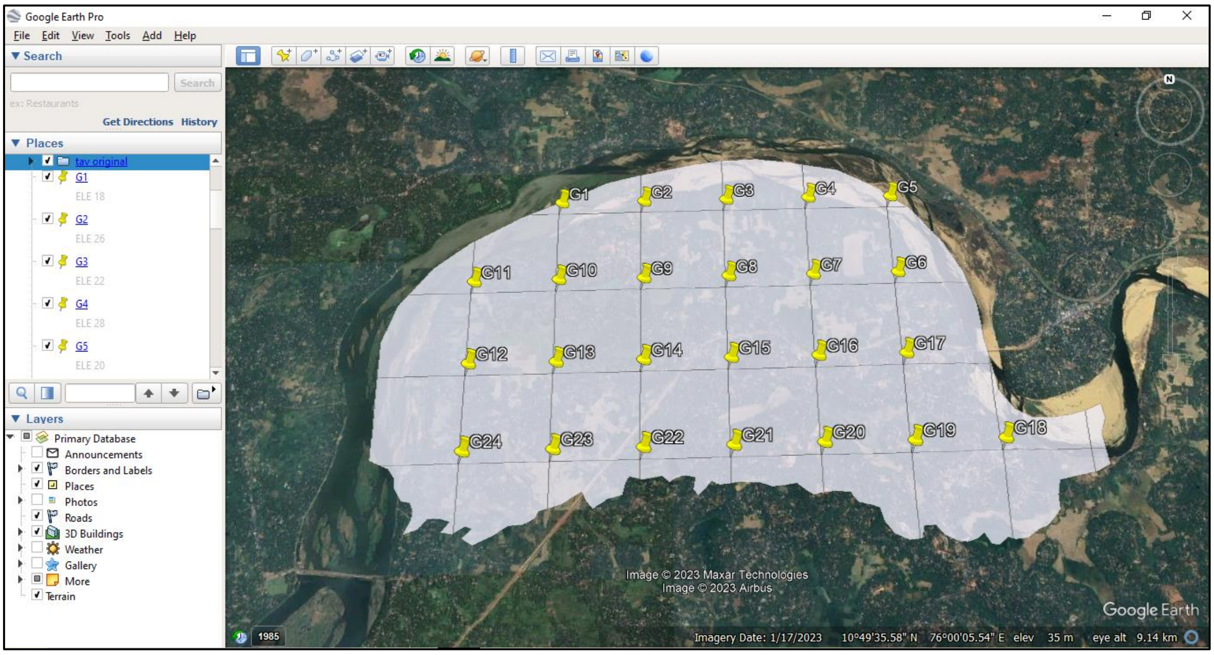

Fig. 3.4 VES locations in the study area

3.4 DATA COLLECTION

3.4.1 Reconnaissance Survey

A reconnaissance survey was conducted in 24 identified locations to check the suitability for VES survey. An area having minimum 100 m length without any obstructions and with less compacted soil is best suited for the survey. The location G5 was identified as unsuitable for VES survey. Plate 3.10 shows the photograph of reconnaissance survey.

Plate 3.10 Reconnaissance survey of VES locations

3.4.2 Vertical Electrical Sounding

The Wenner configuration was used for obtaining the required data and the change in resistivity according to increasing depth was noted. Likewise, the survey was carried out in all the 23 locations of the study area. Plate 3.11 shows the photographs of carrying out the experiment in the field.

Plate 3.11 VES survey using Electrical resistivity meter

3.5 INTERPRETATION OF VES DATA

The data obtained from the VES survey of 23 locations across Tavanur panchayat were initially interpreted using IPI2WIN software. The software gives an output that displays resistivity, thickness and depth of different soil layers from the ground surface (Shishaye *et al*., 2016). The VES location map of Tavanur Grama anchayat is given as Fig. 3.5.

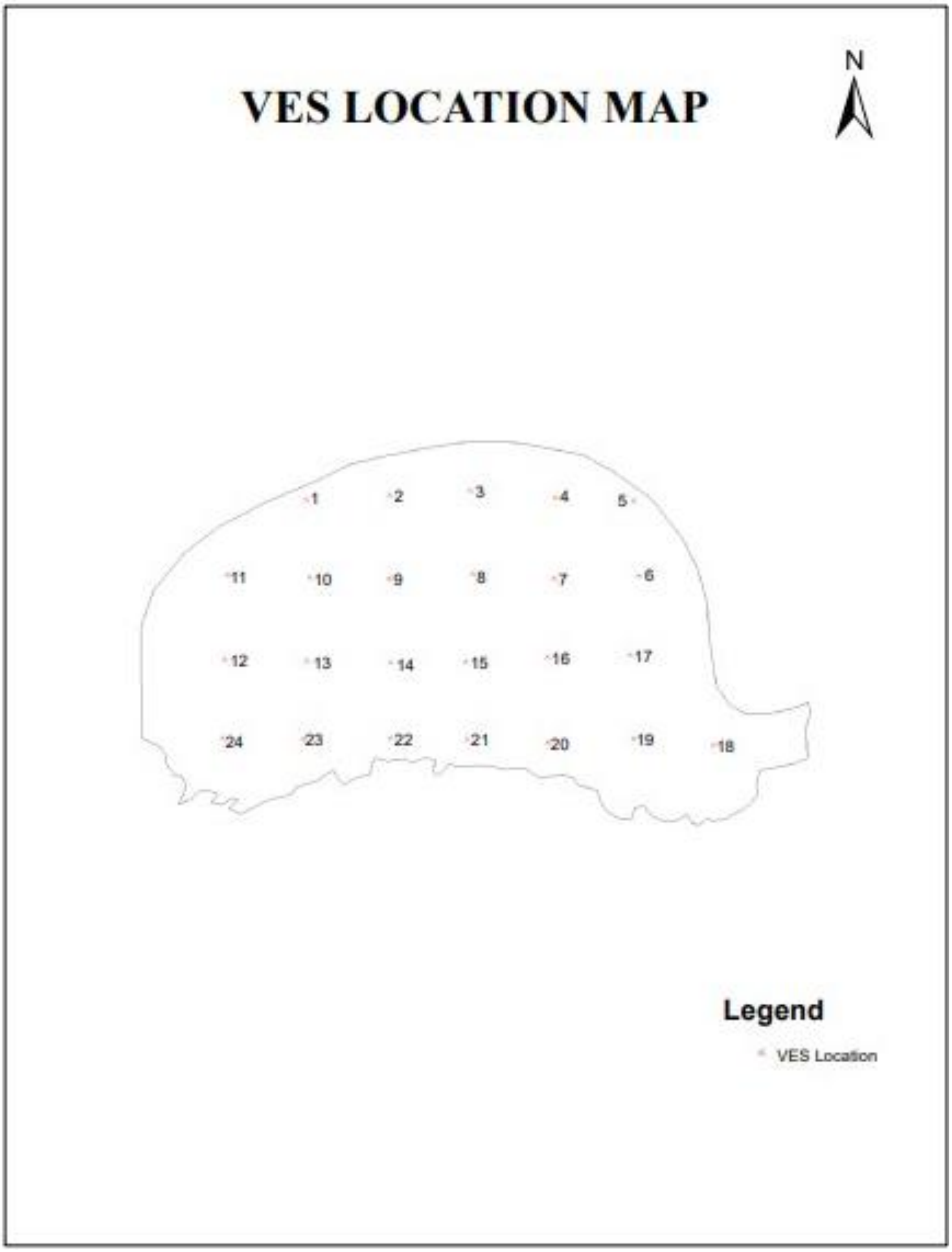

Fig. 3.5 VES locations

3.5.1 Computer Inversion Techniques

In order to avoid the chance of error in the interpretation and judgement of manual curve matching procedure, computer inversion program IPI2WIN version 2.1 developed by the Moscow State University (2001) was used in this study.

The input data given for the execution of inversion includes:

i. Field measurements as spacing and apparent resistivity.
ii. Type of electrode arrangement used (Wenner, Schlumberger or Dipole)
iii. Number of layers
iv. Assumed layer resistivity (ρ) and thickness (h)

The procedure followed by IPI2WIN software was an iterative method. A starting resistivity model was chosen based on a prior information from ground truthing or averaged geophysical measurements and apparent resistivity data was modelled for the type of field survey geometry used. The generated data were then compared with the actual data and the resistivity model was updated based on the difference between observed and calculated data. This procedure was continued until the calculated data matched the actual measurements within an interpreter- defined level of error.

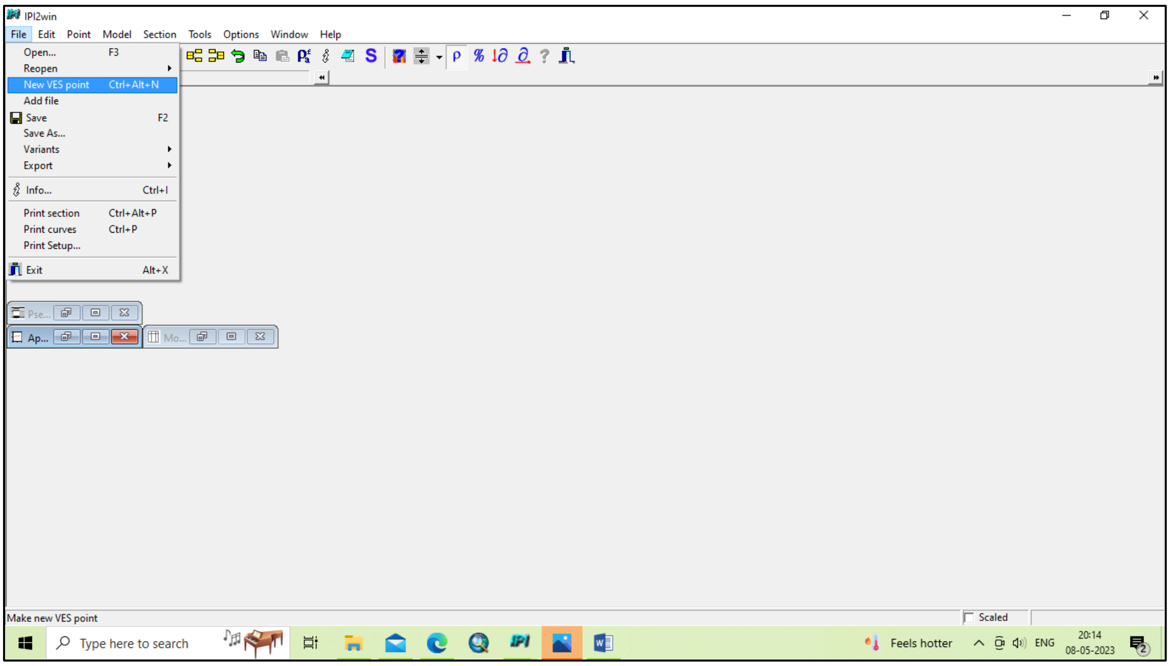

Fig.3.6 Window of IPI2WIN software creating VES file

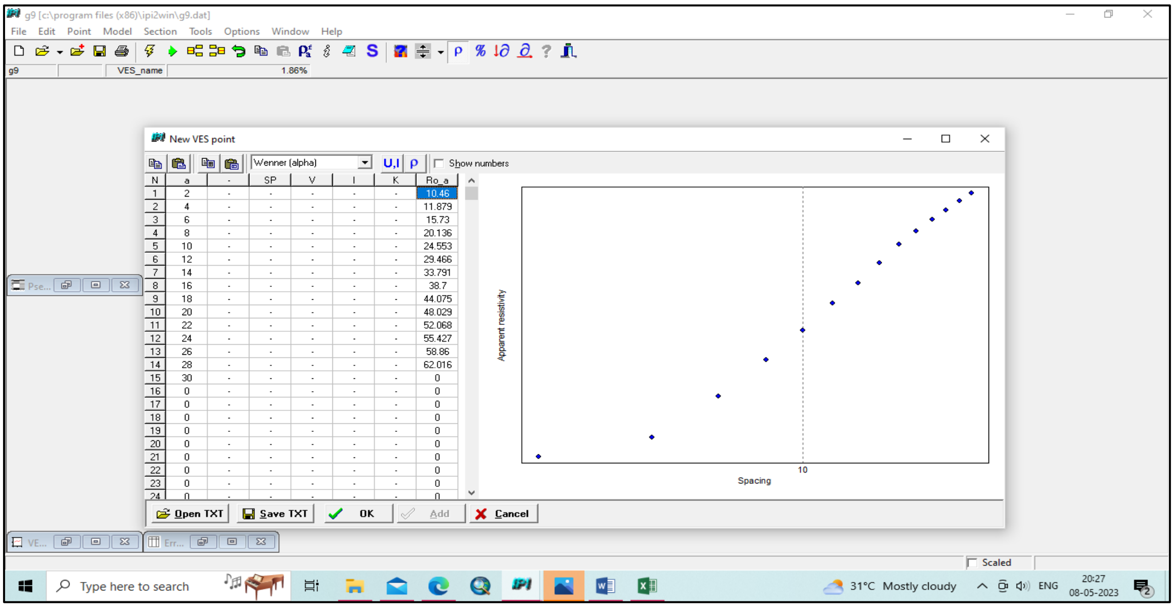

Fig. 3.7 Adding input in VES File

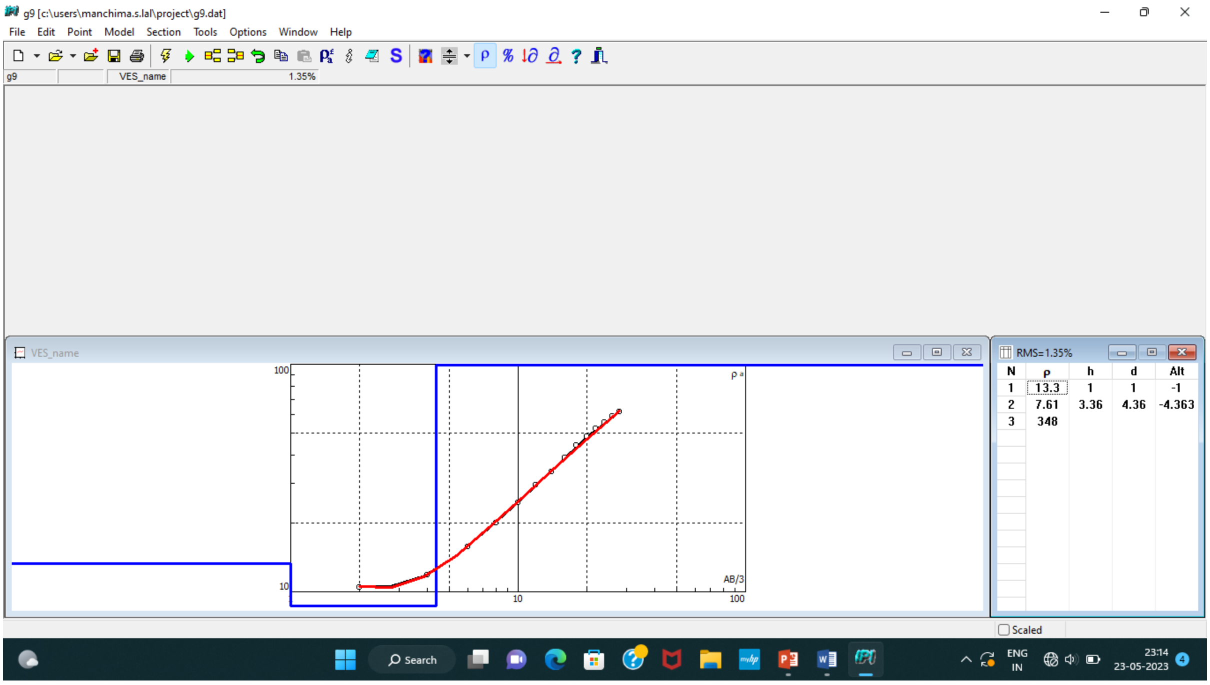

Fig. 3.8 Sounding curve

The type and number of layers of the substrata of the study area were identified by using sounding curves obtained from the interpretation of VES data using IPI2WIN software.

3.5.2 Sounding curves

Based on the geological and hydrogeological formations and the maximum electrode spacing used, various combinations of sounding curves were created. The simplest sounding curves are ascending and descending type of curves with two layer cases. If the ground has two layered structure, with loose top soil or a weathered and a compact basement, the curve will be ascending type. A descending curve is created if the top layer is highly resistive and the bottom layer is conductive due to saline water or some other saturated conditions (Brijesh and Balasubrahmanian, 2014).

Four types of sounding curves are possible in three layered geology of ground substrata. If $\rho 1$, $\rho 2$ and $\rho 3$ are the resistivities of three successive layers, a sounding curve with a low resistivity at centre ($\rho 1 > \rho 2 < \rho 3$) is known as H type curve. This type of curves are obtained in hard rock terrains which consists of dry top soil of high resistivity as the first layer, water saturated weathered layer of low resistivity as the second layer and compact hard rock of very high resistivity as the last layer (Brijesh and Balasubrahmanian, 2014).

If the resistivities of the layers are steadily increasing ($\rho 1 < \rho 2 < \rho 3$) the curve is known as A type curve. This type of curves occurs in the hard rock terrain with conductive soil. Sounding curves showing a maximum hump flanked by low resistivity values ($\rho 1 < \rho 2 > \rho 3$) are called K type curves. In case of coastal areas, these curves are encountered due to the presence of fresh water aquifer underlying a clayey layer overlying a saline water layer (Brijesh and Balasubrahmanian, 2014). A sounding data which has a steadily decreasing resistivity ($\rho 1 > \rho 2 > \rho 3$) will give a Q type curve, found in the coastal areas where saline water is present.

Four layer curves of eight possible combinations (HK, HA, KH, KQ, AA, AK, QQ, QH) are available and complicated sounding curves representing multilayer situations like HKHK, KHKH, HAA etc. are also available for interpretation (Brijesh and Balasubrahmanian, 2014).

3.5.3 Resistivity and pseudo cross sections

The resistivity and pseudo cross sections along 6 sections were prepared using true and apparent resistivity values. The VES data of the first grid point in the straight line was opened in IPI2WIN software. The following procedure was then followed:

File → Add file → Select the next grid point data → Open → Rename the locations → Click OK.

Likewise, the data of all the grid points were added in the selected straight line.

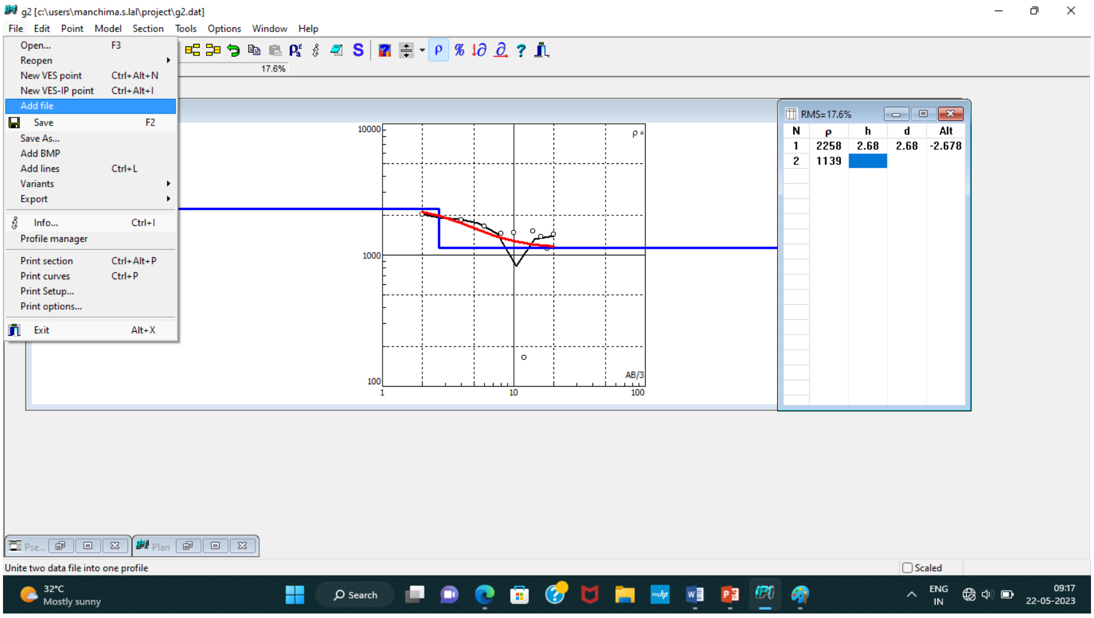

Fig. 3.9 (a) Procedure for creating resistivity and pseudo cross sections

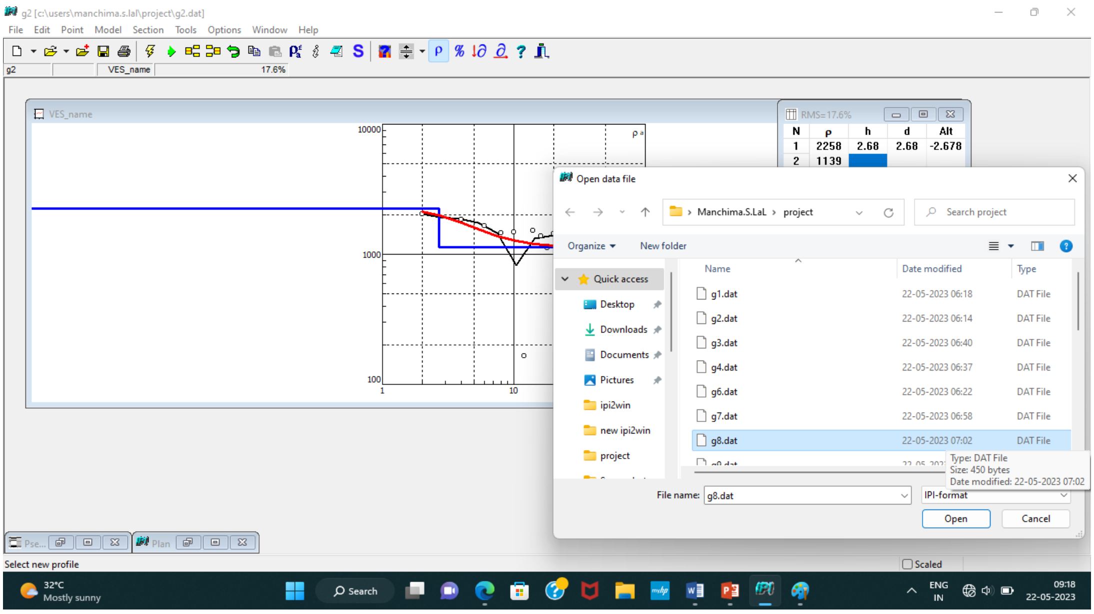

Fig. 3.9 (b) Procedure for creating resistivity and pseudo cross sections

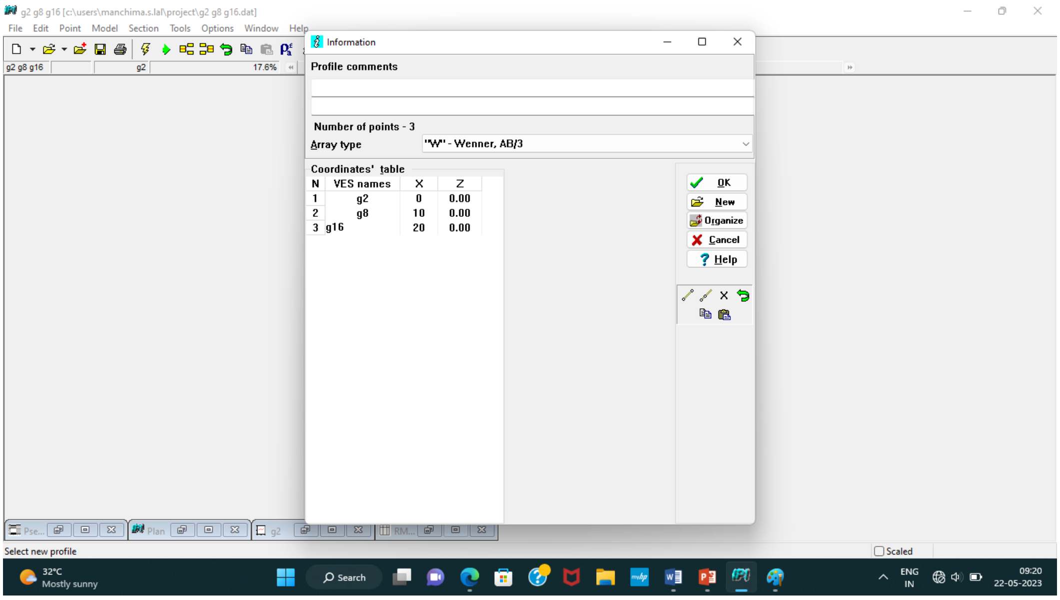

Fig. 3.9 (c) Procedure for creating resistivity and pseudo cross sections

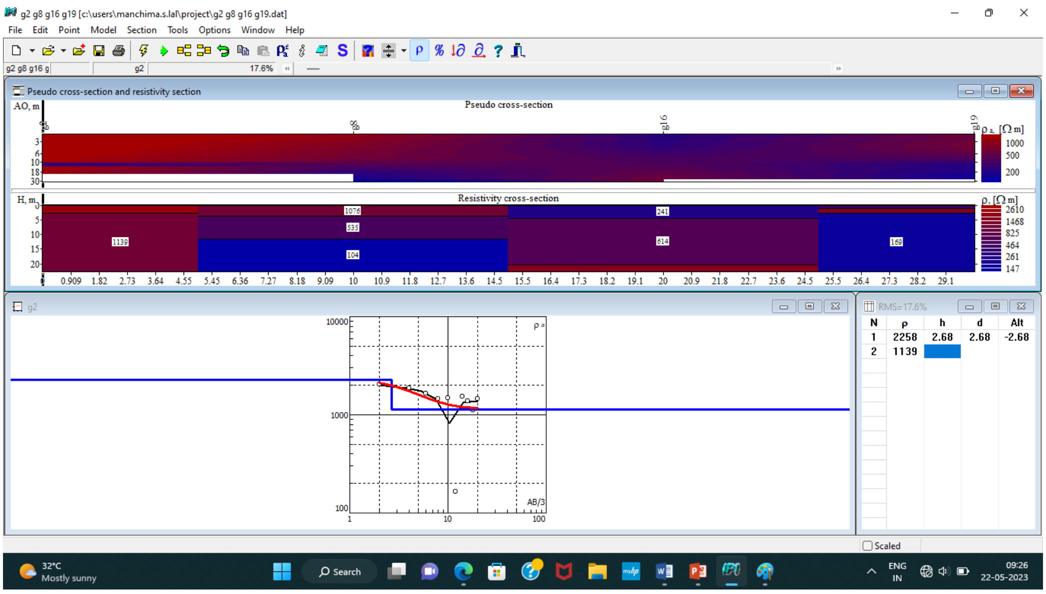

Fig. 3.10 Resistivity and pseudo cross sections

Results and Discussion

CHAPTER IV

RESULTS AND DISCUSSIONS

The variations in the levels of ground water of a region are primarily influenced by a number of elements such as precipitation, topographical features, soil characteristics, land use patterns, geology, hydraulics of rivers and geomorphology. These groundwater fluctuations can be determined effectively by using various geophysical methods. The results obtained from the electrical resistivity method carried out in Tavanur Grama Panchayat and the interpretation of the data are discussed in this chapter.

4.1 AQUIFER CHARACTERISTICS OF THE STUDY AREA

4.1.1 Interpretation of VES data

The field data collected from VES survey were interpreted using IP12WIN software to obtain the resistivity values of different subsurface layers and thickness of each layer which are given in Table 2. By the interpretation of sounding curves, 2 to 4 subsurface layers where identified within the study area with sounding curves H, K, A, Q, HA, HK and QH types. The presence of three layer substrata are represent by H, K, A and Q sounding curves, while the combination curves HK, QH and HA represent four layer sub strata. Out of the 23 locations of VES survey, one location showed two layer substrata, seventeen locations showed three layer substrata and four locations showed four layer sub strata.

Table 2. 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	10.5	162	5030	1	3.04	12.3	16.3
G2	Coconut orchard near lab (KCAET)	2258	1139	-	-	2.68	-	-	2.68
G3	Nambram	21.4	402	0.462	-	3.63	5.07	-	8.7
G4	Kuzhunjodi	42.5	8.02	56	-	2.57	1.21	-	3.78
G6	Madirassery	124	15.2	10.8	2571	1	3.66	17.1	21.8
G7	Vellanchery	175	84.7	23.7	-	1	1.62	-	2.62
G8	Kadakassery	1076	535	104	-	3.66	7.93	-	11.6
G9	Muvankara	13.3	7.61	348	-	1	3.36	-	4.36
G10	Muradavil padi	182	8.88	1785	-	1.87	8.69	-	10.6
G11	Kakkassery kunnu	33.8	5.41	80.3	-	2.02	2.24	-	4.26
G12	Nadet	354	26.5	60.8	0.722	1	3.52	15.9	20.4
G13	Athaloor	17.7	57	140	-	1	23.6	-	24.6
G14	Anthyalam kulam	95.1	48.9	21.7	65.9	1	3.95	19.5	24.5
G15	Kallur	102	200	1178	-	4.52	15.9	-	20.4
G16	Ayankalam	241	614	1474	-	4.52	15.9	-	20.4
G17	Tavanur Central jail	1269	48.2	15500	-	6.87	8.63	-	15.5
G18	MES college	679	34.1	402	-	1	0.8	-	1.8
G19	Pattaparambu	395	1644	169	-	1	1.7	-	2.7
G20	Kachery parambu	755	7692	4.6	-	1.02	3.78	-	4.8
G22	Kadanchery	58.6	18.5	54.2	-	4.36	13.8	-	18.2
G23	Athaloor	43.6	44.7	18	-	1	3.48	-	4.48
G24	Mathoor palli	64.7	30.1	142	-	1	14	-	15

4.1.1.1 H type curve

The sounding curves from Kuzhunjodi (G4), Muvankara (G9), Muradavilpadi (G10), Kakkassery kunnu (G11), Tavanur Central jail (G17), MES college (G18), Kadanchery (G22) and Mathoor palli (G24) showed 'H' type curve with three layer substrata ($\rho1 > \rho2 < \rho3$) 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 the three locations were found to have resistivity ranging from 33.8 to 80.3 Ωm which indicated that the soil formation is lateritic. The second layer was having 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. 4.1, 4.2 and 4.3 respectively.

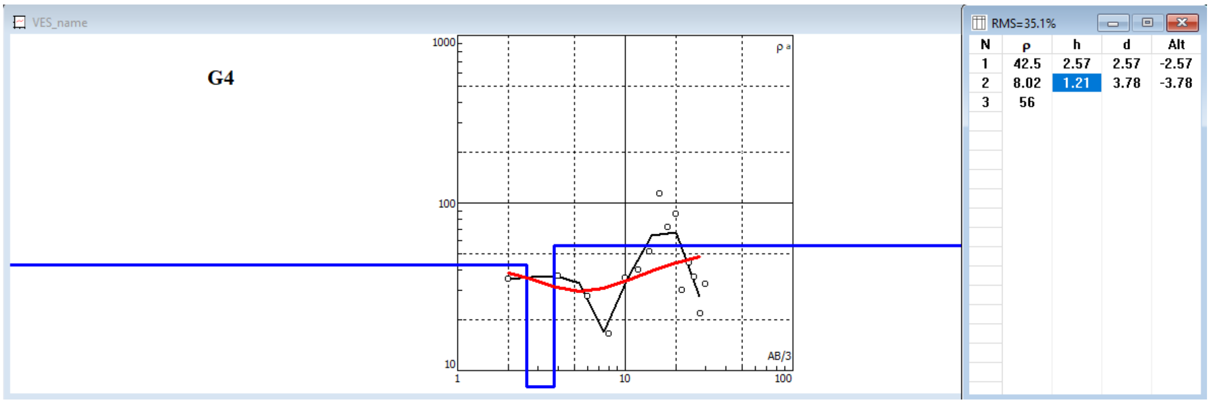

Fig. 4.1 Sounding curve of the location G4 (H-Type)

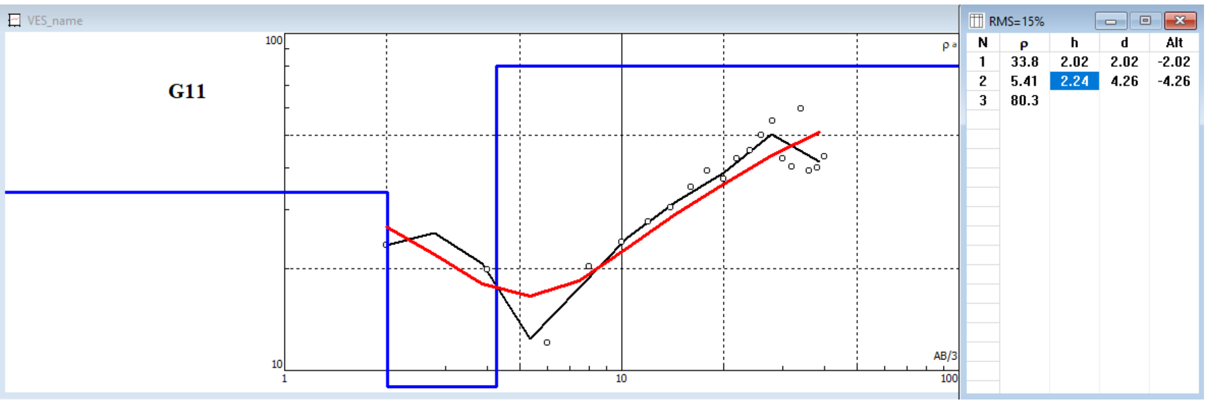

Fig. 4.2 Sounding curve of the location G11 (H-Type)

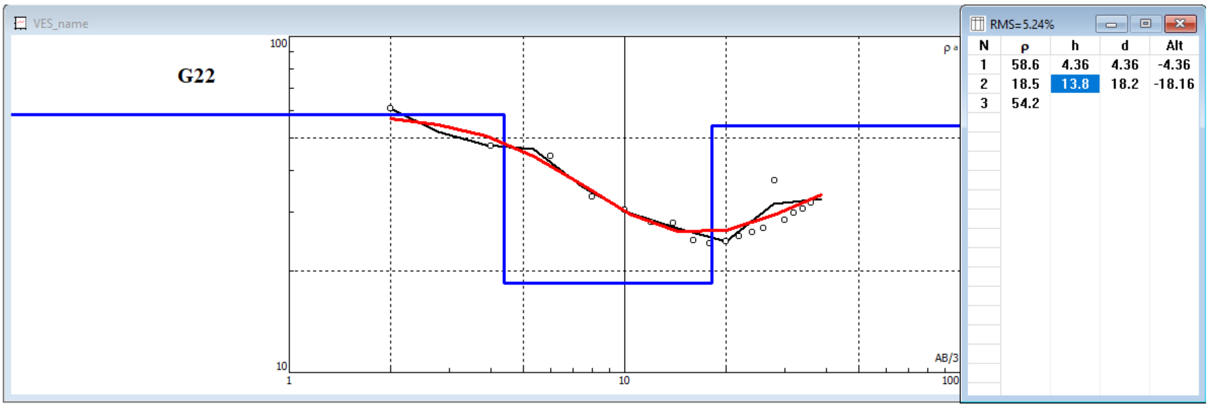

Fig. 4.3 Sounding curve of the location G22 (H-Type)

The first layer of 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 (Fig. 4.4) depicted a third layer of resisitivity of 15500 Ωm, which indicated the presence of hardrock (Metamorphic /Gneiss). This was the location near the Central Jail, Tavanur. The location G18 was having a third layer of hard laterite formation or weathered rock with a resisitivity of 482 Ωm. The sounding curve of the location G18 is shown in Fig. 4.5.

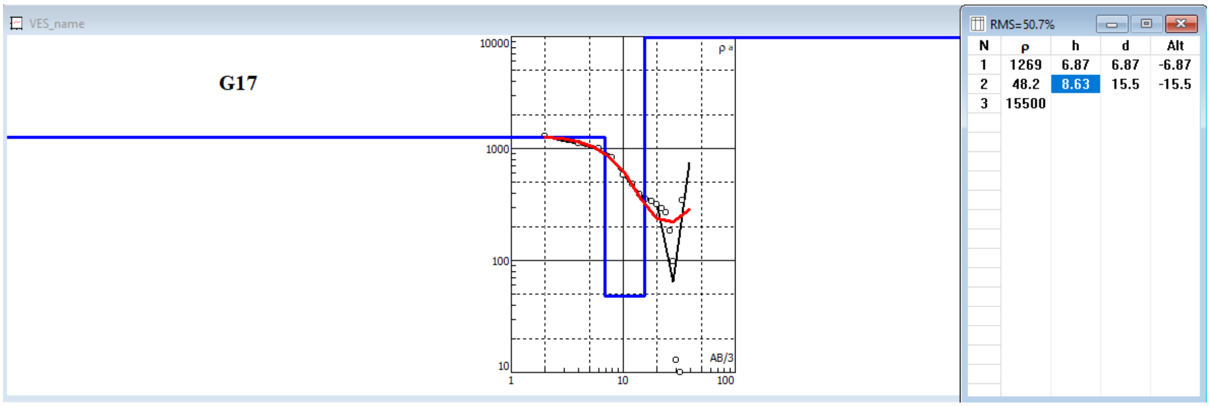

Fig. 4.4 Sounding curve of the location G17 (H-Type)

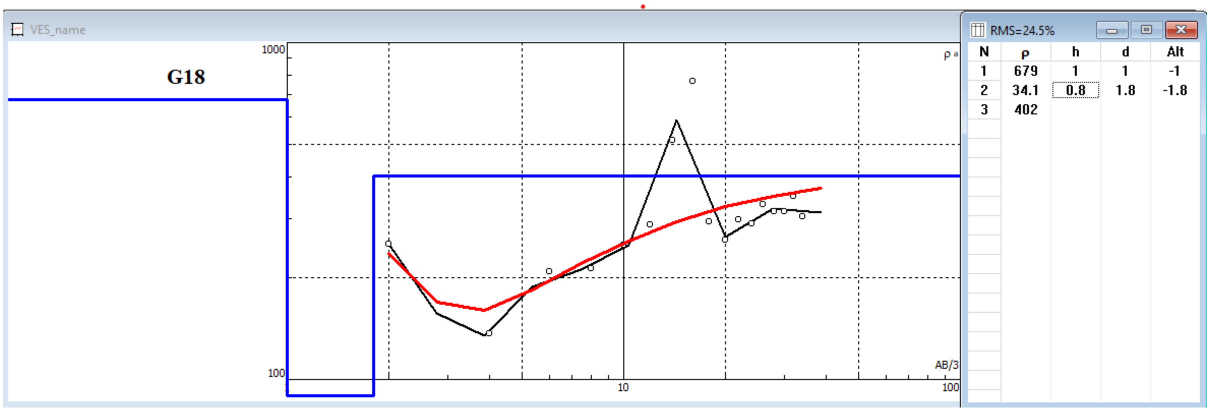

Fig. 4.5 Sounding curve of the location G18 (H-Type)

The sounding curve data of G10 (Fig. 4.6) location 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.

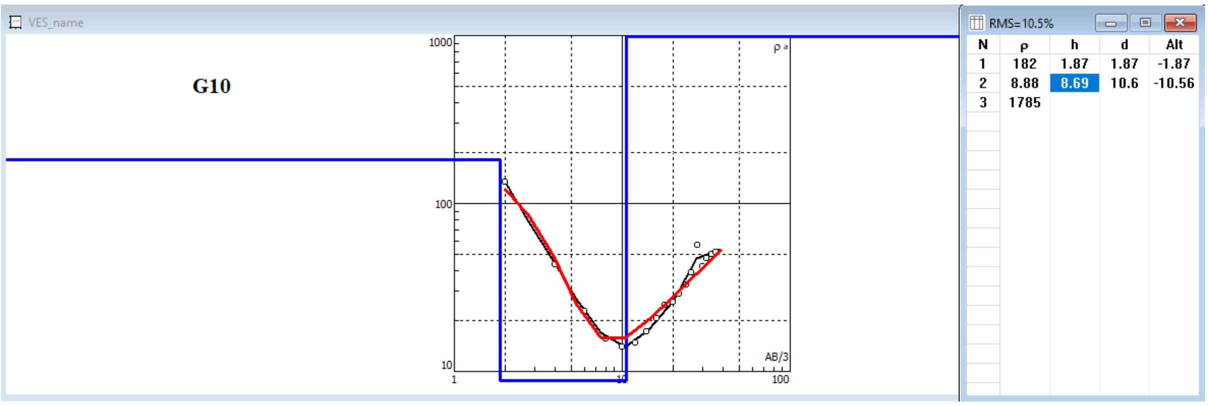

Fig. 4.6 Sounding curve of the location G10 (H-Type)

The sounding curve of G24 (Fig. 4.7) showed low resistivity ranges which indicated the presence of lateritic soil or loose soil.

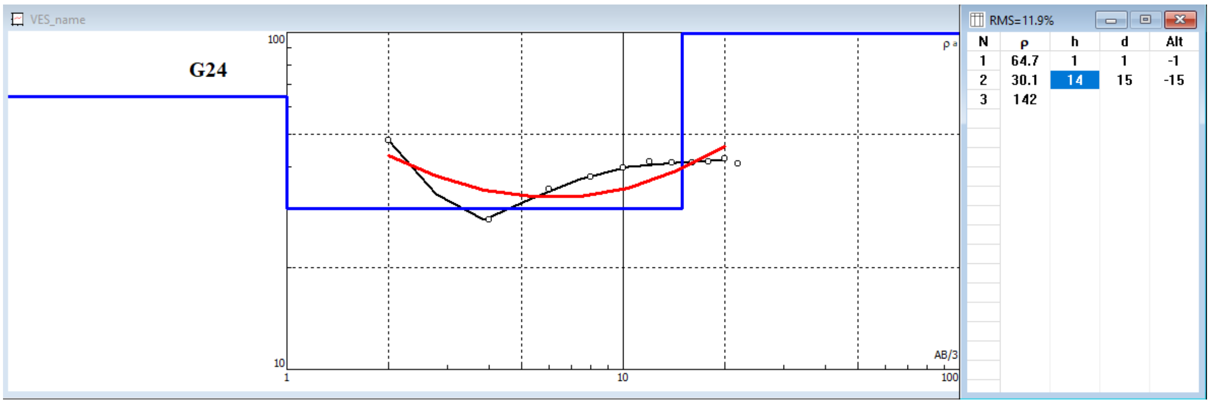

Fig. 4.7 Sounding curve of the location G24 (H-Type)

At the location G9 the top layer was found having low resistivity which indicated the presence of clayey loam formation. The result from the survey was justified with the photograph taken from the location (Plate 4.1).

Plate 4.1 Paddy field of Muvankara (G9)

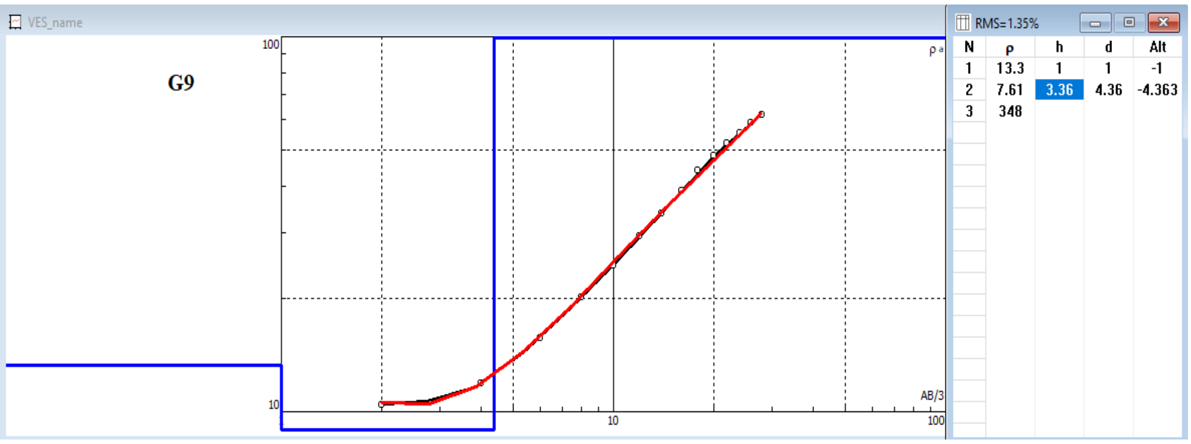

Fig.4.8 Sounding curve of the location G9 (H-Type)

4.1.1.2 K type curve

The soundings curves from Nambram (G3), Pattaparambu (G19), Kachery parambu (G20) and Athaloor (G23) revealed the presence of a three-layered substrata (ρl< ρ2> ρ3) with 'K' type curve as shown in Fig.4.9, 4.10, 4.11 and 4.12 respectively. The resistivity of first layer ranged from 21.4 to 755 Ohm-m with a thickness of 1 to 3.63 m. This indicated the presence of lateritic topsoil. The second layer resistivity ranged from 44.7 to 7692 ohm-m which indicated the presence of hard laterite/unconsolidated sedimentary rock with thickness range of 1.7 m to 5.07 m. Third layer was the low resistivity substrata (0.462 - 169 Ohm-m) such as weathered rock. These results were in agreement with the result reported by Sajeena and Kurien (2015).

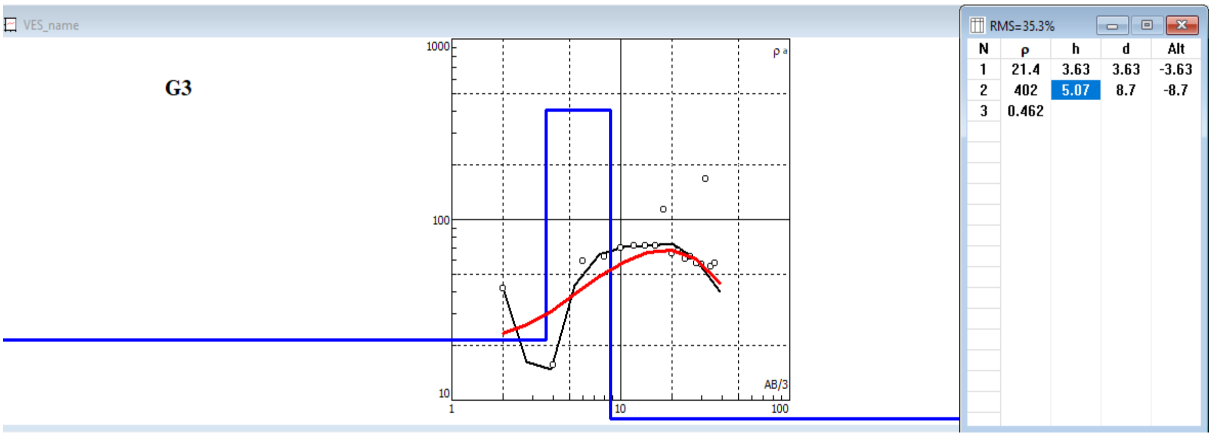

Fig.4.9 Sounding curve of the location G3 (K-Type)

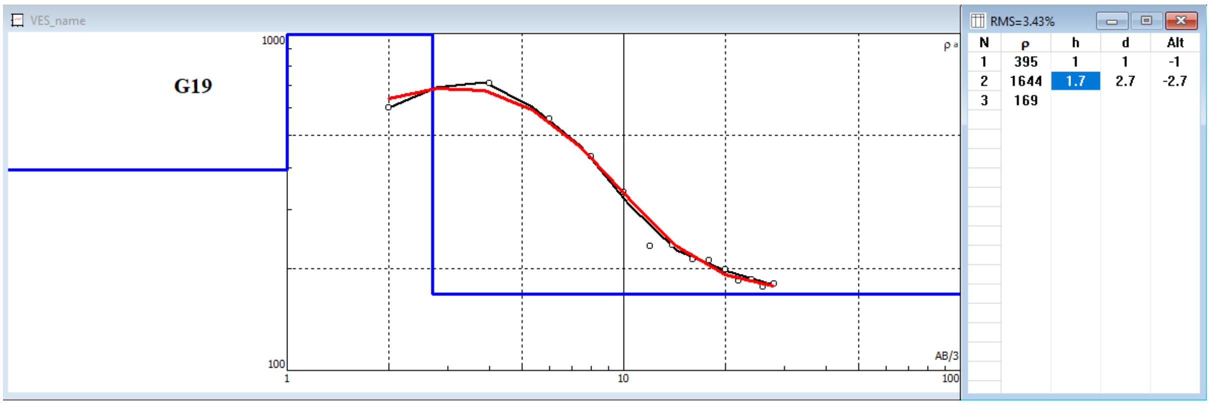

Fig.4.10 Sounding curve of the location G19 (K-Type)

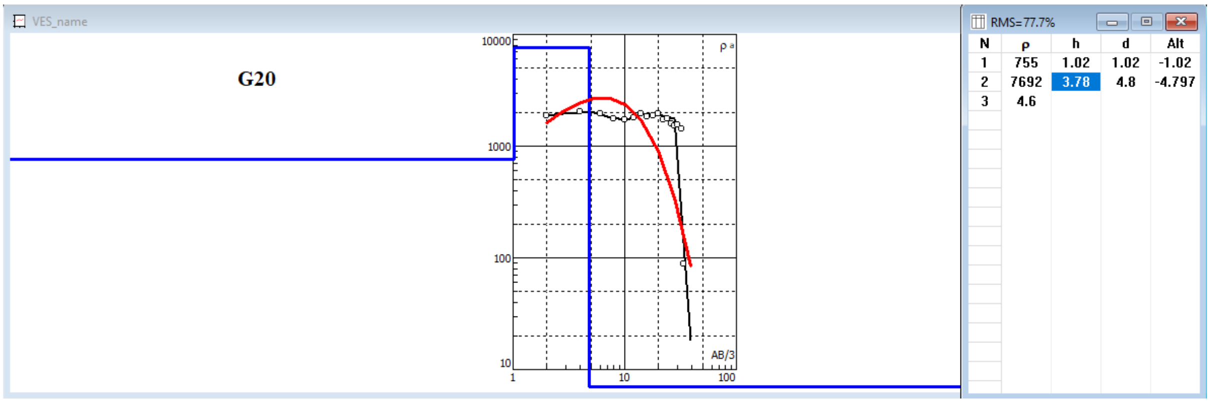

Fig.4.11 Sounding curve of the location G20 (K-Type)

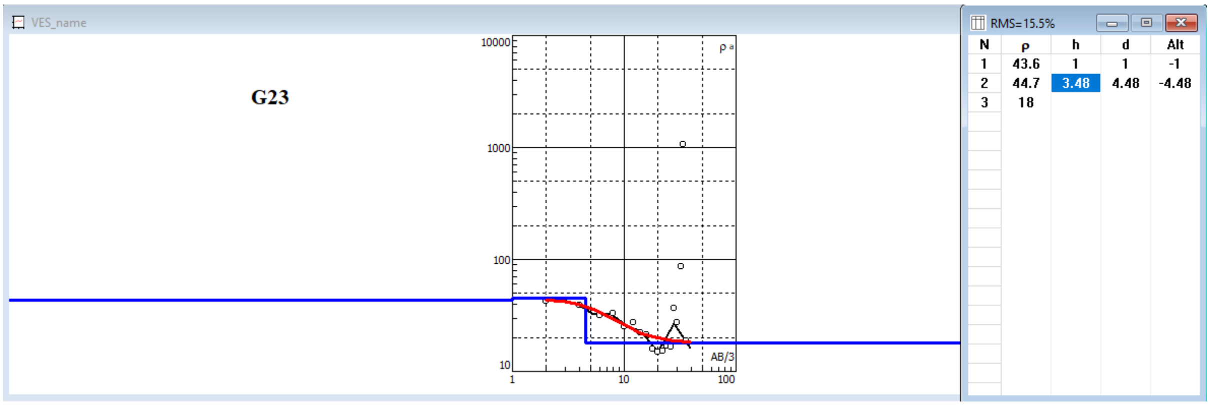

Fig.4.12 Sounding curve of the location G23 (K-Type)

4.1.1.3 A type curve

The sounding curves of the locations Athaloor (G13), Kallur (G15) and Ayankalam (G16) were morphologically defined by a three layer model with the resistivity sequence of ρl< ρ2< ρ3 as shown in Fig.4.13, 4.14, and 4.15. This type of curve implies that the soil is having a low resistivity top layer and a high resistivity third layer showing a steady increase in the resistivity with increase in the depth. The first layer had a resistivity range of 17.7 - 241 Ohm-m of thickness 1 to 4.52 m. This result indicated that this area is suitable for open wells.

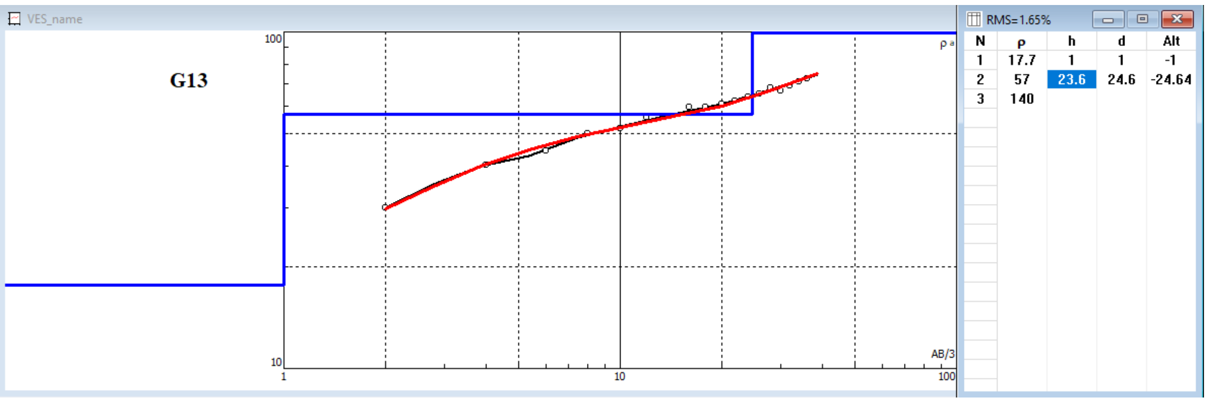

Fig.4.13 Sounding curve of the location G13 (A-Type)

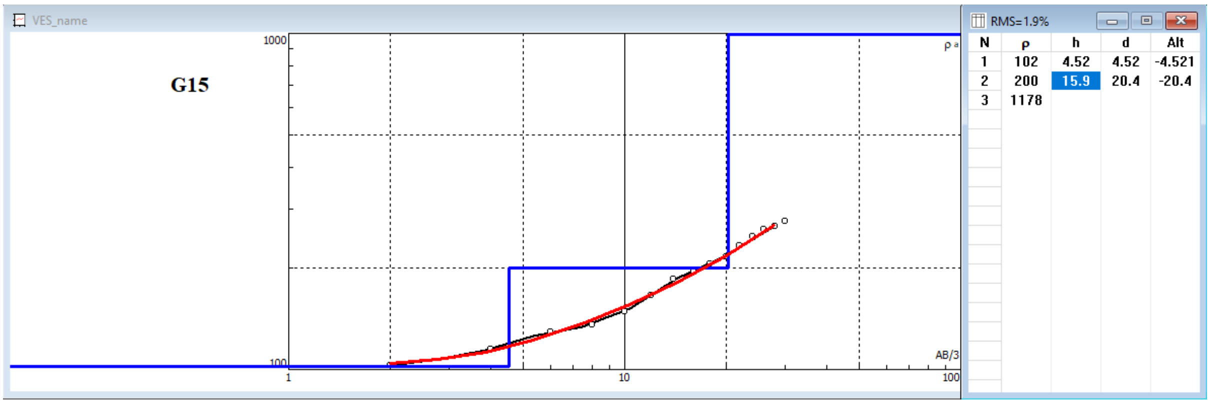

Fig. 4.14 Sounding curve of the location G15 (A-Type)

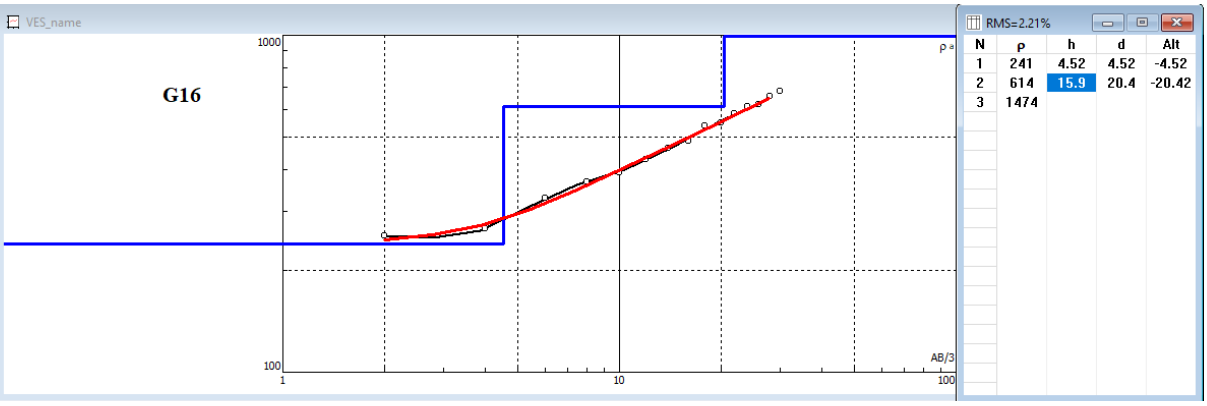

Fig.4.15 Sounding curve of the location G16 (A-Type)

4.1.1.4 Q type curve

The sounding curves from the locations Vellanchery (G7) and Kadakassery (G8) could be explained by the three layered model with steady decrease in the soil resistivity ($\rho 1>\rho 2>\rho 3$) which indicated that the top soil has a high resistivity and the substrata followed a low resistivity pattern as shown in the Fig. 4.16. At the location G7, the first layer was having the resistivity 175 ohm-m followed by a layer of resistivity 84.7 ohm-m. This indicated that the top soil is followed by a clay layer. At the location G8, the top layer was having resistivity 1076 ohm-m, and was decreasing towards the bedrock (Fig. 4.17). This indicated the presence of hard laterite layer at the top and its hardness found decreasing towards the bottom.

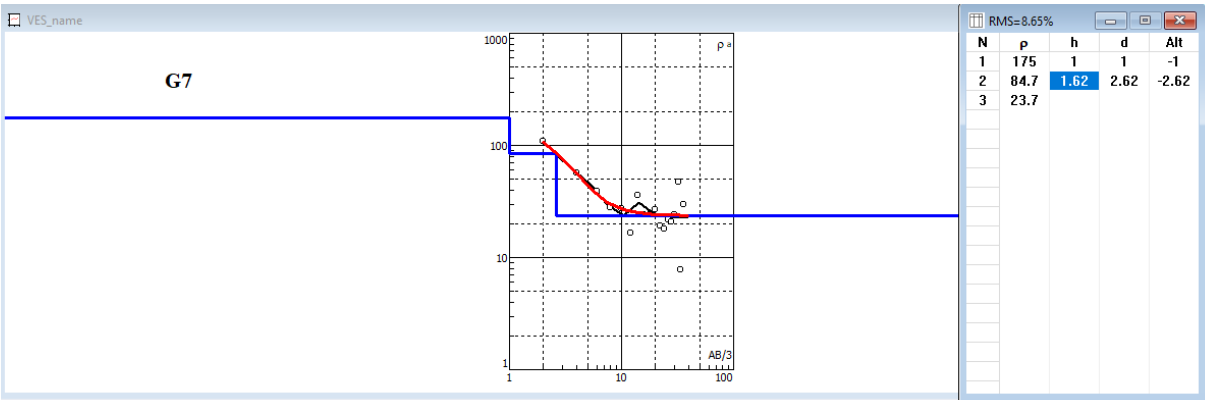

Fig.4.16 Sounding curve of the location G7 (Q-Type)

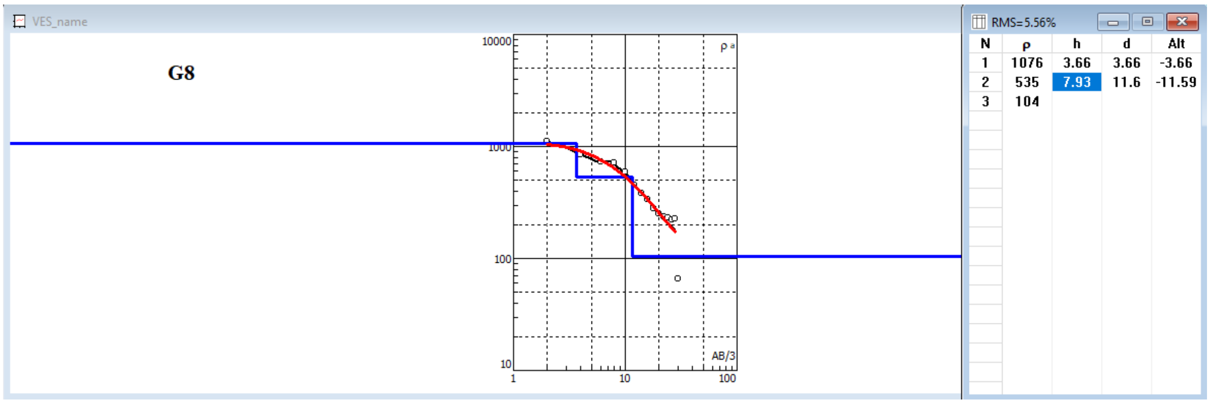

Fig.4.17 Sounding curve of the location G8 (Q-Type)

4.1.1.5 HK type curve

The sounding curve obtained for the location Nadet (G12) could be explained with a four layer model with a resistivity sequence of ρ1> ρ2< ρ3> ρ4, 'HK' type curve as shown in Fig. 4.18. This showed the probability of 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 sudden raise in resistivity value with the indication of the absence or lack of fractured rock layers. Fourth layer indicated slight reduction in the resistivity value due to the presence of interconnected fractures, which could be used for moderate groundwater supply.

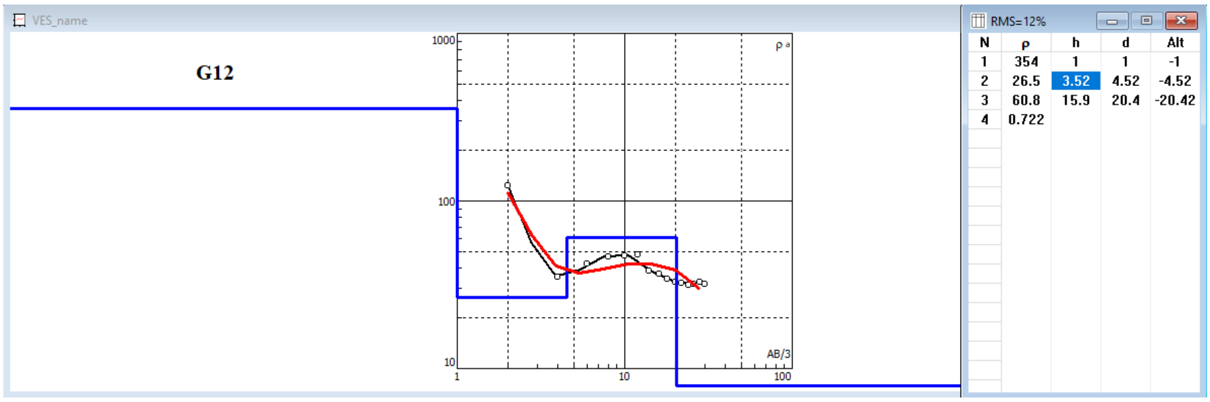

Fig.4.18 Sounding curve of the location G12 (HK-Type)

4.1.1.6 QH type curve

The sounding curves of the locations Madirassery (G6) and Anthyalam kulam (G14) showed QH type curve representing a four layered model which can be morphologically explained by resistivity sequence ρl> ρ2> ρ3< ρ4 as shown in Fig.4.19 and 4.20. 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.

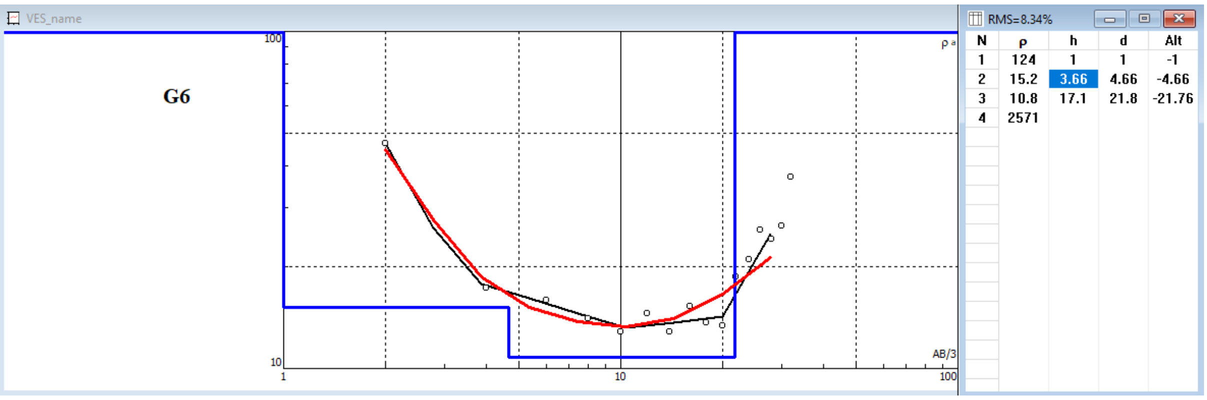

Fig.4.19 Sounding curve of the location G6 (QH-Type)

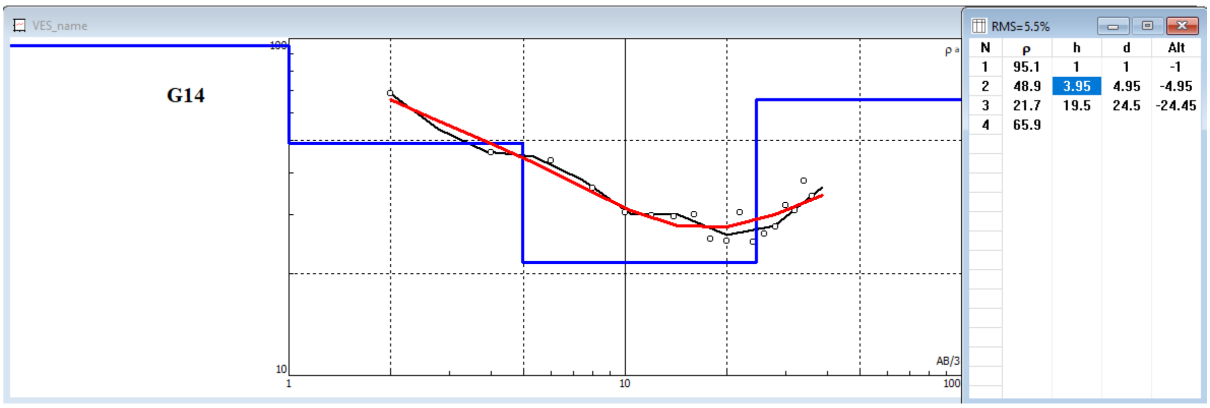

Fig.4.20 Sounding curve of the location G14 (QH-Type)

4.1.1.7 HA type curve

The sounding curves obtained from Coconut orchard near Nila, KCAET (G1) was morphologically defined by four layer model with the resistivity sequence of ρl> ρ2< ρ3< ρ4 as shown in Fig.4.21. This was as HA type curve and it implied a layer of lateritic top soil followed by clayey layer. The fourth layer was having high resistivity of 5030 ohm-m, which indicated the presence of hard rock.

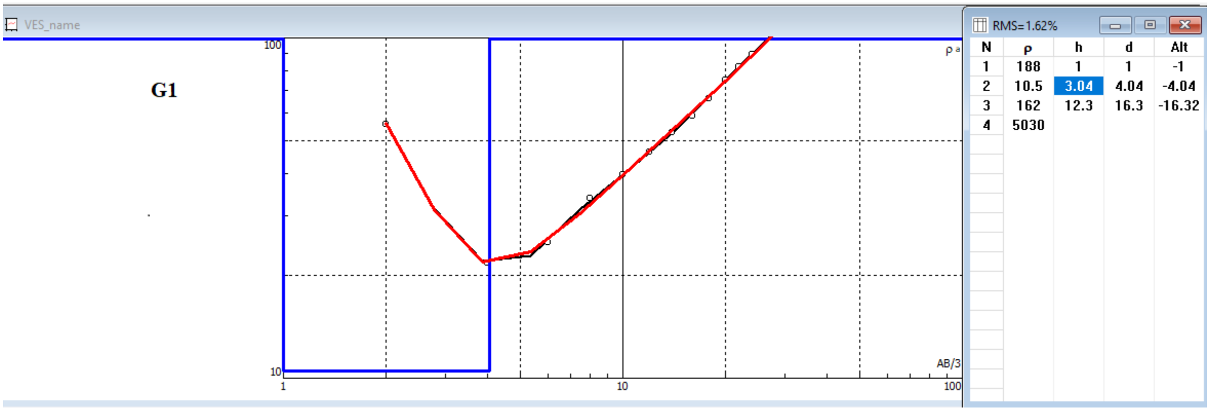

Fig.4.21 Sounding curve of the location G1 (HA-Type)

4.1.2 Resistivity and Pseudo sections

In order to create the resistivity and pseudo cross sections, a section having maximum points in a straight line were selected as shown in Fig 4.22. The resistivity and pseudo cross sections along AA' to FF' were prepared using true and apparent resistivity values.

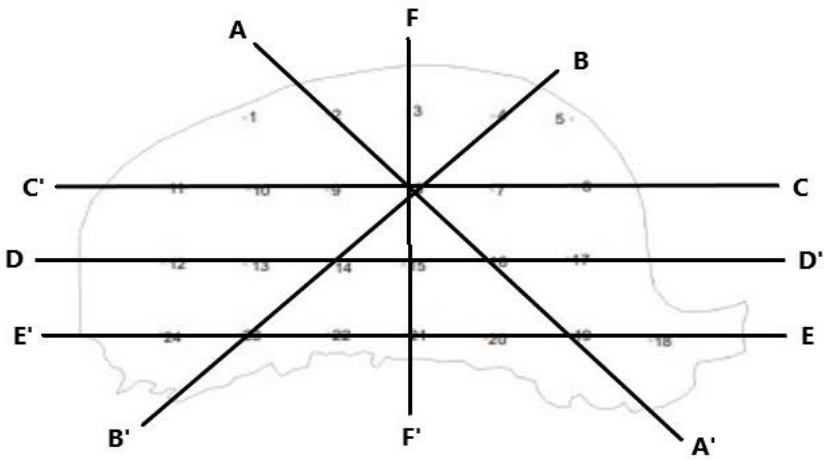

Fig.4.22 Sections of resistivity and pseudo cross sections

AA' represents the cross section along the VES locations viz Coconut orchard near lab, KCAET (G2), Kadakassery (G8), Ayankalam (G16) and Pattaparambu (G19). BB' represents cross section along the VES location viz Kuzhunjodi (G4), Kadakassery (G8), Anthyalam kulam (G14) and Athaloor (G23). CC' represents the cross sections along the VES location viz Athaloor (G6), Vellanchery (G7), Kadakassery (G8), Muvankara (G9), Muradavil padi (G10) and Kakkassery kunnu (G11) . DD' represents the cross sections along the VES locations viz Nadet (G12), Athaloor (G13), Anthyalam kulam (G14), Kallur (G15), Ayankalam (G16) and Central jail (G17). EE' represents the the cross sections along the VES locations viz MES college (G18), Pattaparambu (G19), Kachery parambu (G20), Kadanchery (G22), Athaloor (G23) and Mathoor palli (G24). FF' represents the cross sections along the VES locations viz Nambram (G3), Kadakassery (G8) and Kallur (G15).

Fig. 4.23 shows the resistivity and pseudo cross sections along the AA' ection. 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.

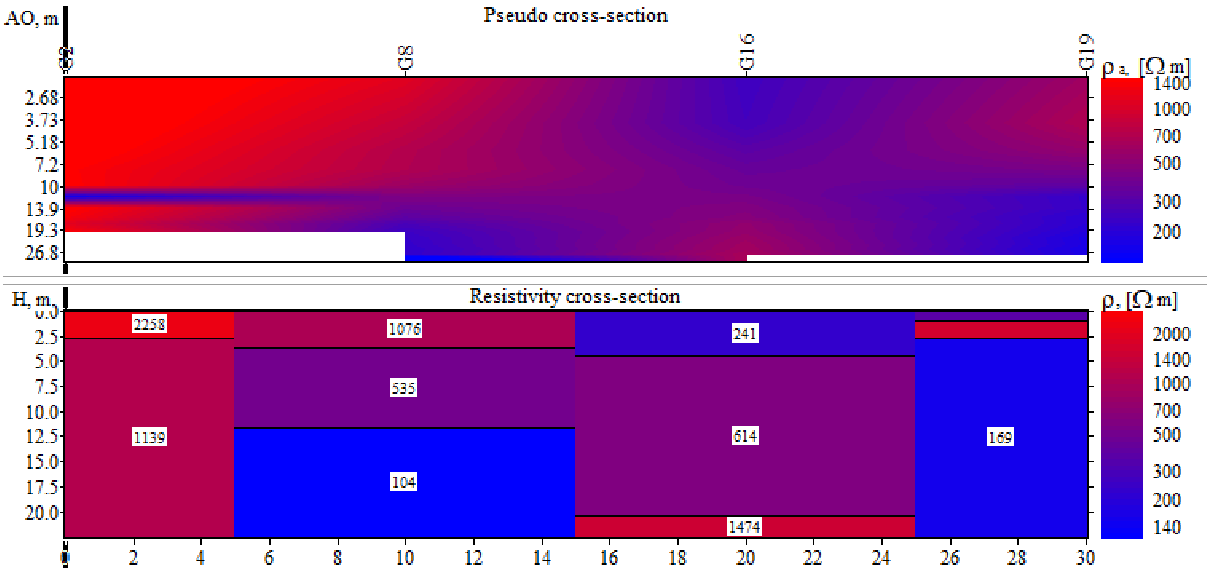

Fig.4.23 Resistivity and Pseudo cross sections along section AA'

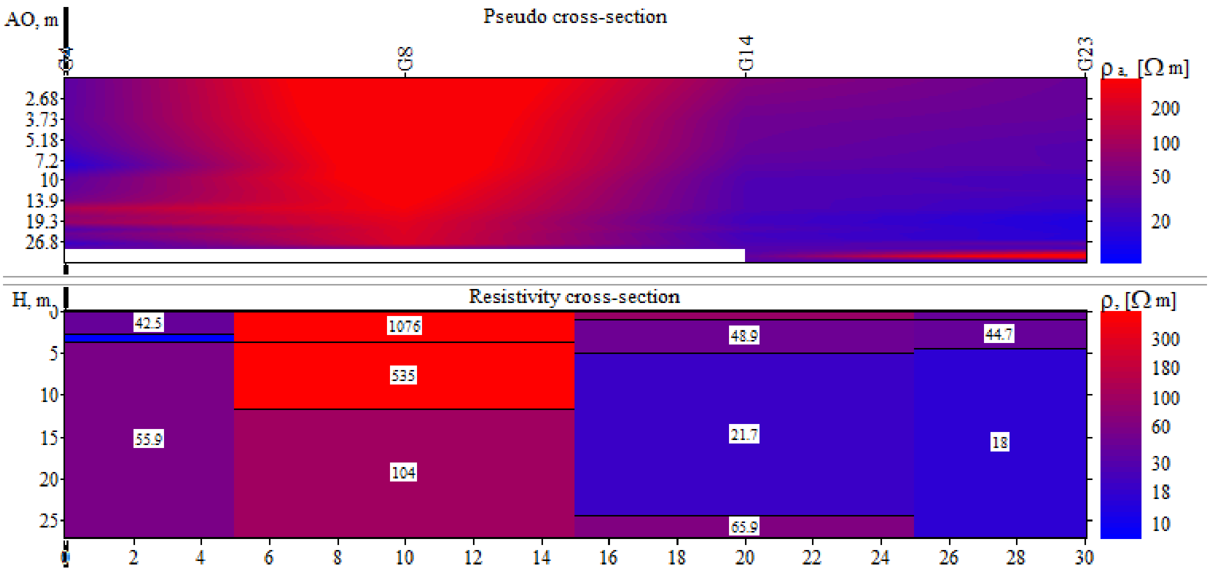

Fig.4.24. Resistivity and Pseudo cross sections along section BB'

Fig. 4.24 depicts the resistivity and pseudo cross sections along section BB'. This section represented 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.

Fig. 4.25 depicts the resistivity and pseudo cross sections along section CC'. 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.

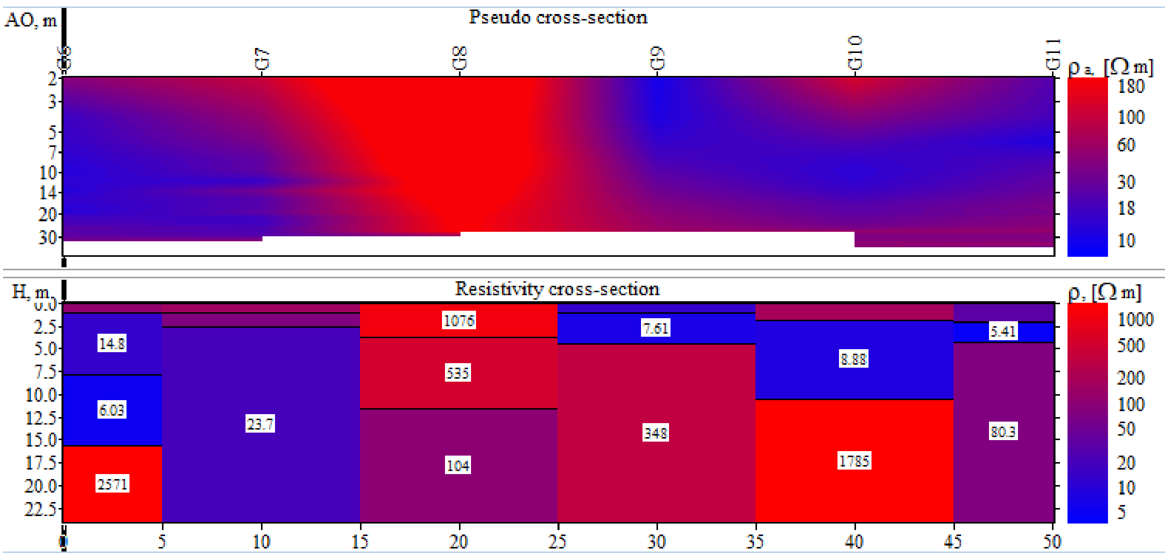

Fig. 4.25. Resistivity and Pseudo cross sections along section CC'

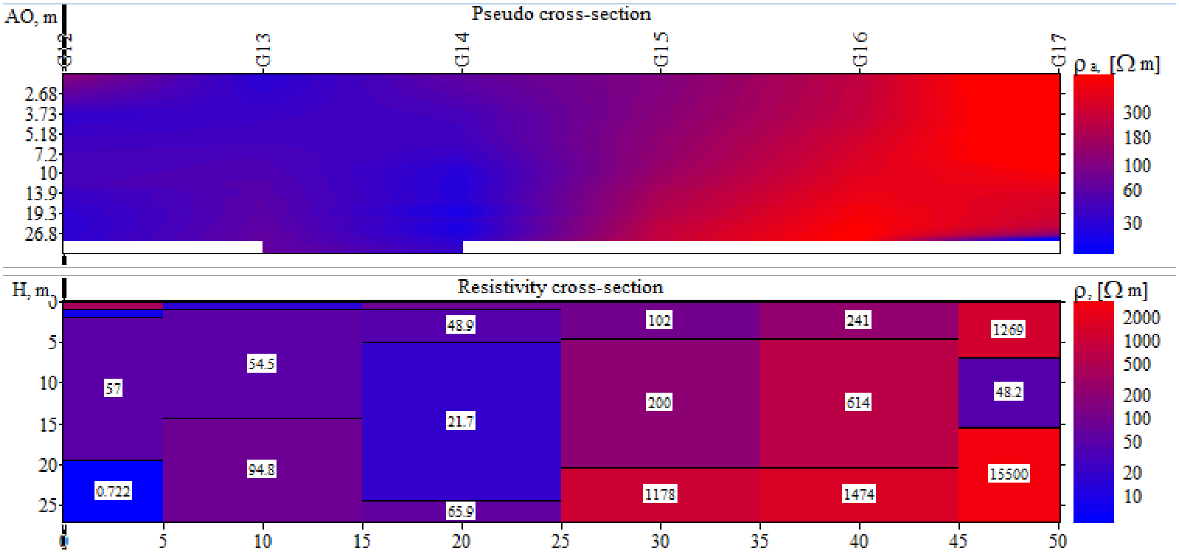

Fig. 4.26. Resistivity and Pseudo cross sections along section DD'

Fig. 4.26 depicts the resistivity and pseudo cross sections along section DD'. This figure included the horizontal section showing varying resistivity values from Nedath to Central jail area of Tavanur Grama Panchayat. Here, the soil formation was found to show a gradual variation from lateritic to unconsolidated rock formation.

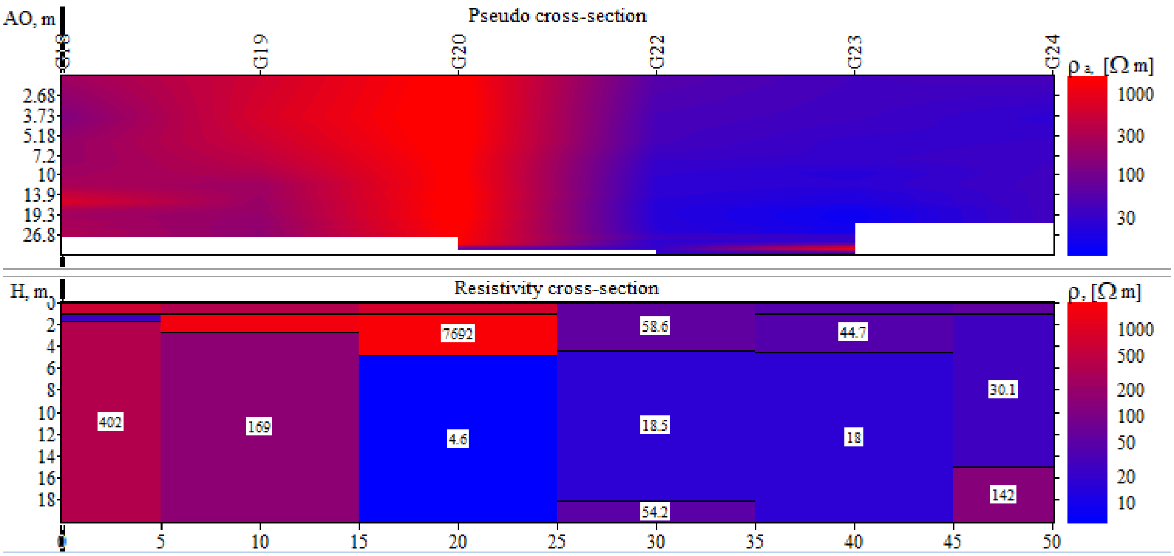

Fig. 4.27. Resistivity and Pseudo cross sections along section EE'

The Fig. 4.27 showing the resistivity and pseudo cross sections along the section EE' represents the horizontal section of the area between MES College and Mathoor Palli region in Tavanur Grama Panchayat. The soil formation in the 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 was having lateritic soil, between G19 and G20 was unconsolidated sedimentary rock, between G20 and G22 was lateritic soil and rest of the area being clay.

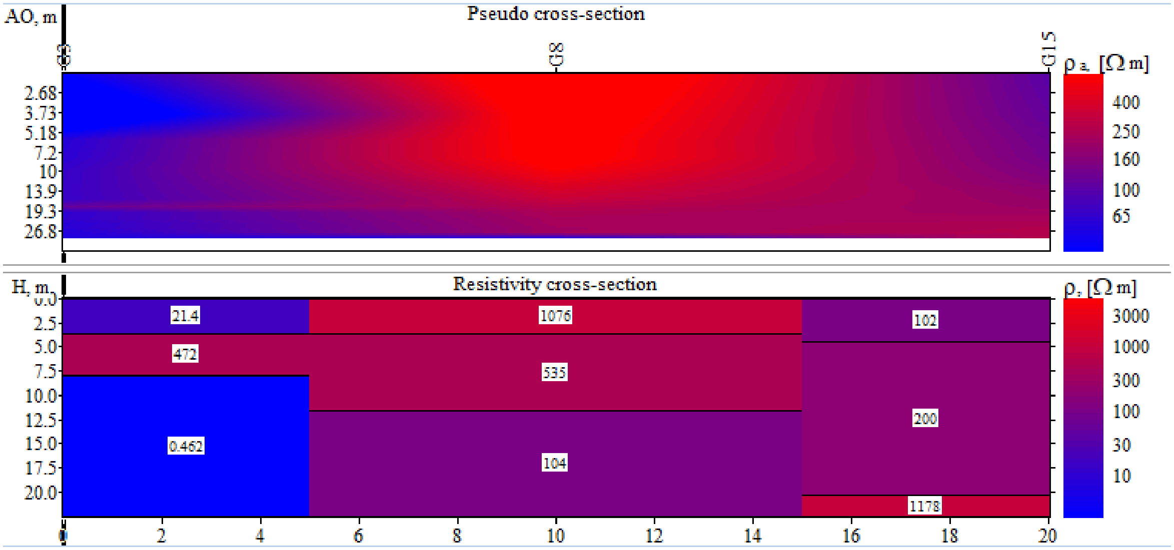

Fig. 4.28. Resistivity and Pseudo cross sections along section FF'

Fig. 4.28 showing the resistivity and pseudo cross section along the vertical section between Nambram and Kallur indicated the presence of both clay and lateritic soil formation. The area from G3 to G8 showed a transition from clay to lateritic oil and area from G8 to G15 showed a transition from lateritic to clay soil.

Summary and conclusion

CHAPTER V

SUMMARY AND CONCLUSION

Geophysical investigations are conducted on the surface of the earth to explore the ground water resources by observing some physical parameters like density, velocity, conductivity, resistivity, magnetic, electromagnetic and radioactive phenomena. Geophysical methods comprise of measurement of signals from natural or induced phenomena of physical properties of sub surface formation. They detects the differences or anomalies of physical properties within the earth's crust. Density, magnetism, elasticity, and electrical resistivity are the properties that are most commonly measured.

In the present study, the groundwater potential zones of Tavanur Grama Panchayat was analysed and investigated using electrical resistivity method. The map of the study area was downloaded from Google Earth as KML file. The grid map (1000 x 1000 m) of the study area was created using ArcGIS 10.7. The grid map was then exported to google earth for marking the locations in the real field for conducting the vertical electrical sounding survey and 24 sites were located.

As the first step of the geophysical investigation, reconnaissance survey was conducted to find the suitability of the selected locations. Vertical Electrical Sounding (VES) survey was conducted in the selected locations using signal stacking resistivity meter to study the hydrogeological characteristics of the area. Wenner electrode configuration was used to perform VES survey and the resistivity data were obtained.

The output obtained from VES survey was interpreted using the sounding curves derived from IPI2WIN software. From the sounding curves of 24 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 type.

H type sounding curves having a resistivity profile $\rho 1 > \rho 2 < \rho 3$, were found in the locations Kuzhunjodi (G4), Muvankara (G9), Muradavil padi (G10), Kakkassery kunnu (G11), Tavanur Central jail (G17), MES college (G18), Kadanchery (G22) and Mathoor palli (G24). H type curve indicates good aquifer characteristics with lower resistivity in the middle layer. In the present study, G17 had a third layer of resistivity 15500 Ωm, which indicated the presence of hardrock (Metamorphic/Gneiss) at the bottom. The sounding curves of the locations G4, G11 and G22 showed the presence of same soil formation. At the location G9, the top layer was having low resistivity indicating the presence of clayey loam formation.

The sounding curves obtained for the locations Athaloor (G13), Kallur (G15) and Ayankalam (G16) were morphologically defined by a three layer model with the resistivity sequence of $\rho 1 < \rho 2 < \rho 3$ representing an A type curve. A type curve indicates the suitability for constructing open wells.

Vellanchery (G7) and Kadakassery (G8) got Q type sounding curves with a steady decrease in the soil resistivity ($\rho l > \rho 2 > \rho 3$). The sounding curves of all the other locations showed combination curves morphologically defined by 4 layer substrata.

The resistivity and pseudo cross sections along AA', BB', CC', DD', EE' and FF' were prepared using the true and apparent resistivity values. All pseudo cross sections indicated that the formation of the study area was having the oil texture from lateritic clay to lateritic soil. The results obtained from the sounding curves of the VES locations were also acceptable by observed actual field conditions.

The study can be concluded as…

Out of the 24 locations, 8 locations showed the H type and 3 locations showed A type sounding curves in the data interpretation using IPI2WIN. This indicates that, a majority of the study area is having groundwater potential formations and found suitable for the construction of open wells.

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Appendices

APPENDIX 1

Data obtained from Vertical Electrical Sounding survey

Table 1: VES survey output for location G1

AB/2	MN/2	D	R	RHO
3	1	2	4.44531	55.839
6	2	4	0.8649	21.7461
9	3	6	0.66276	24.9936
12	4	8	0.67057	33.7204
15	5	10	0.63145	39.6912
18	6	12	0.61418	46.3267
21	7	14	0.6011	52.8971
24	8	16	0.58586	58.9209
27	9	18	0.58823	66.555
30	10	20	0.59907	75.312
33	11	22	0.59439	82.1959
36	12	24	0.59456	89.6943

Table 2: VES survey output for location G2

AB/2	MN/2	D	R	RHO
3	1	2	161.031	2024.39
6	2	4	73.9446	1859.17
9	3	6	43.9326	1656.88
12	4	8	28.8982	1453.17
15	5	10	23.6721	1487.96
18	6	12	2.20075	165.999
21	7	14	17.3703	1528.58
24	8	16	13.62	1369.78
27	9	18	9.09105	1120.23
30	10	20	11.4867	1444.05

Table 3: VES survey output for location G3

AB/2	MN/2	D	R	RHO
3	1	2	3.30518	41.5509
6	2	4	0.62337	15.6735
9	3	6	1.56734	59.1114
12	4	8	1.24385	62.5482
15	5	10	1.11007	69.7759
18	6	12	0.94195	71.0504
21	7	14	0.8183	72.0107

24	8	16	0.7117	71.577
27	9	18	1.00438	113.638
30	10	20	0.51731	65.0332
33	11	22	0.48084	66.4941
36	12	24	0.40337	60.8522
39	13	26	0.38014	62.1258
42	14	28	0.32704	57.5592
45	15	30	0.30116	56.7911
48	16	32	0.83246	167.443
51	17	34	0.25709	54.945
54	18	36	0.25138	56.8848

Table 4: VES survey output for location G4

AB/2	MN/2	D	R	RHO
3	1	2	2.78949	35.0678
6	2	4	1.45373	36.5509
9	3	6	0.73911	27.8752
12	4	8	0.32899	16.5435
15	5	10	0.56616	35.5876
18	6	12	0.52963	39.9499
21	7	14	0.58158	51.1796
24	8	16	1.13443	114.091
27	9	18	0.63356	71.683
30	10	20	0.68405	85.9948
33	11	22	0.21753	30.0812
36	12	24	0.29085	43.8781
39	13	26	0.21942	35.8594
42	14	28	0.12396	21.8141
45	15	30	0.17397	32.8057

Table 5: VES survey output for location G6

AB/2	MN/2	D	R	RHO
3	1	2	3.71075	46.6494
6	2	4	0.68875	17.3173
9	3	6	0.42122	15.8862
12	4	8	0.2788	14.0196
15	5	10	0.20383	12.8125
18	6	12	0.19315	14.5691
21	7	14	0.14623	12.8682
24	8	16	0.15176	15.2636
27	9	18	0.12104	13.6949
30	10	20	0.10683	13.4339
33	11	22	0.135	18.6692

36	12	24	0.139863	21.0654
39	13	26	0.15774	25.7802
42	14	28	0.13758	24.2156
45	15	30	0.14017	26.433
48	16	32	0.18385	36.9805

Table 6: VES survey output for location G7

AB/2	MN/2	D	R	RHO
3	1	2	8.57642	107.817
6	2	4	2.23782	56.2651
9	3	6	1.02893	38.8053
12	4	8	0.55294	27.805
15	5	10	0.43113	27.0996
18	6	12	0.21924	16.5373
21	7	14	0.40337	35.4965
24	8	16	0.23808	23.9441
27	9	18	0.21433	24.2499
30	10	20	0.21134	26.569
33	11	22	0.1381	19.0975
36	12	24	0.12021	18.1359
39	13	26	0.13315	21.7609
42	14	28	0.111853	20.8614
45	15	30	0.1266	23.8749
48	16	32	0.23538	47.3452
51	17	34	0.03673	7.85006
54	18	36	0.13236	29.9516

Table 7: VES survey output for location G8

AB/2	MN/2	D	R	RHO
3	1	2	88.8212	1116.6
6	2	4	33.9119	852.643
9	3	6	19.332	729.094
12	4	8	14.1849	713.297
15	5	10	9.35834	588.238
18	6	12	6.01674	453.834
21	7	14	4.35316	383.078
24	8	16	3.31926	333.823
27	9	18	2.47719	280.276
30	10	20	1.98079	249.013
33	11	22	1.70308	235.512
36	12	24	1.53167	231.063
39	13	26	1.36496	223.074
42	14	28	1.27592	224.563

45	15	30	0.34533	65.1196

Table 8: VES survey output for location G9

AB/2	MN/2	D	R	RHO
3	1	2	0.83202	10.4597
6	2	4	0.47247	11.8793
9	3	6	0.41709	15.7302
12	4	8	0.40043	20.136
15	5	10	0.39061	24.5529
18	6	12	0.39065	29.4665
21	7	14	0.38399	33.7912
24	8	16	0.38479	38.6998
27	9	18	0.38955	44.0747
30	10	20	0.38205	48.0294
33	11	22	0.37652	52.0678
36	12	24	0.36741	55.4272
39	13	26	0.36015	58.86
42	14	28	0.35236	62.016

Table 9: VES survey output for location G10

AB/2	MN/2	D	R	RHO
3	1	2	10.6809	134.275
6	2	4	1.71757	43.1846
9	3	6	0.60262	22.7273
12	4	8	0.31242	15.7104
15	5	10	0.22423	14.0949
18	6	12	0.19702	14.8615
21	7	14	0.19521	17.1787
24	8	16	0.20474	20.5916
27	9	18	0.21827	24.6956
30	10	20	0.20495	25.765
33	11	22	0.21005	29.0473
36	12	24	0.21768	32.839
39	13	26	0.23794	38.8874
42	14	28	0.31945	56.2242
45	15	30	0.2195	42.094
48	16	32	0.23313	46.8941
51	17	34	0.23332	49.8646
54	18	36	0.22515	50.9491

Table 10: VES survey output for location G11

AB/2	MN/2	D	R	RHO
3	1	2	1.87349	23.5525

6	2	4	0.79052	19.876
9	3	6	0.31894	12.0287
12	4	8	0.40333	20.2819
15	5	10	0.38232	24.0315
18	6	12	0.36695	27.6791
21	7	14	0.34583	30.433
24	8	16	0.34779	34.9781
27	9	18	0.34669	39.2259
30	10	20	0.29464	37.0415
33	11	22	0.30763	42.5415
36	12	24	0.29702	44.8055
39	13	26	0.3056	49.9451
42	14	28	0.3134	55.1592
45	15	30	0.22614	42.6443
48	16	32	0.19928	40.0855
51	17	34	0.27903	59.6335
54	18	36	0.17331	39.2177
57	19	38	0.16704	39.8995
60	20	40	0.17126	43.0612

Table 11: VES survey output for location G12

AB/2	MN/2	D	R	RHO
3	1	2	9.81285	123.361
6	2	4	1.39225	35.0051
9	3	6	1.11893	42.1996
12	4	8	0.92878	46.7045
15	5	10	0.74499	46.8285
18	6	12	0.63281	47.7321
21	7	14	0.43615	38.3813
24	8	16	0.36221	36.4285
27	9	18	0.30262	34.2399
30	10	20	0.25956	32.6309
33	11	22	0.23387	32.3412
36	12	24	0.2088	31.4999
39	13	26	0.19392	31.6923
42	14	28	0.18591	32.7215
45	15	30	0.16854	31.7833

Table 12: VES survey output for location G13

AB/2	MN/2	D	R	RHO
3	1	2	2.38361	29.9654
6	2	4	1.60311	40.3068
9	3	6	1.178	44.1931

12	4	8	0.98947	49.7564
15	5	10	0.82311	51.7388
18	6	12	0.73816	55.679
21	7	14	0.63642	56.0052
24	8	16	0.59315	59.6545
27	9	18	0.5271	59.638
30	10	20	0.48629	61.1338
33	11	22	0.45052	62.3006
36	12	24	0.4259	64.2503
39	13	26	0.40143	65.6059
42	14	28	0.38857	68.3884
45	15	30	0.35501	66.9463
48	16	32	0.34432	69.259
51	17	34	0.33296	71.1585
54	18	36	0.32021	72.4589

Table 13: VES survey output for location G14

AB/2	MN/2	D	R	RHO
3	1	2	5.45797	68.6145
6	2	4	1.8263	45.9185
9	3	6	1.1536	43.5073
12	4	8	0.7152	35.9646
15	5	10	0.48327	30.3773
18	6	12	0.39427	29.7394
21	7	14	0.33731	29.6839
24	8	16	0.29865	30.0365
27	9	18	0.2243	25.3782
30	10	20	0.19949	25.0794
33	11	22	0.22082	30.5371
36	12	24	0.16526	24.9317
39	13	26	0.16058	26.2434
42	14	28	0.15712	27.6544
45	15	30	0.17002	32.0615
48	16	32	0.15311	30.7984
51	17	34	0.17729	37.89
54	18	36	0.15071	34.104

Table 14: VES survey output for location G15

AB/2	MN/2	D	R	RHO
3	1	2	8.17312	102.747
6	2	4	4.58181	115.199
9	3	6	3.41988	128.978
12	4	8	2.7008	135.775

15	5	10	2.36891	148.903
18	6	12	2.2068	166.455
21	7	14	2.10647	185.369
24	8	16	1.93877	194.985
27	9	18	1.8161	205.479
30	10	20	1.72627	217.017
33	11	22	1.69377	234.224
36	12	24	1.64719	248.491
39	13	26	1.59357	216.435
42	14	28	1.52107	267.709
45	15	30	1.46352	275.976

Table 15: VES survey output for location G16

AB/2	MN/2	D	R	RHO
3	1	2	20.1876	253.787
6	2	4	10.594	266.364
9	3	6	8.69273	327.84
12	4	8	7.31353	367.766
15	5	10	6.23906	392.169
18	6	12	5.69281	429.4
21	7	14	5.26364	463.201
24	8	16	4.82	484.754
27	9	18	4.74574	536.946
30	10	20	4.38262	550.958
33	11	22	4.23574	585.743
36	12	24	4.06026	612.519
39	13	26	3.81482	623.451
42	14	28	3.73125	656.7
45	15	30	3.61209	681.138

Table 16: VES survey output for location G17

AB/2	MN/2	D	R	RHO
3	1	2	101.728	1278.87
6	2	4	43.7465	1099.91
9	3	6	26.3704	994.541
12	4	8	16.4897	829.198
15	5	10	9.23255	580.332
18	6	12	6.39133	482.08
21	7	14	4.47421	393.73
24	8	16	3.52742	354.758
27	9	18	2.95872	334.758
30	10	20	2.52121	316.952
33	11	22	2.11254	292.134

36	12	24	1.76202	265.814
39	13	26	1.13375	185.287
42	14	28	0.56132	98.7925
45	15	30	0.06864	12.9452
48	16	32	0.04981	10.0198
51	17	34	1.61767	345.716

Table 17: VES survey output for location G18

AB/2	MN/2	D	R	RHO
3	1	2	20.0621	252.209
6	2	4	5.44869	136.995
9	3	6	5.52712	208.451
12	4	8	4.24309	213.366
15	5	10	3.99241	250.952
18	6	12	3.82797	288.738
21	7	14	5.82909	512.9
24	8	16	7.6296	767.32
27	9	18	2.59035	293.08
30	10	20	2.05875	258.814
33	11	22	2.15165	297.543
36	12	24	1.92177	289.913
39	13	26	2.02282	330.586
42	14	28	1.78171	314.99
45	15	30	1.67541	315.936
48	16	32	1.74204	350.4
51	17	34	1.42446	304.428

Table 18: VES survey output for location G19

AB/2	MN/2	D	R	RHO
3	1	2	47.9555	602.869
6	2	4	28.2145	709.393
9	3	6	14.7793	557.393
12	4	8	8.59957	432.435
15	5	10	5.36997	337.541
18	6	12	3.10734	234.382
21	7	14	2.67557	235.45
24	8	16	2.12377	213.591
27	9	18	1.87503	212.146
30	10	20	1.58501	199.259
33	11	22	1.33301	184.336
36	12	24	1.23052	185.633
39	13	26	1.0848	177.288
42	14	28	1.0277	180.876

Table 19: VES survey output for location G20

AB/2	MN/2	D	R	RHO
3	1	2	147.689	1856.66
6	2	4	80.3526	2020.29
9	3	6	51.8118	1954.04
12	4	8	34.6762	1743.72
15	5	10	27.1823	1708.6
18	6	12	23.6933	1787.15
21	7	14	22.088	1943.74
24	8	16	18.223	1832.72
27	9	18	16.6528	1884.15
30	10	20	15.6196	1963.61
33	11	22	12.512	1730.23
36	12	24	11.7652	1774.86
39	13	26	9.67295	1580.83
42	14	28	8.69803	1530.85
45	15	30	8.22086	1550.22
48	16	32	7.12468	1433.07
51	17	34	0.41165	87.9758

Table 20: VES survey output for location G21

AB/2	MN/2	D	R	RHO
3	1	2	0.52527	84.9186
6	2	4	1.66120	40.6669
9	3	6	0.63500	55.5835
12	4	8	49.0655	26.1609
15	5	10	20.6914	22.6115
18	6	12	13.7370	18.9822
21	7	14	11.0762	15.2663
24	8	16	7.86084	11.5796
27	9	18	6.32388	7.7937
30	10	20	3.50502	4.05678
33	11	22	4.52975	0
36	12	24	7.33546	9999999
39	13	26	12.1856	9999999

Table 21: VES survey output for location G22

AB/2	MN/2	D	R	RHO
3	1	2	4.85882	61.0823
6	2	4	1.87502	47.1434
9	3	6	1.16532	43.9493
12	4	8	0.66454	33.417
15	5	10	0.48573	30.5316
18	6	12	0.37073	27.964
21	7	14	0.31621	27.8272
24	8	16	0.24548	24.689
27	9	18	0.2142	24.2546
30	10	20	0.19517	24.536
33	11	22	0.18376	24.4122
36	12	24	0.17261	26.0397
39	13	26	0.176434	26.8585
42	14	28	0.21123	37.177
45	15	30	0.1509	28.4568
48	16	32	0.14796	29.7629
51	17	34	0.14313	30.5908
54	18	36	0.14112	31.9351
57	19	38	0.13986	33.4067

Table 22: VES survey output for location G23

AB/2	MN/2	D	R	RHO
3	1	2	3.39355	42.6618
6	2	4	1.55606	39.1238
9	3	6	0.83772	31.5942
12	4	8	0.65242	32.8074
15	5	10	0.39632	24.912
18	6	12	0.36114	27.2406
21	7	14	0.2533	22.2906
24	8	16	0.21041	21.1621
27	9	18	0.13876	15.7
30	10	20	0.11816	14.8546
33	11	22	0.11084	15.3288
36	12	24	0.11199	16.8957
39	13	26	0.10064	16.4487
42	14	28	0.2086	36.7152
45	15	30	0.14376	27.1106
48	16	32	0.42601	85.6888
51	17	34	4.94807	1057.47
54	18	36	0.08236	18.6382

Table 23: VES survey output for location G24

AB/2	MN/2	D	R	RHO
3	1	2	3.81781	47.9953
6	2	4	1.10625	27.8143
9	3	6	0.9104	34.3351
12	4	8	0.74193	37.3087
15	5	10	0.63973	39.5835
18	6	12	0.54647	41.2199
21	7	14	0.46563	40.9755
24	8	16	0.4074	40.944
27	9	18	0.36554	41.3587
30	10	20	0.33645	42.2969
33	11	22	0.29549	40.8625

GEOPHYSICAL TECHNIQUES FOR AQUIFER CHARACTERISTIC STUDIES – A CASE STUDY OF TAVANUR GRAMA PANCHAYAT, MALAPURAM, KERALA

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ABSTRACT OF THESIS

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ABSTRACT

A study on the aquifer characteristics of Tavanur Grama panchayat, Malapuram, Kerala was conducted across 23 VES locations by vertical electrical sounding survey. The study aimed at analysing the hydrogeological characteristic of the geological formations of Tavanur Panchayat using Electrical Resistivity Meter. The data obtained from the vertical electrical sounding was interpreted using IPI2WIN software.

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 type. 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, majority of the study area is having lateritic soil to hard laterite with medium to high groundwater potential and found suitable for the construction of open wells.