DATA ANALYSIS & VISUALISATION OF VERTICAL ELECTRICAL SOUNDING USING R-STUDIO AND PYTHON

Project Report Submitted

In the partial fulfilment of the requirements for the award of the degree of **Bachelor of Engineering** in **Civil Engineering**

by

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DEPARTMENT OF CIVIL ENGINEERING

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CERTIFICATION

This is to certify that the **THEME BASED PROJECT** work entitled **“DATA ANALYIS AND VISUALISATION OF VERTICAL ELECTRICAL SONDING USING R-STUDIO AND PYTHON”** is being submitted in a partial fulfilment for the award of Bachelor of Engineering in Civil Engineering Department, Vasavi College of Engineering(Affiliated to Osmania University), Ibrahimbagh, Hyderabad 500031,is record of Bonafide work carried out by

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Dr. M.Srinivas	**Dr. B.Sridhar**
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Sincerely,

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ABSTRACT

This Report amounts to the Depth of investigation of Water Table by performing Vertical Electrical Sounding in the College Premises. The analysis and calculation of the readings obtained by performing experiment is done by the program written in two different programming languages namely R-Studio and Python, by using efficient packages and modules as per the requirement and necessity. The Report depicts the need of computer programming languages in different departments.

The Report comprises of the basic knowledge of the Electrical Resistivity Method, R-Studio and Python. The methodology consists of procedure and readings collected from the field and a set of values from a source for the purpose of testing the code. The Analysis part comprises of the code we have written in R-Studio and Python. The Output of the code is shown in the Results and Discussions part. The major objective of the Project is to provide analysis and visualisation tool to Geologists and Hydrologists. It will really avoid the manual errors. It makes the work easier when there are myriad readings.

1. INTRODUCTION

If We would like to find the best location to drill a water well in any location. One option we could have is to bring a long drilling rig and drill an exploration well for every 20 metres or so, may be we would find the right place… may be not… It would waste a lot of time and more importantly a lot of money because drilling is very expensive. So, Is there a cheaper option ? Yes, there is! It's called Resistivity Survey. This can be done by various configurations. After performing the experiment it's hard to make all the calculations and to figure out the depth of water table. To make all these things easier this project has been done. Where we wrote a program to do all these calculations and find the depth of water table.

1.1. OBJECTIVES

- To provide an efficient calculating tool for Geologists and Hydrologists to perform the calculations of VES.
- To avoid manual and rounding errors during the calculations.
- To computerise the work done by them.
- To make their work easier.
- To convert the data into various graphs.
- To figure out the results in less time

2. LITERATURE REVIEW

2.1. INTRODUCTION TO ERM

The geophysical method which dominant by geophysicists become one of most popular method applied by engineers in civil engineering fields. Electrical Resistivity Method (ERM) is one of geophysical tool that offer very attractive technique for subsurface profile characterization in larger area. Applicable alternative technique in groundwater exploration such as ERM which complement with existing conventional method may produce comprehensive and convincing output thus effective in terms of cost, time, data coverage and sustainable. ERM has been applied by various application in groundwater exploration. Over the years, conventional method such as excavation and test boring are the tools used to obtain information of earth layer especially during site investigation. There are several problems regarding the application of conventional technique as it only provides information at actual drilling point only. This review paper was carried out to expose the application of ERM in groundwater exploration. Results from ERM could be additional information to respective expert for their problem solving such as the information on groundwater pollution, leachate, underground and source of water supply.

Rapid interest in recent years in underground sources had led for more intensive studies of the geometry and properties of aquifers. Groundwater is a very important component of water resources in nature. Groundwater is defined as subsurface water that fill in soil pore spaces and in fracture of rock formations. It is known as an alternative water supply for all living things. The problem faces by engineers is to determine the exact location of groundwater zone in subsurface layer. Geophysical is the application of physics that study the earth by taking measurement at or near the surface of earth. Geophysical method seen as the most suitable tools in exploration of groundwater as this method has been widely applied in geotechnical and geo-environment investigation. Geophysics has played a useful part in such investigations for many years in improving the instruments and development for better result in widening its applications. Electrical Resistivity Method (ERM) is part of geophysical methods which used as preliminary step involve in any groundwater exploration. ERM has been applied for many years to determine the thickness of layered media as well to map geological environment of existing aquifer. It has been effectively used for groundwater due to simplicity of the technique, efficient and non-destructive of implementation in producing the subsurface imaging compared to conventional method. Table 1 indicate the comparison between the conventional method and ERM in groundwater exploration. Furthermore, with support borehole data and profile image produced from this method reliable information regarding groundwater and location of underground layers could be obtained.

Table 1. Comparison between conventional method and ERM in groundwater exploration.

Conventional method	**ERM**
Provide information at drilling point only.	Offer larger data coverage.
Lacks equipment and application for difficult accessibility condition.	Capable to conduct in difficult accessibility situation. Suitable for investigation of saltwater intrusion, groundwater pollution, indicate shallow aquifer for water resources, contamination, leachate etc.
Destructive method (changes the nature of the ground).	Non-destructive method (observe the ground without permanently changing or altering its characteristics).
Expensive and limited.	Generally effective in terms of cost and time consuming

2.1.1. RESISTIVITY THEORY

ERM basically conducted to measure and map the resistivity of subsurface materials. It also refers as survey that carried out to present the image of electrical properties of the subsurface by passing an electrical current along many different paths and measuring the associated voltage. ERM is based on the response between the earth and the flow of electrical current. It sensitive to variations in the electrical resistivity of the subsurface measured in Ohm meters. Resistivity measurements are conducted by inducing an electric current into the earth through two current (C1 and C2) electrodes and measuring the resulting voltage at two potential electrodes (P1 and P2). The apparent resistivity (pa) value can be calculated based on the current (I) and voltage (V).

$$pa = k\ V / I$$

k represented the geometric factor that depends on the arrangement of four electrodes. Imaging depth of ERM method is dependent on the spacing between electrodes. Greater depth is achieved by increasing the electrode spacing. The total length of electrode array also plays role in resulting greater imaging depth. The overall subsurface resistivity also affects the imaging depth with highly resistive ground tending to decrease the depth after inversion. In accordance to, the resistivity values of groundwater vary in range from 10 to 100 ohm-m depending on the concentration of dissolved salts contain as refer in Table 2. However, the overlap value resistivity of different classes of waters was depending on several factors such as porosity, degree of water saturation and concentration of dissolved salts.

Table 2. Resistivity values of some types of waters

Type of water	**Resistivity (ohm-m)**
Precipitation	30 – 1000
Surface water in area of igneous rock	30 – 500
Surface water in area of sedimentary rock	10 –100
Groundwater in area of igneous rock	30 – 150
Groundwater in area of sedimentary rock	> 1
Sea water	0.2
Freshwater	10 – 100
Drinking water (max. salt content 0.25%)	> 1.8
Water for irrigation and stock watering (max salt content 0.25%)	> 0.65

2.1.2. Electrode Configuration

In electrical resistivity survey, high resolution, reliable and good imaging are depending on choices of electrode configuration or normally known as array. Several studies have been conducted regarding the performance of various array. In data acquisition, there are many types of arrays to be used. Wenner, Schlumberger, Dipole-dipole, Pole-pole and Pole-dipole were the common array used in investigating the underground layer. The array configuration has a substantial influence on the resolution, sensitivity, and depth of investigation. Table 3 shows the characteristics of each array configurations in terms of sensitivity of array to horizontal and vertical heterogeneities, depth of investigation, horizontal data coverage and the signal strength. Each of the array has its own specific advantages and limitations. In choosing appropriate array several factors are considered such as depth of object, type of heterogeneity to be mapped, vertical and horizontal changes of the subsurface and signal strength. However, the objective of the survey is the main factor to be considered. Emphasizes that on certain cases the use of various configuration can improve the different reading characteristics of the subsoil and lead to a better interpretation.

Table 3. Characteristics of array configuration

	Wenner	Schlumberger	Dipole-dipole	Pole-pole	Pole-dipole
Sensitivity of the array horizontal structures	++++	++	+	++	++
Sensitivity of the array vertical structures	+	++	++++	++	+
Depth of investigation	+	++	+++	++++	+++
Horizontal data coverage	+	++	+++	++++	+++
Signal strength	++++	+++	+	++++	++

The labels are classified (+) to (++++) equivalent at poor sensitivity to high sensitivity for the different configurations.

2.1.3. Factors Influence ERM Value

The electrical resistivity is based on the principle that the earth material is being tested acts as a resistor in a circuit. After electrical current induced into the ground, the ability of a material to resist current were measured. Various of earth materials could be distinguished by using this application since various of earth materials exhibit characteristics of resistivity value. There were several factors that affected resistivity values of earth materials. The ground resistivity value is influenced by various factors such as density, moisture content, void ratio, grain size fraction and porosity. ERM capable in imaging changes of apparent resistivity with depth locally and to detect the water saturated clay, which identified as lower resistivity zone. This application has theoretically stated that water content in subsurface materials has a close correlation with the electrical conductivity. Thus, the resistivity value will change or constant according to water content in the materials. Degree of fractures is the common factors that influence resistivity values. The fractures are commonly filled with groundwater. The greater the fractures the lower the resistivity value of the rock layer. The statement could be understood, example by resistivity of granite that varies within 5,000 ohm-m for wet condition to 10,000 ohm-m in dry condition. Resistivity value of these rocks will be low to moderate, which from few ohm-m to less of hundred ohm-m when saturated with water. Soils that located above water table are much drier and have a higher resistivity value of several hundreds to thousand ohm-m. While soils below the water table generally gives resistivity value of less than 100 ohm-m. Other factors such as density, porosity, pore size and shape of the aquifer, quality of water encountered in the aquifer and temperature of subsurface environment also influence the resistivity value.

2.1.4. Groundwater Exploration using ERM

The application of geophysical method offers a better way than most conventional method in groundwater exploration. Well drilling is one of the conventional method which applied a direct way in exploring subsurface groundwater system, however the cost is very expensive. Sufficient numbers of boreholes are required to be drilled to describe the depth and constituency of various geological formation. Geophysical method was originally developed for oil and mineral exploration, as water becomes more valuable and scarcer this technique was also applied for groundwater exploration and had improved the understanding of groundwater resources. ERM has been proved to be the most effective technique in mapping groundwater resource as groundwater movement and existence are largely localized and hard to determine. With a support borehole data and interpretation from the resistivity imaging obtained, the reliable information regarding groundwater can be produced. To locate the groundwater application of electrical resistivity imaging method is the common technique utilized nowadays. In Malaysia, application of ERM had already implemented as an alternative tool to solve various problems, especially in civil engineering fields and research. Most common problem in the field was subsurface failure and underground contamination. Successful implementation of this tools had help especially engineers to identify the sources of failure in the subsurface thus prevent damage for surrounding structure and material investigated. The occurrence of groundwater resources in an area is defined by various geological factors that includes structure, geological sequences and stratigraphic distributions of hydrological units. Recharge rate is also an important factor in determining the occurrence of groundwater in an area. Groundwater recharge in an aquifer occurs through the following mechanism: direct infiltration of rainfall, infiltration through river and lateral subsurface inflows commonly through fractures. Various geophysical techniques are currently being applied to assess and explore groundwater. However, ERM is the most powerful and cost-effective techniques in groundwater studies. This is due to the close relationships between the electrical properties and some of hydrogeological properties of the aquifer. Many researchers in Malaysia had applied geophysical technique especially ERM for exploration of groundwater.

The rapid of urban development and growing of population for public, domestic, commercial water supply have caused the local authority to utilize groundwater as an alternative source for water supply. Study at Banting, Selangor proposed the application of 2D resistivity to delineate the groundwater aquifer for extensive exploration for groundwater resources as well as mapping the thickness of aquifer and bedrock in this area. The geological setting of study area is formed by silt and sands as well as peat and clayey materials.

2.2. INTRODUCTION TO R-STUDIO

R Studio is an integrated development environment(IDE) for R. IDE is a GUI, where you can write your quotes, see the results and also see the variables that are generated during the course of programming.

- R Studio is available as both Open source and Commercial software.
- R Studio is also available as both Desktop and Server version.
- R Studio is also available for various platforms such as Windows, Linux, and macOS.

2.2.1. HISTORY OF R-STUDIO

The RStudio IDE is partly written in the C++ programming language and uses the Qt framework for its graphical user interface. The bigger percentage of the code is written in Java. JavaScript is also amongst the languages used.

Work on the RStudio IDE started around December 2010, and the first public beta version (v0.92) was officially announced in February 2011. Version 1.0 was released on 1 November 2016. Version 1.1 was released on 9 October 2017.

In April 2018, RStudio PBC (at the time RStudio, Inc.) announced that it will provide operational and infrastructure support to Ursa Labs in support of the Labs focus on building a new data science runtime powered by Apache Arrow.

In April 2019, RStudio PBC (at the time RStudio, Inc.) released a new product, the RStudio Job Launcher. The Job Launcher is an adjunct to RStudio Server. The launcher provides the ability to start processes within various batch processing systems (e.g. Slurm) and container orchestration platforms (e.g. Kubernetes). This function is only available in RStudio Server Pro (fee-based application).

2.2.2. PACKAGES USED

Readxl: The readxl package makes it easy to get data out of Excel and into R. Compared to many of the existing packages (e.g., gdata, xlsx, xlsReadWrite) readxl has no external dependencies, so it's easy to install and use on all operating systems. It is designed to work with tabular data.

Dplyr: dplyr is a new package which provides a set of tools for efficiently manipulating datasets in R. dplyr is the next iteration of plyr , focussing on only data frames. ... With dplyr , anything you can do to a local data frame you can also do to a remote database table.

Ggplot2: ggplot2 is a plotting package that makes it simple to create complex plots from data in a data frame. It provides a more programmatic interface for specifying what variables to plot, how they are displayed, and general visual properties.

2.3. INTRODUCTION TO PYTHON

Python is a popular programming language. It was created by Guido van Rossum, and released in 1991.

It is used for:

- web development (server-side).
- software development.

- mathematics.
- system scripting.

2.3.1. WHY PYTHON ?

- Python works on different platforms (Windows, Mac, Linux, Raspberry Pi, etc).
- Python has a simple syntax similar to the English language.
- Python has syntax that allows developers to write programs with fewer lines than some other programming languages.
- Python runs on an interpreter system, meaning that code can be executed as soon as it is written. This means that prototyping can be very quick.
- Python can be treated in a procedural way, an object-oriented way or a functional way.

2.3.2. PLATFORM USED

The Jupyter Notebook App is a server-client application that allows editing and running notebook documents via a web browser. The Jupyter Notebook App can be executed on a local desktop requiring no internet access (as described in this document) or can be installed on a remote server and accessed through the internet.

2.3.3. MODULES USED

Matplotlib: Visualization with Python. Matplotlib is a comprehensive library for creating static, animated, and interactive visualizations in Python. Matplotlib makes easy things easy and hard things possible.

Pandas: Pandas is a fast, powerful, flexible and easy to use open source data analysis and manipulation tool, built on top of the Python programming language.

NumPy: It is a Python library used for working with arrays. It also has functions for working in domain of linear algebra, Fourier transform, and matrices. NumPy stands for Numerical Python.

SciPy: It is a scientific computation library that uses NumPy underneath. SciPy stands for Scientific Python. It provides more utility functions for optimization, stats and signal processing.

3. METHODOLOGY ADOPTED

3.1. Arrangement Picked: Schlumberger Arrangement

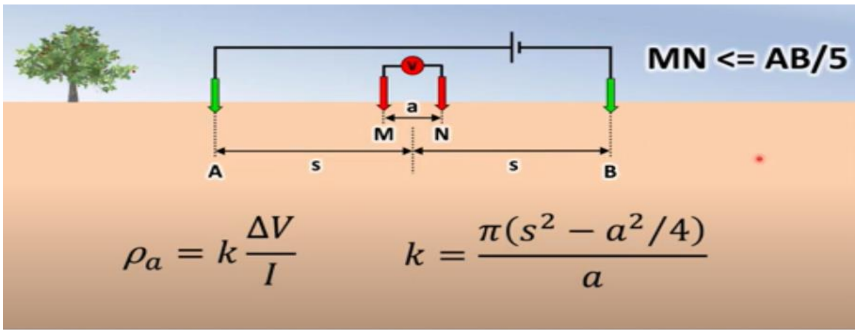


Fig1. Schlumberger Arrangement

The Schlumberger array is an array where four electrodes are placed in line around a common midpoint. The two outer electrodes, A and B, are current electrodes, and the two inner electrodes, M and N, are potential electrodes placed close together.

With the Schlumberger array, for each measurement the current electrodes A and B are moved outward to a greater separation throughout the survey, while the potential electrodes M and N stay in the same position until the observed voltage becomes too small to measure (source). At this point, the potential electrodes M and N are moved outward to a new spacing. As a rule of the thumb, the reasonable distance between M and N should be equal or less than one-fifth of the distance between A and B at the beginning. This ratio goes about up to one-tenth or one-fifteenth depending on the signal strength.

3.2. **Apparatus Required**:

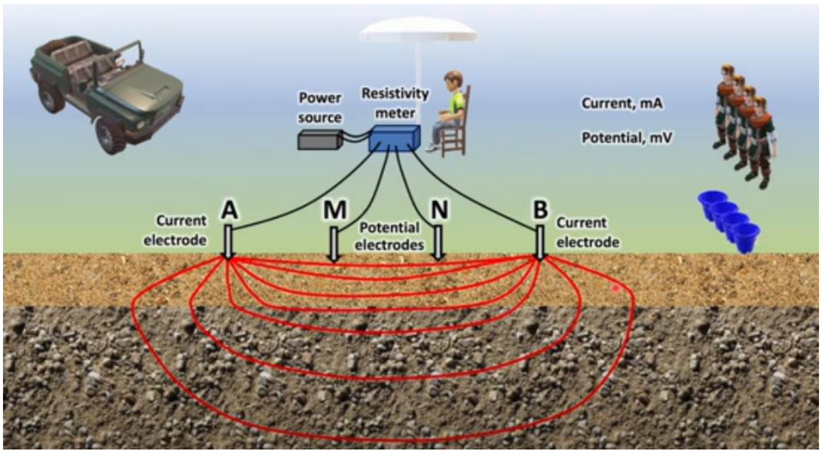


Fig2: Apparatus Required

Current Electrodes.
Potential Electrodes.
Resistivity Meter.
Power Source.
Water.
Connecting wires.

3.3. **Procedure:**

- Go to the location where you want to measure the depth of water table.
- Try to figure out the range or length, you want to make your investigation.
- Setup the apparatus at the centre of line of investigation.
- Make all the necessary connections to the power source, Resistivity meter, Current electrodes, Potential electrodes using Connecting wires.
- Insert the Potential electrodes and Current electrodes into the ground separated by the distances MN and AB respectively. Where AB is greater than MN.
- Go on increasing the distances between the electrodes till you reach your range of investigation.
- Note the readings of Direct and Reverse potentials of voltmeter and Direct and Reverse Currents of Ammeter of the equipment at every point of investigation.

3.4. Observations (Readings):

Table4: Readings noted during the experiment.

S.no	Current Electrode Distance (AB/2)	Potential electrode distance (MN/2)	Direct voltmeter reading (V1)	Reverse voltmeter reading (V2)	Direct current meter reading (I1)	Reverse current meter reading. (I2)
1	2	0.5	211	213	43.5	44
2	3	0.5	38	40	17.6	18.1
3	4	0.5	25	26	21.2	21.6
4	5	0.5	9	9	12.6	12.9
5	6	1	30	28	30.1	29.9
6	8	1	16	15	30.3	30.4
7	10	1	7	7	15.3	23.6
8	15	2	11	13	30.8	37.5
9	20	2	5	4	26.9	22
10	30	4	8	8	38.3	36.5
11	40	4	10	8	79.7	72.6
12	50	4	3	3	26.6	33.9

3.5. Readings for Testing:

In order to test our code which, we wrote to analyse the readings of experiment and to determine the depth of water table by plotting a graph. We considered a set of values from a YouTube Channel. That is.

Table5: Readings for testing the code.

S.no	Current Electrode Distance (AB/2)	Potential electrode distance (MN/2	Direct voltmeter reading (V1)	Reverse voltmeter reading (V2)	Direct current meter reading (I1)	Reverse current meter reading. (I2)
1	0.9	0.3	11420	11330	340	350

2	1.5	0.5	6630	6830	360	370
3	2.4	0.8	3720	3590	340	340
4	3	1	2470	2340	300	300
5	4.5	1.5	1330	1015	270	270
6	9	3	415	416	290	290
7	13.5	4.5	80	205	167	162
8	22.5	7.5	-20	104	106	106
9	30	10	17	114	230	230
10	45	15	5	101	180	180
11	90	30	78	41	200	200

4. ANALYSIS

4.1. Code in R-Studio

```
# Importing required libraries

#install.packages("readxl")

#install.packages("dplyr")

#install.packages("ggplot2)

# Loading libraries into the file

library(readxl)

library(dplyr)

library(ggplot2)

# Getting and Setting the directory

getwd()

setwd(choose.dir())

getwd()

# Importing excel file using readxl library

ExptData <- read_xlsx(choose.files())

is.na.data.frame(ExptData)# Checking for missing or blank values from the data
imported

View(ExptData) # Viewing the imported data as a whole

# Checking the type and dimensionalities

typeof(ExptData)

ncol(ExptData)

dim.data.frame(ExptData)
```

```
is.data.frame(ExptData)

# Understanding the structure and summary of data

str(ExptData)

summary(ExptData)

# Assigning column names

names(ExptData) <- c("Sno", "current_ed", "potential_ed", "vr_direct", "vr_reverse", "cr_direct", "cr_reverse")

names(ExptData)

# Checking the first and last 5 rows

head(ExptData, n = 5)

tail(ExptData, n = 5)

# Performing calculations required on the columns

# Mutating and adding additional columns to the existing dataframe

ExptData <- mutate(ExptData, Avg_pd = (vr_direct + vr_reverse)/2, Avg_curr = (cr_direct + cr_reverse)/2)

ExptData <- mutate(ExptData, R = (Avg_pd/Avg_curr))

ExptData <- mutate(ExptData, K = ((pi * ((current_ed ** 2) - (potential_ed ** 2)))/(potential_ed * 2)))

ExptData <- mutate(ExptData, Apparent_res = K*R)

# Rounding the table values to 3 decimal places

ExptData <- round(ExptData, 3)

# Viewing the table

View(ExptData)

# Maximum and minimum values of Apparent Resistivity

max(ExptData$Apparent_res)

min_val <- min(ExptData$Apparent_res)

min_val

# Depth of the water table

depth <- ExptData[ExptData$Apparent_res == min_val,"current_ed"]

names(depth) <- NULL

depth <- as.integer(depth)
```

```
typeof(depth)

depth

# Plotting the graph between "Distance" and "Apparent resistivity"

logPlot <- ggplot(data = ExptData, aes(x = current_ed, y = Apparent_res)) +
geom_line() + geom_point(size = 3)

# Adding labels and plot title

logPlot <- logPlot + xlab("Distance") +

  ylab("Apparent Resistivity") +

  ggtitle("L/2 vs. Apparent Resistivity")

# Setting log-scale

logPlot <- logPlot + scale_x_continuous(expand = c(0,0), trans = "log10", limits =
c(1,10000))+

  scale_y_continuous(expand = c(0,0), trans = "log10", limits = c(1,1000))

# Adding aesthetic layer

# Styling the labels and title

logPlot <- logPlot + theme(axis.title.x = element_text(colour = "red", size = 20,
family = "serif"),

       axis.title.y = element_text(colour = "Dark blue", size = 20, family = "serif"),

        axis.text.x = element_text(size = 15),

        axis.text.y = element_text(size = 15),

        plot.title = element_text(colour = "Dark Green", size = 27, family = "serif", hjust
= 0.5))

# Setting background and grid for the plot

logPlot <- logPlot + theme(plot.background = element_rect(fill = "grey"))

logPlot <- logPlot + theme(panel.grid.major = element_line(colour = "black"))

# Viewing the end plot

logPlot <- logPlot + geom_hline(yintercept = min(ExptData$Apparent_res), colour =
"red")

logPlot <- logPlot + geom_vline(xintercept = as.integer(depth), colour = "blue")

logPlot

# Depth of the water table from the graph

print(paste("The depth of the water table is", depth,"mts"))
```

4.2. Code in Python

```
In [68]: #Importing the required libraries
         import pandas as pd
         import numpy as np
         import matplotlib.pyplot as plt

In [28]: #importing the data into the environment
         ExptData = pd.read_excel("VES1.xlsx")
         ExptData

In [21]: #Checking the type and dimensionalities
         print(type(ExptData))

         <class 'pandas.core.frame.DataFrame'>

In [24]: print(len(ExptData.columns))
         print(ExptData.shape)

         7
         (12, 7)

In [30]: ExptData.describe() #Understanding the summary of the data

In [33]: #Renaming or assigning row names for the sake of mitigating ambiguity
         ExptData = ExptData.rename(columns = {"current_electrode_distace(l/2)" : "current_ed", "potential_electrode_distance(b/2)" : "potential_ed",
                                               "direct_voltmeter_reading(v1)" : "vr_direct", "reverse_voltmeter_reading(v2)" : "vr_reverse",
                                               "direct_currentmeter_reading(i1)" : "cr_direct", "reverse_currentmeter_reading(i2)" : "cr_reverse"})

In [36]: #Checking the first and last 5 rows of the DataFrame
         ExptData.head() #first 5

In [37]: ExptData.tail() #bottom 5

In [49]: #Performing calculations required on the columns
         #Mutating and adding additional columns to the existing dataframe

         ExptData["Avg_pd"] = (ExptData["vr_direct"] + ExptData["vr_reverse"])/2
         ExptData["Avg_curr"] = (ExptData["cr_direct"] + ExptData["cr_reverse"])/2
         ExptData["R"] = ExptData["Avg_pd"]/ ExptData["Avg_curr"]
         ExptData["K"] = ((np.pi * ((ExptData["current_ed"] ** 2)) - (ExptData["potential_ed"] ** 2))/ (ExptData["potential_ed"] * 2))
         ExptData["Apparent_res"] = ExptData["K"] * ExptData["R"]

In [53]: #Rounding the values upto 3 decimal places
         ExptData = round(ExptData, 3)

In [55]: ExptData #Viewing the table

In [59]: #Maximum and minimum values of Apparent Resistivity
         print(ExptData["Apparent_res"].max()) #max value
         print(ExptData["Apparent_res"].min()) #min value

         97.165
         51.087

In [66]: #Depth of the water table
         min_value = ExptData["Apparent_res"].min()
         depth = ExptData.loc[ExptData["Apparent_res"] == min_value, "current_ed"].iloc[0]
         print("Depth of the water table is {} mts.".format(depth))

In [85]: #Plotting the graph between "Distance" and "Apparent resistivity"
         plt.plot(ExptData["current_ed"], ExptData["Apparent_res"])

         #Adding labels and plot title
         plt.xlabel("Distance")
         plt.ylabel("Apparent Resistivity")
         plt.title("L/2 vs. Apparent Resistivity")

         #Setting log-log scale
         plt.xscale("log")
         plt.yscale("log")

         #Setting the limits for the plot
         plt.xlim(1,1000)
         plt.ylim(1,1000)

         #Pointing the end point or minimum point on the graph
         plt.axvline(x = depth, color = 'g')
         plt.axhline(y = min(ExptData["Apparent_res"]), color = 'r')

         #Displaying output graph
         plt.show()
```

5. RESULTS AND DISCUSSION

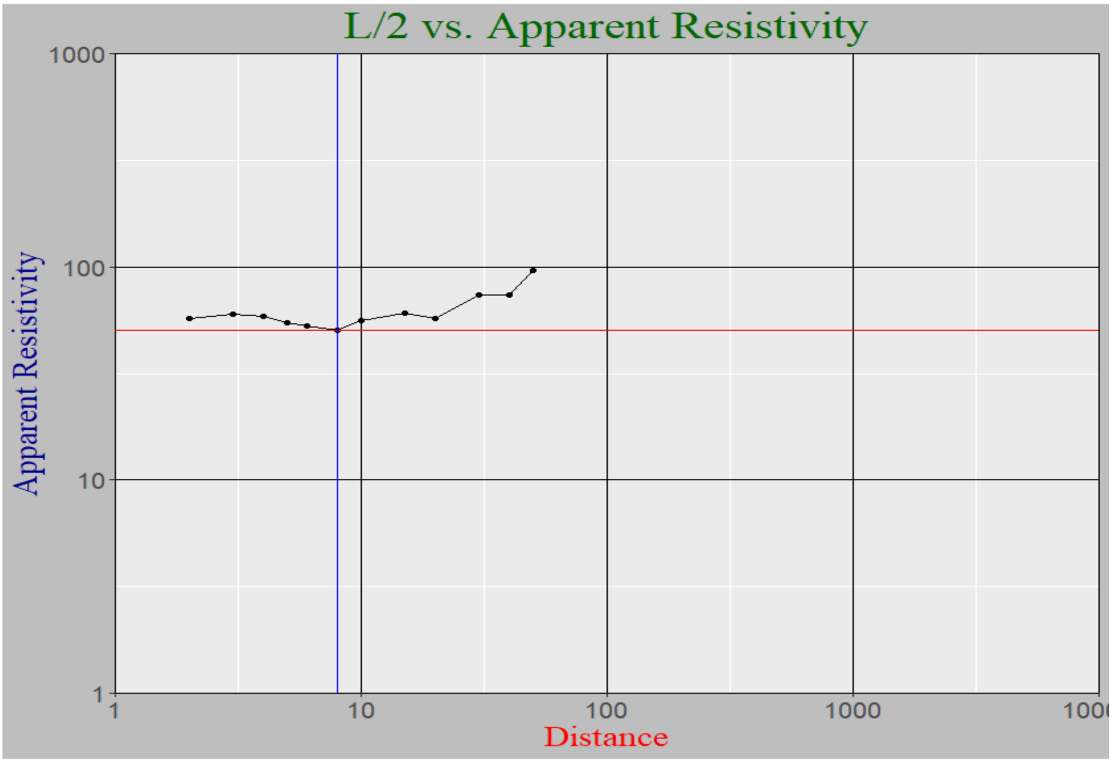
5.1. Results in R-Studio:

5.1.1. Results of Experiment :

Output of the code:

	Sno	current_ed	potential_ed	vr_direct	vr_reverse	cr_direct	cr_reverse	Avg_pd	Avg_curr	R	K	Apparent_res
1	1	2	0.5	211	213	43.5	44.0	212.0	43.75	4.846	11.781	57.087
2	2	3	0.5	38	40	17.6	18.1	39.0	17.85	2.185	27.489	60.060
3	3	4	0.5	25	26	21.2	21.6	25.5	21.40	1.192	49.480	58.960
4	4	5	0.5	9	9	12.6	12.9	9.0	12.75	0.706	77.754	54.885
5	5	6	1.0	30	28	30.1	29.9	29.0	30.00	0.967	54.978	53.145
6	6	8	1.0	16	15	30.3	30.4	15.5	30.35	0.511	98.960	50.540
7	7	10	1.0	7	7	15.3	23.6	7.0	19.45	0.360	155.509	55.967
8	8	15	2.0	11	13	30.8	37.5	12.0	34.15	0.351	173.573	60.992
9	9	20	2.0	5	4	26.9	22.0	4.5	24.45	0.184	311.018	57.243
10	10	30	4.0	8	8	38.3	36.5	8.0	37.40	0.214	347.146	74.256
11	11	40	4.0	10	8	79.7	72.6	9.0	76.15	0.118	622.035	73.517
12	12	50	4.0	3	3	26.6	33.9	3.0	30.25	0.099	975.465	96.740

Plot :



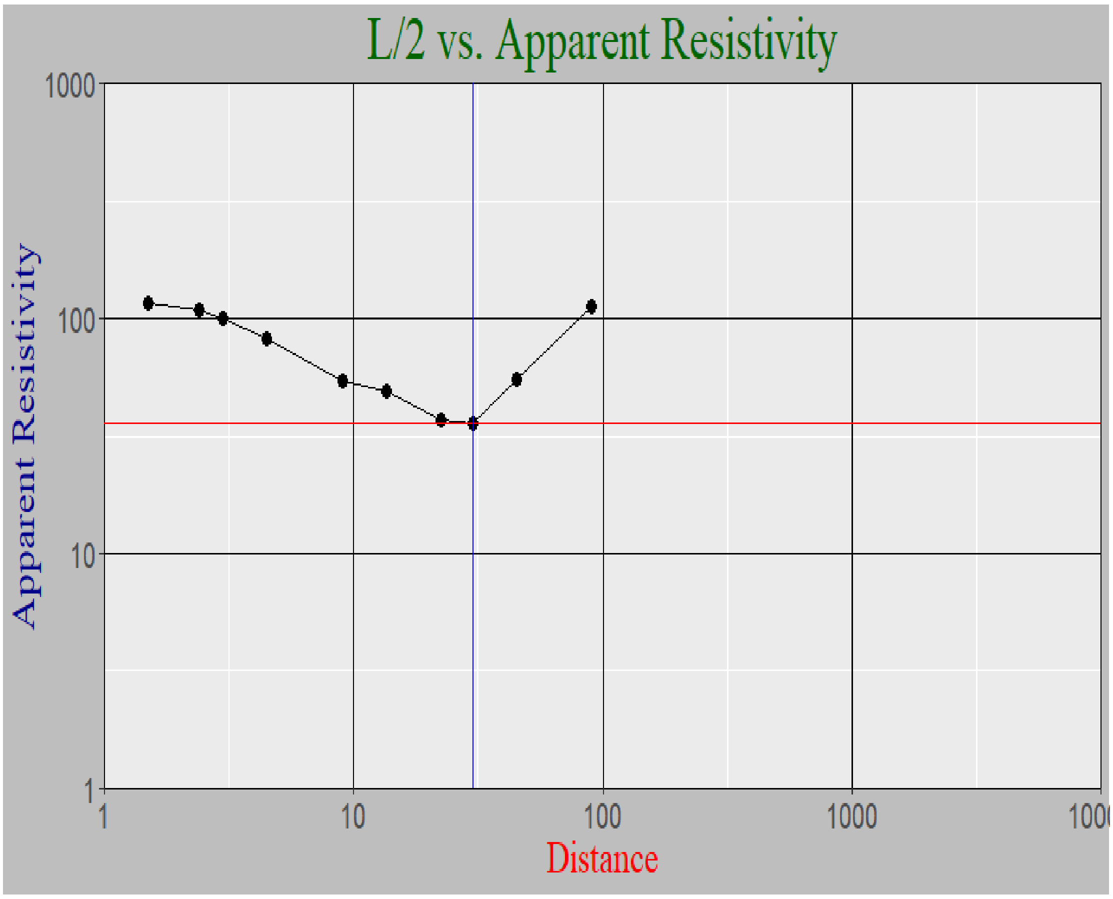
"The depth of the water table is 8 mts"

5.1.2. Results of Test values:

Output of the code:

	Sno	current_ed	potential_ed	vr_direct	vr_reverse	cr_direct	cr_reverse	Avg_pd	Avg_curr	R	K	Apparent_res
1	1	0.9	0.3	11420	11330	340	350	11375.0	345.0	32.971	3.770	124.298
2	2	1.5	0.5	6630	6830	360	370	6730.0	365.0	18.438	6.283	115.852
3	3	2.4	0.8	3720	3590	340	340	3655.0	340.0	10.750	10.053	108.071
4	4	3.0	1.0	2470	2340	300	300	2405.0	300.0	8.017	12.566	100.740
5	5	4.5	1.5	1330	1015	270	270	1172.5	270.0	4.343	18.850	81.856
6	6	9.0	3.0	415	416	290	290	415.5	290.0	1.433	37.699	54.014
7	7	13.5	4.5	80	205	167	162	142.5	164.5	0.866	56.549	48.986
8	8	22.5	7.5	-20	104	106	106	42.0	106.0	0.396	94.248	37.343
9	9	30.0	10.0	17	114	230	230	65.5	230.0	0.285	125.664	35.787
10	10	45.0	15.0	5	101	180	180	53.0	180.0	0.294	188.496	55.501
11	11	90.0	30.0	78	41	200	200	59.5	200.0	0.298	376.991	112.155

Plot :



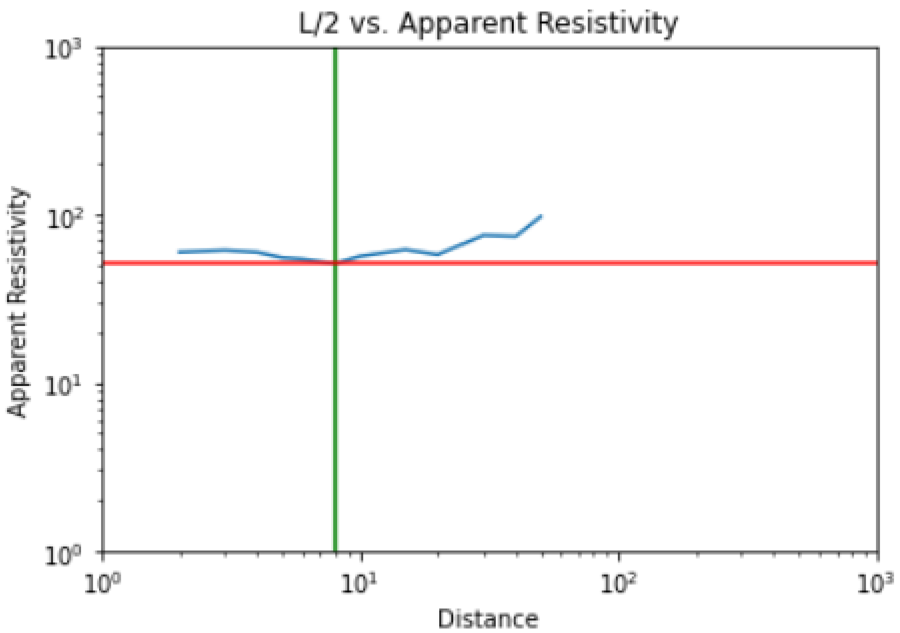
"The depth of the water table is 30 mts"

5.2. Results in Python :

Out[55]:

	S.no	current_ed	potential_ed	vr_direct	vr_reverse	cr_direct	cr_reverse	Avg_pd	Avg_curr	R	K	Apparent_res
0	1	2	0.5	211	213	43.5	44.0	212.0	43.75	4.846	12.316	59.682
1	2	3	0.5	38	40	17.6	18.1	39.0	17.85	2.185	28.024	61.230
2	3	4	0.5	25	26	21.2	21.6	25.5	21.40	1.192	50.015	59.598
3	4	5	0.5	9	9	12.6	12.9	9.0	12.75	0.706	78.290	55.263
4	5	6	1.0	30	28	30.1	29.9	29.0	30.00	0.967	56.049	54.180
5	6	8	1.0	16	15	30.3	30.4	15.5	30.35	0.511	100.031	51.087
6	7	10	1.0	7	7	15.3	23.6	7.0	19.45	0.360	156.580	56.353
7	8	15	2.0	11	13	30.8	37.5	12.0	34.15	0.351	175.715	61.745
8	9	20	2.0	5	4	26.9	22.0	4.5	24.45	0.184	313.159	57.637
9	10	30	4.0	8	8	38.3	36.5	8.0	37.40	0.214	351.429	75.172
10	11	40	4.0	10	8	79.7	72.6	9.0	76.15	0.118	626.319	74.023
11	12	50	4.0	3	3	26.6	33.9	3.0	30.25	0.099	979.748	97.165

Depth of the water table is 8 mts.



6. SUMMARY AND CONCLUSION:

Programming languages use classes and functions that control commands. The reason that programming is so important is that it directs a computer to complete these commands over and over again, so people do not have to do the task repeatedly. Instead, the software can do it automatically and accurately. The efficient method to figure out the location to dig a borewell is Vertical Electrical Sounding. This can be done by performing experiment then, the need of programming comes here. Where numerous calculations to be done. We resolved this problem by writing code in two different programming languages they are R-Studio and Python. The code is tested by using a known set of values and verified the efficiency of code. Thus, the objective of the project is justified.

8. REFERENCES:

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Application of Electrical Resistivity Method (ERM) in Groundwater Exploration. Akhtar Izzaty Riwayat, Mohd Ariff Ahmad Nazri and Mohd Hazreek Zaina. Abidin Published under licence by IOP Publishing Ltd

Values for Testing:

Geoserch International: Hydrogeology 101: Introduction to Resistivity Surveys https://youtu.be/MvOR4xY1Mb8

Python:

https://github.com/chenomg/CS_BOOKS/blob/master/Python%20for%20Data%20Analysis%2C%202nd%20Edition.pdf

Cheat sheets for R and python:

https://www.business-science.io/learning-r/2019/01/07/data-science-with-r-cheat-sheet.html

Adding log axis for graphs:

https://www.kite.com/python/answers/how-to-plot-on-a-log-scale-with-matplotlib-in-python