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SOIL RESISTIVITY TEST FOR GREEN FIELD APPLICATIONS

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Abstract : Earth soil is abundantly available throughout the world. It provides us with minerals, metals, foods, etc. It has electrical properties such as resistivity. Electrical resistivity of soil characterizes its ability to oppose the passage of a current. Using resistivity, we can deduce geophysical characteristics of any soil sample. These characteristics include soil composition, temperature and moisture content. Hence, soil resistivity is a crucial property in industry and agriculture. It affects grounding systems and determines the best location for transmitters and substations. Understanding soil resistivity also helps in planning crops and correcting poor soil conditions. So it's important that we develop an efficient way of measuring soil resistivity. Yet, most of the conventional tests used to test for it are costly, time consuming and labor intensive. The Wenner method is the most reliable method for measuring soil resistivity as it provides an optimal value for deeper depths. This method is cost effective and non-destructive to the sample. In this paper the study of different soil samples using a self designed kit (based on the Wenner 4 pin method) in open field grounds of Maitreyi College, Delhi University premises is presented. The geophysical properties of the soil samples were deduced by conducting by analyzing the uniformity of soil and the results are presented in the form of tables and graphs. The variation in the soil types are found at different locations and best use of respective lands are proposed in this paper.

IndexTerms - Soil resistivity, Wenner method, soil types, industry, agriculture, geophysical characteristics

1. INTRODUCTION

The study of soil properties and their behavior is a fundamental aspect of geotechnical engineering. Proper understanding of soil characteristics is vital for designing safe and stable structures, foundations, and underground utilities. One of the key parameters that plays a crucial role in this field is soil resistivity. Soil resistivity refers to the inherent property of soil that opposes the flow of electric current through it. It is a critical factor in determining the corrosivity of the soil, designing grounding systems, and evaluating the potential for electrical interference in buried utilities. Soil resistivity testing has emerged as an indispensable technique in geotechnical investigations and engineering design [1].

The behavior of soil in response to electrical currents provides valuable insights into its composition, moisture content, mineralogy, and degree of compaction. These factors collectively influence the resistivity of the soil and consequently impact its engineering properties. Soil resistivity is directly linked to the movement of groundwater and the presence of soluble salts. High soil resistivity indicates low moisture content and suggests the potential for rapid drainage, which can affect the stability of slopes and embankments. On the other hand, low soil resistivity often signifies high moisture levels, indicating poor drainage and the possibility of soil liquefaction during seismic events. There are so many applications in Geotechnical Engineering such as [2]:

1. **Foundation Design**: Soil resistivity testing aids in the design of proper grounding systems for structures, which is essential for ensuring safety against lightning strikes and electrical faults. Accurate knowledge of soil resistivity helps engineers determine the depth and type of grounding electrodes required.
2. **Corrosion Analysis**: Corrosion of buried structures, such as pipelines and underground storage tanks, is influenced by the resistivity of the surrounding soil. Soil resistivity testing assists in identifying areas with corrosive conditions, facilitating the selection of appropriate coatings and cathodic protection measures.
3. **Electromagnetic Interference**: Buried utilities, such as power and communication cables, can experience electromagnetic interference from nearby sources. Soil resistivity testing helps in assessing the potential for such interference and aids in designing proper shielding and separation strategies.
4. **Slope Stability Assessment**: Soil resistivity values provide insights into the potential for water movement within slopes. This information is crucial for analyzing slope stability, especially in areas prone to landslides and erosion.
5. **Soil Classification**: The resistivity of soil can indirectly indicate its type and compaction. This data is useful in soil classification and geotechnical profiling, aiding engineers in making informed decisions during construction projects.

Several methods are commonly employed to measure soil resistivity, including the Wenner, Schlumberger, and pole-dipole [5] techniques. The Wenner method involves driving four equally spaced electrodes into the ground in a straight line and passing current between the outer electrodes while measuring the voltage drop across the inner electrodes. Various factors influence soil resistivity, including moisture content, temperature, soil type, mineral composition, and the presence of contaminants. Moisture content has a significant impact on soil resistivity, with wetter soils generally exhibiting lower resistivity due to the higher conductivity of water. Temperature variations also influence resistivity, as the conductivity of most soils decreases with decreasing temperatures. In conclusion, this research paper seeks to elucidate the critical role of soil resistivity testing in green field applications. By offering a comprehensive overview of the methodologies and significance of these tests, we aim to equip practitioners with the knowledge and insights needed to make informed decisions regarding the design, installation, and maintenance of electrical systems. As we navigate the complexities of modern construction and technology, the accurate assessment of soil resistivity stands as a cornerstone in ensuring the efficiency, reliability, and safety of electrical infrastructures in green field projects.

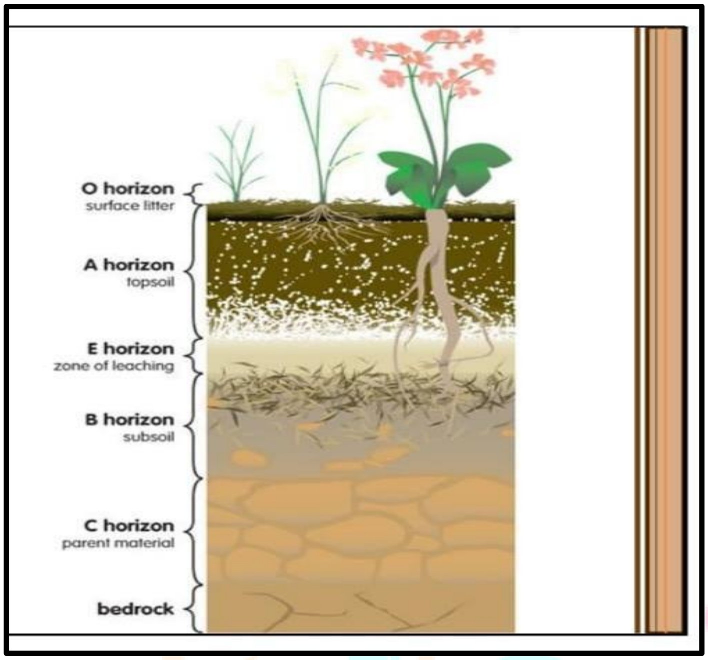


Fig 1:Soil horizon [source: wikipedia]

2. METHOD AND METHODOLOGY

For the soil resistivity test, an in-house low cost / economical kit was designed by us with the specifications as described below. Using the same kit, measurements were made within the Maitreyi College Campus at various locations to measure the soil resistivity and draw inferences with respect to the composition of the ground in the college campus.

2.1 Description of materials and apparatus used

2.1.1 For designing the soil resistivity kit:

- **Copper rods -** Four copper rods, each of 31 cm length and diameter 0.75 cm, were driven into the soil up to depth (d) of 20cm. The rods at the extremities are called current rods (C1 and C2) and the inner rods are called potential rods (P1 and P2). Since the electrical resistance of copper is less than any other material, its contribution to earth's resistance is quite less and hence the measurements will be more accurate.
- **Battery** - A battery (DC source) of voltage 27 V to 32 V was used as a source for the circuit. The positive end of the battery was connected to the current rod (C1). The negative end of the battery was connected in series with a negative terminal of the multimeter (m1).
- **Voltmeter and ammeter** - Multimeters were used as voltmeter and ammeter. The multimeter (m1) with a range 10 Amperes was used as an ammeter. To complete the circuit, the negative terminal of the ammeter was connected to the negative terminal of the battery and its positive terminal was connected to the current rod (C2). The multimeter (m2) was used as a voltmeter. The range of voltmeter selected was 600 V. The negative terminal of the voltmeter was connected to the potential rod (P2) and the positive terminal of the voltmeter was connected to the potential rod (P1).
- **Connecting Wires** - The connections were made using insulated copper wires and crocodile clips were used for better grip between wires and rods.

2.1.2 For conducting the experiment:

- **Self designed soil resistivity kit**
- **Chalk powder, hammer, scale, inch tape and thread** - Scale, inch tape and thread (12 m and 2 m) were used for marking purposes. The area under investigation was divided into grids of equal size (~ 2 sqm). The copper rods were secured in the ground by hammering them to a depth of 20 cm.
- **Soil** - Soil resistivity measurements were carried out at different locations within our college premises. A total of eight locations were identified and at each location, multiple readings were taken for different distances between the rods. The resistivity calculated was used to determine the moisture content and pH of the soil [3].

2.2 Wenner 4 pin method - explanation and derivation of formula:

Amongst the various methods available, we used the Wenner 4 pin array for investigation, as it is one of the most commonly used and simple methods [4].

In the Wenner 4 pin method (Fig 2), four electrodes of equal size are driven into the soil surface in a straight line at equal spacing (a). When the DC source is connected, current I flows between the outer pair of the rods (C1 and C2). As a result a potential difference V is developed between the two inner pair of the rods (P1 and P2). The current flowing into the ground through each rod moves in the form of a hemispherical waveform of radius (r). By sign convention, the current in C1 is +I and the current in C2 is -I.

Using Ohm's Law, the resistance between the two potential rods can be determined [5].

$$V = IR \qquad \text{— (1)}$$

The resistance (R) of specimen (rod or wire) of length L, resistivity ρ and area of cross section A is given as:

$$R = \rho * L/A$$

The area of the hemispherical waveform of radius r formed is in the soil, is □ = 2□□^{2}

$$R = \rho * L/2\pi r^2 \qquad \text{— (2)}$$

Substituting equation (2) in (1) gives:

□ = □ ∗□* L/2πr^2

For small length dr the value of potential drop

$$dV = I * \rho * dr/2\pi r^2$$

Hence, as the radius of the hemispherical waveform increases, the potential decreases.

Therefore,

$$dV = -(I * \rho * dr/2\pi r^2)$$

—(3)

Integrating equation (3) for distance R from source.

$$\int_0^V dV = -(I * \rho * \int_0^R dr/2\pi r^2)$$

$$V = I \times \rho / 2\pi R \qquad \text{—(4)}$$

Potential at point M in fig(2) is,

$$V(M) = V(AM) + V(BM) \qquad \text{—(5)}$$

where ,V(AM) is potential at R=AM and V(BM) is potential at R=BM.

Using equation (4) and (5)

$$V(M) = I \times \rho / 2\pi [1/(AM) - 1/(BM)]$$

Similarly potential at point (N), rod (P2) is

$$V(N) = I \times \rho / 2\pi [1/(AN) - 1/(BN)]$$

Now , the potential difference across rods P1 and P2 is

$$\Delta V(MN) = V(M) - V(N)$$

$$V(M) - V(N) = (I \times \rho / 2\pi) \times [1/(AM) - 1/(BM) - 1/(AN) + 1/(BN)] \qquad \text{—(6)}$$

Equation (6) can also be written as

$$\rho = \Delta V(MN) \times k / I. \qquad \text{—(7)}$$

Where, $k = 2\pi \times [1/(AM) - 1/(BM) - 1/(AN) + 1/(BN)]^{-}1$

For Wenner array,

AM=BN=a and BM=AN=2a

The value of k becomes 2πa.

Substituting the value of k in (7)

$$\rho = \Delta V(MN) \times 2\pi a / I$$

Final formula for resistivity (ρ) is

$$\boldsymbol{\rho = \Delta V(MN) \times 2\pi a / I} \qquad \text{— (8)}$$

where,

- ρ is resistivity of soil
- a is the distance between two successive rods.
- R is resistance of the soil
- π is constant value 3.14
- d is the depth of the rod in the soil.

The expression obtained in (8) is used to calculate the resistivity of the soil. If the spacing (a) between the four electrodes is considerably small, the measured soil resistivity is the result of the resistivity of the upper layer of the soil. If the spacing (a) is increased, the current will penetrate deeper into the soil. With the increase in value of (a) the value of (d) will also change [6]. The measured soil resistivity will be an indication of the average soil resistivity over a larger area. The profiling technique (the entire array was moved along a profile line while keeping d, a and h constant) was used to measure this change in resistivity. The spacing between the two array positions were the same for one location and adjusted according to the dimensions of the area under investigation. The depth to which current penetrates (p) is equal to (a).

We have designed our model for a penetration capacity of current (p) as 2 m from the ground surface, with d, the depth to which the rod was buried in the soil = 20 cm. The relations between a, d and p are given by the following relations [7]:

$d \leq 0.1\, a$

And, p = a

The values of input parameters chosen are:

a = 2 m; p = 2 m; d = 20 cm

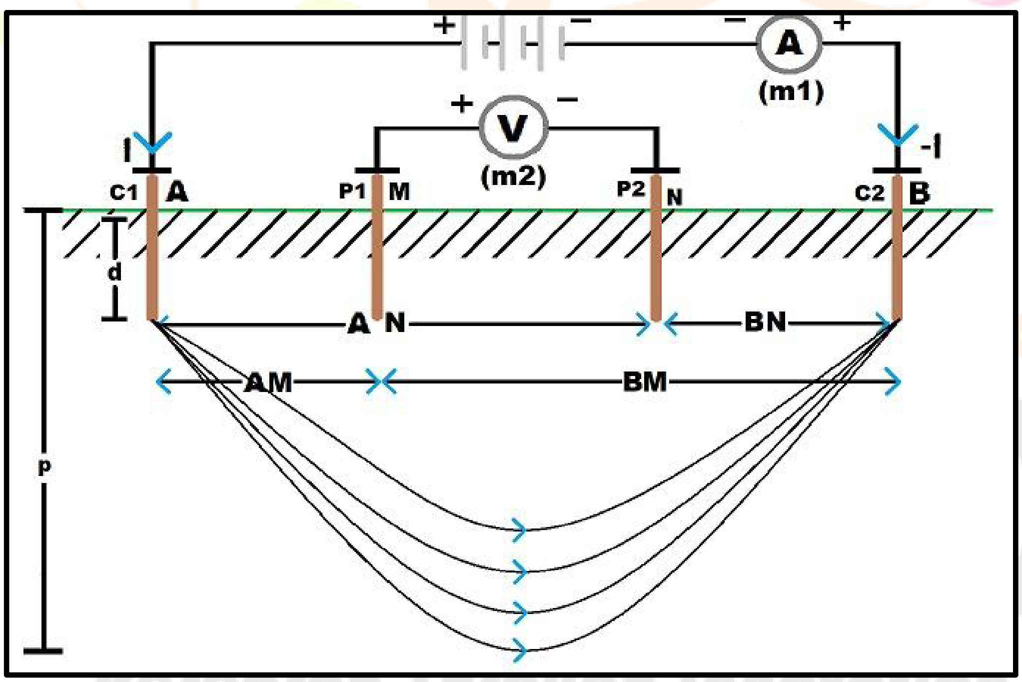


Fig 2: Wenner array

Software used: MS Paint

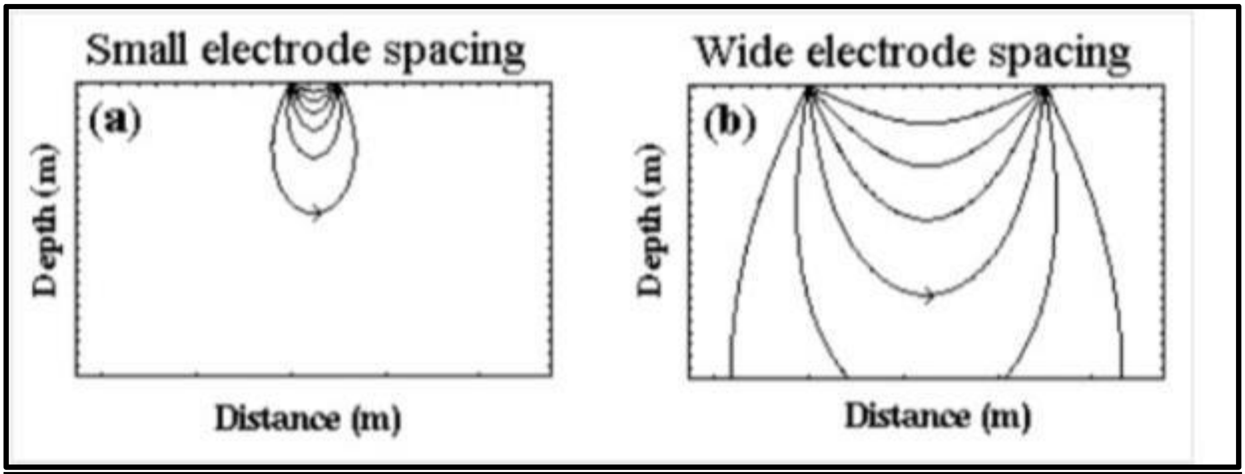


Fig 3: Illustration of how expanding an electrode array allows electrical current to penetrate deeper into the soil.

(Source: https://www.nature.com/scitable/knowledge/library/identifying-groundwater-contamination-using-resistivity-surveys-at-87665012/)

Fig 4: Wenner arrangement

3. OBSERVATIONS

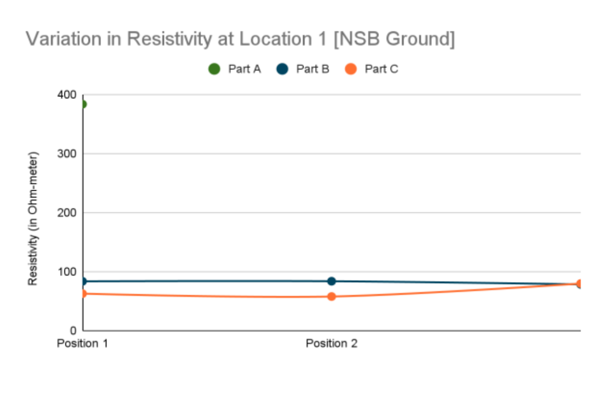
At a particular location, depending upon its size, the whole area was divided into two or three parts (Part A, Part B, etc.). In each part, the resistivity was calculated at different positions and results tabulated.

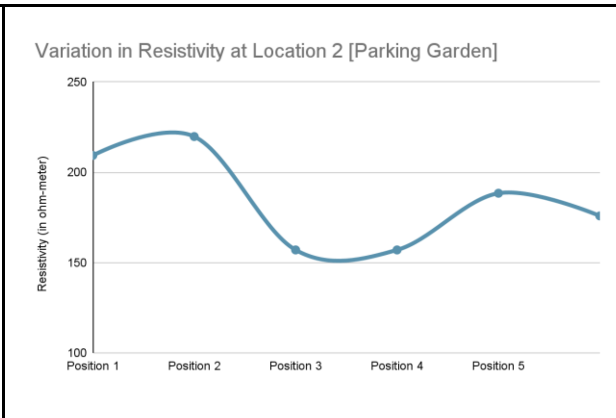
Following are the values of fixed parameters:

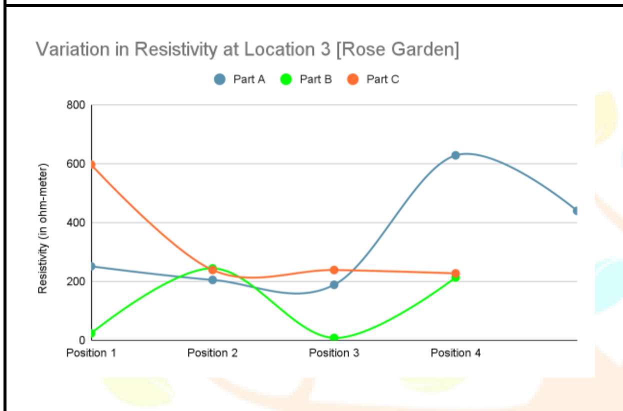
a = 2 m

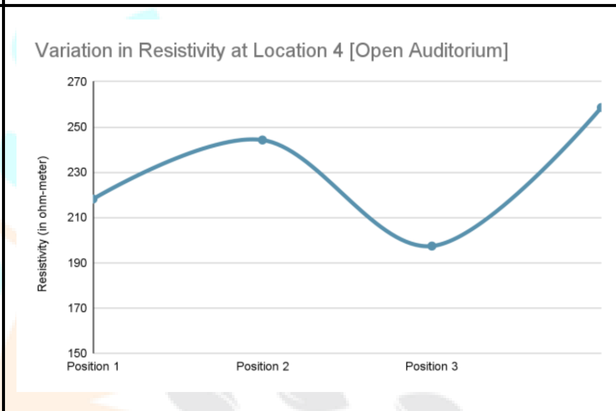
d = 20 cm

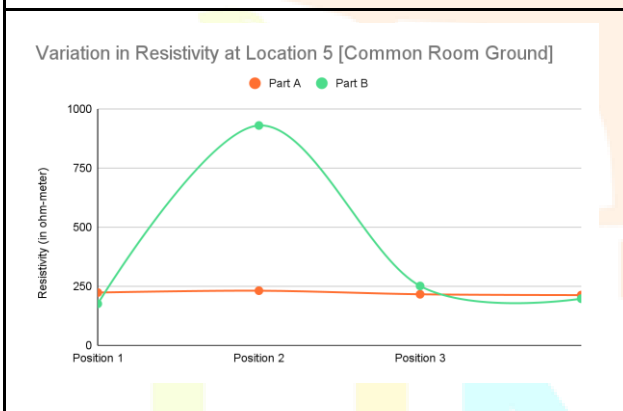
p = 2m

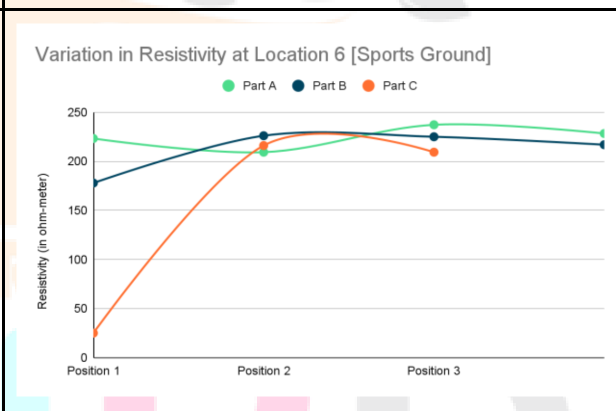

Variation in Resistivity at Location 1 [NSB Ground]
Part A
Part B
Part C
Resistivity (in Ohm-meter)
400
300
200
100
0
Position 1
Position 2

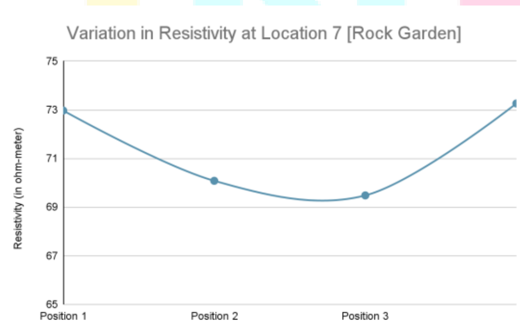

Variation in Resistivity at Location 2 [Parking Garden]
Resistivity (in ohm-meter)
250
200
150
100
Position 1
Position 2
Position 3
Position 4
Position 5


Variation in Resistivity at Location 3 [Rose Garden]
Part A
Part B
Part C
Resistivity (in ohm-meter)
800
600
400
200
0
Position 1
Position 2
Position 3
Position 4


Variation in Resistivity at Location 4 [Open Auditorium]
Resistivity (in ohm-meter)
270
250
230
210
190
170
150
Position 1
Position 2
Position 3


Variation in Resistivity at Location 5 [Common Room Ground]
Part A
Part B
Resistivity (in ohm-meter)
1000
750
500
250
0
Position 1
Position 2
Position 3


Variation in Resistivity at Location 6 [Sports Ground]
Part A
Part B
Part C
Resistivity (in ohm-meter)
250
200
150
100
50
0
Position 1
Position 2
Position 3


Variation in Resistivity at Location 7 [Rock Garden]
Resistivity (in ohm-meter)
75
73
71
69
67
65
Position 1
Position 2
Position 3

4. RESULT AND DISCUSSION

Tabulated below are the standard values of soil resistivity for different types of soil (Table-1), moisture content (Table-2) and pH values (Table-3). These values were compared with the soil resistivity obtained for our sample locations, thereby helping us to estimate the nature of the soil present.

Table-1: Standard values for Soil Resistivity for different types of Soil [9]

Electrical Resistivity (in ohm-meter)	**Type of soil**
<100	Clay and saturated silt
100 - 250	Sandy clay and wet silty sand
250 - 500	Clayey sand and saturated sand
500 - 1500	Sand
1500 - 5000	Gravel
1000 - 2000	Weathered rock
1500 - 10000	Sound rock

Table-2:Moisture Content & Soil Resistivity [8]

Moisture Content (% by weight of dry soil)	**Resistivity of Top Soil (in ohm-meter)**
2	***
4	***
6	1350
8	900
10	600
12	360
14	250
16	200

18	150
20	120
22	100
24	100

Table-3:pH of Soil & Resistivity [10]

pH	Resistivity (in ohm-meter)
< 3.5	Any
3.5 - 4.5	45
4.5 - 5.5	45 - 50
5.5 - 6.0	10 - 100

In NSB garden low resistivity (in Parts B and C) indicates the presence of fine particles, adequate amount of humus and high moisture content. The rest of the NSB garden is highly uniform everywhere in terms of soil composition.

Moderate value of resistivity was observed in the sports ground area at all the three locations. There were many big particles and the soil was dry at some but moist (location B) at other parts.

In the open auditorium, parking area and ground near the common room, since the value of resistivity was found to be moderate, it can be inferred that these areas have soil with good moisture content, no rocky particles and highly uniform soil.

The entire area of the rose garden was divided into three sections - Part A, Part B and Part C. The area of the rose garden was covered by taking the value of x as 3m. As can be seen from the graph, there is large variation in the resistivity in this region. The region of low value of soil resistivity is indicative of very high moisture content in the soil. In this area a variety of soil was found.

5. CONCLUSION & FUTURE PROSPECTS

After analyzing the values of soil resistivity at various locations with our kit, we conclude that there are three types of soil present in our college premises - (**1)** Clay & Saturated Silt, (**2)** Sandy Clay & Wet Silty Sand, and (**3)** Clayey Sand & Saturated Sand. The moisture laden acidic character of soil in our college premises can be said to be perfect for plants like Amaryllis, Apple etc. [8]. The soil with fine particles shows less resistivity (suitable for agriculture). The properties discussed in the observation tables are estimations made with help of apparent resistivity measured by the kit.

The kit designed by us is affordable as the components used in it are easily available. Therefore it is also low-cost on maintenance. The kit can be easily customized as per the specific requirements of the user, thereby offering numerous possibilities for detailed and in-depth studies.

We plan to extend our study to the neighboring lands and hope to draw confirmed conclusions to estimate the types of plantation which can thrive in these areas. The same can be extended for better and sustainable landscaping in this area. This method of measuring electrical resistivity (profiling + VES) [12] can also be used for locating fresh or salt-water boundaries within a given region [9], and which supplements the study of soil using seismic refraction and electrical sounding, the other geophysical methods. Our work inspires more research and extensive surveys in this field [11].

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